An-Najah National University

Faculty of Graduate Studies

PV-GRID CONNECTED POWER SYSTEM TO TUBAS ELECTRIC NETWORK (TDECO): FIELD TESTS, EVALUATION AND OPTIMIZATION.

By

Ishraq Serhan Jarrar

Supervisor

Prof. Dr. Marwan Mahmoud

This Thesis is submitted in Partial Fulfillment of the Requirements for the Degree of Master of Clean Energy and Conservation Strategy Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus, Palestine.

2018

PV-GRID CONNECTED POWER SYSTEM TO TUBAS ELECTRIC NETWORK (TDECO): FIELD TESTS, EVALUATION, AND OPTIMIZATION.

By
Ishraq Serhan Jarrar

This thesis was defended successfully on 4/10/2018 and approved by:

Defense Committee Members	**Signature**
Prof. Marwan Mahmoud / Supervisor	**………..………**
Dr. Osama Al Omari / External Examiner	**………..………**
Dr. Moien Omer / Internal Examiner	**………..………**

Dedication

أهدي هذا العمل الى:

أمي الحبيبة سندس جرار التي من دونها لم أكن سأستطيع إتمام دراستي الماجستير حيث كانت هي المشع والداعم الرئيسي خلال مسيرتي التعليمية،

أبي الغالي سرحان جرار،

رفيق دربي وشريك حياتي العزيز داوود خمايسة،

أبنائي احبائي مصطفى وأحمد،

أختي الحبيبة إخلاص لدعمها لي في أوقات الشدة خلال دراستي،

أخواتي العزيزات شكور وزمزم،

أخي الغالي غيث وزوجته أسيل وابنته زينة،

عمتي الغالية عزيزة جرار،

ولا أنسى من الذكر عمي الأستاذ الفاضل بسام خمايسة وخالتي فتحية خمايسة،

الى صديقاتي أسماء خليل وأسماء عفيفي وفردوس وريما واحلام لدعمهن وتشجيعهن،

الى أستاذي الفاضل ومعلمي الدكتور مروان محمود،

الى روح جدي الحاج رضا جرار وجدي محمد جرار وعمتي أمل والغالية ابتهال،

الى أرواح الشهداء الأبرار أبناء عمي أحمد إسماعيل جرار وأحمد نصر جرار،

وأجعل هذا العمل وقفا لله تعالى عن أرواح المسلمين سائلة الله عز وجل أن يكون في ميزان حسناتنا.

Acknowledgment

I would like to express my gratitude to each of my University "An-Najah National University", graduate studies faculty specifically clean energy and energy conservation-engineering program.

I specify my thanks to my supervisor Prof. Marwan Mahmoud, who enriched me with valuable information about renewable energy, that has helped me enormously while writing my research.

Deep thanks to all my teachers: Dr. Amer Hamouz, Dr. Abdel Raheem Abu Safa, Dr. Emad Breik, Dr. Muhammad Asayyed and Dr. Waleed al-Kukhun whom I benefited a lot from their lectures.

Special thanks to Dr. Ikhlas Jarrar for her advices throughout the writing process of my research.

I'm also grateful to my manager at work Eng. Abdullah Nierat, Mr. Tala Abu Rub, Eng. Jamal Muslamani and Eng. Farhan Alswadeh for their support during my master study time.

I also thank my wonderful mates at the department of planning Eng. Asma Khalil and Eng. Reema Daraghmeh for their valuable efforts in helping me collecting my data.

Special thanks also to Dr. Osama Al Omari my external examiner and Dr. Moien Omer the internal examiner.

Finally, many thanks to the Czech Development Agency for their support of renewable energy projects in TDECO mainly 350kWp PV power station that made it possible for me to perform this research project.

الإقرار

أنا الموقعة أدناه مقدمة الرسالة التي تحمل العنوان:

PV-GRID CONNECTED POWER SYSTEM TO TUBAS ELECTRIC NETWORK (TDECO): FIELD TESTS, EVALUATION AND OPTIMIZATION.

اقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وان هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: **اسم الطالب:**

Signature: **التوقيع:**

Date: **التاريخ:**

Table of Content

No.	Contents	Pages

List of Tables

List of Figures

List of Appendices

List of Abbreviations and Symbols

AC	Alternative Current
AFD	Agency France Development.
AM	Air Mass
AS	Australian Standards
Avg.	Average
CB	Circuit Breaker
CF	Capacity Factor
CT	Current Transformer
DB	Distribution Board
DC	Direct Current
DESCOs	Distribution Electricity Companies
$E_{exp,inv.fault}$	Expected Output Energy, if There is No Inverters Faults
EIA	Environmental Impact Assessment
$E_{PV,AC}$	The Annual, Monthly or Daily Actual AC Output Energy Generated form PV Power Station (kWh).
EQA	Environment Quality Authority
$E_{solar,T}$	Total Tilted Energy on Array Plane (kWh).
ESP	Environmental Strategy Plan
FF_{NOCT}	Fill Factor According NOCT
FF_{SCT}	Fill Factor According STC
GHG	Green House Gas
GNP	Gross National Product
G_T	Total tilted irradiance on POA (kWh/m2).
h_v	Temperature Coefficients of Voltage (% / °C).
IEC	International Electro Technical Commission
IECo	Israel Electricity Company
IEEE	Institute of Electrical and Electronics Engineers
IET	Institution of Engineering and Technology
I_{mpp}	Current at Maximum Power
IR	Infra-Red
I_{sc}	Short Circuit Current PV module/ String
LCC	Life Cycle Cost
LCOE	Levelized Cost of Energy
LV	Low Voltage
Max	Maximum
MC4	formerly Multi-Contact for the 4mm Diameter

MCB	Miniature Circuit Breaker
MDB	Main Distribution Board
Min	Minimum
MPPT	Maximum Power Point
MRR	Minimum Rate of Return
MV	Medium Voltage
MΩ	Mega-Ohm
NEC	National Electrical Code
NERSA	National Energy Regulator of South Africa
NFPA	National Fire Protection Association
NOCT	Normal Operating Cell Temperature
N_{series}	Number of Modules in Series per String
$N_{strings}$	Number of String per MPPT
OCPD	Over Current Protection Device
ONAN	Oil Nature Air Nature
PCB	Printed Circuit Board
Pdcr	Rated DC Inverter Input Power From Inverter Datasheet
PEA	Palestinian Energy Authority
PEC	Palestinian Energy and Environment Research Center
PENRA	Palestinian Energy and Natural Resources Authority
PERC	Palestinian Electricity Regulatory Council.
PETL	Palestinian Electricity Transmission Ltd
PLO	Palestinian Liberation Organization
P_{max}	Maximum Power
PNA	Palestinian National Authority
POA	Plane of Array
POC	Point Of Coupling
PPA	Power Purchase Agreement
$PPV_{@STC}$	Installed Capacity of PV Power Station at STC (kWp)
PR	Performance Ratio
PS	Palestinian Standards
PSI	Palestinian Solar Initiative
PV	Photo Voltaic
R.O.C.O.F	Rate of Change of Frequency
RCD	Residual Current Device
RPP	Renewable Power Plants
SPBP	Simple Pay Back Period

SPD	Surge Protection Device
STC	Standard Testing Conditions (Irradiance of 1000W/m² at AM 1.5 Solar Spectrum and a Temperature of 25°C).
T_c	Cell Temperature (°C).
TDECO	Tubas District Electricity Co.
T_m	Module Temperature (°C).
TR	Transformer.
UL	Underwriters Laboratories
UV	Ultraviolet.
V	Volt.
$V_{max,abs}$	The Absolute Maximum DC Input Voltage of the Inverter.
V_{mpp}	Voltage at Maximum Power.
V_{oc}	Open Circuit Voltage.
$V_{OC, string@T}$	Open Circuit Voltage for String at Specific Temperature
$V_{OC,STC}$	Open Circuit Voltage of Module at STC Condition.

PV-GRID CONNECTED POWER SYSTEM TO TUBAS ELECTRIC NETWORK (TDECO): FIELD TESTS, EVALUATION AND OPTIMIZATION

By
Ishraq Serhan Jarrar
Supervisor
Prof. Dr. Marwan Mahmoud

Abstract

Grid connected PV systems became the best alternatives in renewable energy fields. A 4771 kWp PV stations are connected with Tubas District Electricity Co (TDECO). Among these, 350kWp PV power station - donated from Czech Republic - is the largest solar power plant in Tubas. The site receives high average annual solar radiation amounting to 5.13 and 5.925 kWh/m^2-day for horizontal and tilted surfaces respectively. The annual average temperature of this site is about 20.5°C during 2016.

This thesis presents the technical installation evaluation of the 350kWp PV power station according to national and international standards and the associated recommendations are presented. The system performance is evaluated also, two types of power losses are discussed; uncontrollable losses (like inverters faults and grid shortage) and PV power station equipment (like PV modules, DC cables, Inverters, AC cables and meter). The overall system efficiency is calculated, it amounts to 11.94%.The system operational performance parameters as annual, monthly, actual and expected performance ratio (PR)are calculated. The actual and expected PR is 75.6% and 80.2% respectively. The actual and expected specific annual yield (Y_s) is 1640 kWh/kWp and 1740 kWh/kWp respectively. The actual and expected capacity factor (CF) is 18.7%, 19.81%, respectively, which is in the acceptable range (12%-24%).The annual actual and expected energy production in 2016 is 574039kWh and 609029kWh/year respectively.

The other main aspect of this thesis is studying the effect of irradiance, temperature, dust and the number of maximum power point string trackers on the energy production of this PV power station. Moreover, studying of utilized DC cables and transformer optimization are discussed.

Analysis is carried out to provide economic evaluation in terms of life cycle cost and energy cost. The obtained results show that the donated PV power station is economically feasible with an average energy cost of 0.0276NIS/kWh while it is not feasible if TDECO was the financing body of the PV power station since it would not be feasible; because of high costs of ground and land preparation.

Furthermore, this PV power station contributes in protecting the Palestinian environment since it reduces the CO_2 emission by 577.97ton per year.

Chapter 1

Introduction

1. Introduction

1.1. TDECO's Electric Grid History

Palestine is among the highest countries in the world depending on foreign energy sources. In 2012, about 95% of the country's energy needs came from Israeli electric company, Jordan and Egypt. This almost reliance on foreign source consumes a significant amount of Palestine finance before few years; some of villages and towns were depending on diesel generators in production of electricity. According to the Oslo agreement between the Palestinian Liberation Organization (PLO) and Israel, Palestine has to purchase electrical energy from the Israel Electricity Company (IECo) at prices equal to those given to Israeli cities and sometimes higher even the financial income in Israel is much higher than in Palestine.

The supplied electrical energy to Palestine is not enough to cover the load demands. Each city or electrical distribution company has to wait years to obtain extra energy. Building of electric power generation stations is not absolutely possible and economically feasible due to various factors. These factors are mainly represented in that no fuel sources are locally available and Palestine is obliged to buy all needed fuel derivatives at relatively high prices only from Israel (buying oil from neighboring countries is not allowed). In addition, Israel controls all Palestinian imports, which means that buying all necessary hardware components of such power stations require difficult official permission, which either is refused or requires waiting time for years.

In Palestine 7 GWh of electrical energy were consumed in the year 2012. As a result, 6643000 kg of CO_2 have been emitted. In the next 20 years, an increase in electricity demand by at least 50% is expected because of the economic boom and population growth.

Palestinian Energy Authority (PEA) is committed to the promotion of renewable energies and already presented a master plan for the energy sector in the year 2012. Until 2020, the share of renewables in electricity generation shall grow to 15 percent, mainly solar energy systems are intended to contribute beside wind energy and biogas energy.

Solar power technology is really clean technology because no fossil resources are consumed. Furthermore; Palestine is located in what is called solar belt and has a good solar radiation level with an a daily average of about 7.5 hours sunshine duration and a solar radiation average ranging between 4.8 and 6.4 kWh/m^2 per day. The annual daily average of solar irradiance on horizontal surface is about 5.4 kWh/m^2 [1], which makes producing electricity from sunlight feasible and economic.

Building such solar energy projects will help Palestine economy in achieving partial energy independence.

This project will help to minimize Green House Gas (GHG) emissions and help in keeping safe environment.

Tubas District Electricity Company (TDECO) is one of the distribution companies in Palestine that has electricity concession in Tubas governorate and southern of Jenin governorate. It has been working since 2002 in supplying electrical energy for 34 communities (around 30,000 consumers).

Tubas is located in the northeastern part of Palestine, 100 km north of Jerusalem, 21 kilometers northeast of Nablus, a few kilometers west of the Jordan River. Tubas Governorate lies on 407km^2 area, 400 meters above sea level at 32.323789° latitude and 35.36109° longitude with 85000-person population and 295.1 person/km^2 population density.

At present, many customers are asking to apply for joining TDECO, but unfortunately, there is no enough energy to fulfill their demands. On the other hand the cost of generation was very high due to the initial cost of the generator and its running costs, which amounts in average to 2NIS/kWh. The unit price of selling to consumers in these communities was 2.5 NIS/kWh, which is relatively very high. The unit price purchased from Israeli company at that time was 0.34 NIS/kWh but the electric energy supply was mostly limited to only 12-18 hours/day.

TEDCO purchase electrical energy from the one IECo connection point on medium voltage grid 33kV and distributes it to 14 communities and to other 20 communities (municipal and local councils) around on the low voltage network. The maximum available supplying power is 20 MVA while there is an additional demand for at least 5-8 MVA. This additional power amount was requested from IECo in 2012 without providing it until now.Figure (1.1)[1] shows the daily load curve for TDECO for the four seasons; winter, spring, summer and autumn that represented by the following dates in 2017 respectively (Jan.1st, March.1st, Jun.1st and Oct.1st). The maximum demand in winter and autumn were at afternoon around 20MVA and the minimum

[1] See Appendix E1 for higher resolution figure

was in spring around 7.56MVA. In summer, the electrical consumption was almost the same during the 24 hours because the agricultural crops need more water; so the water pumping loads were increased in that time of the year, but in spring the load demand was from 8:00am to 4:00 pm.

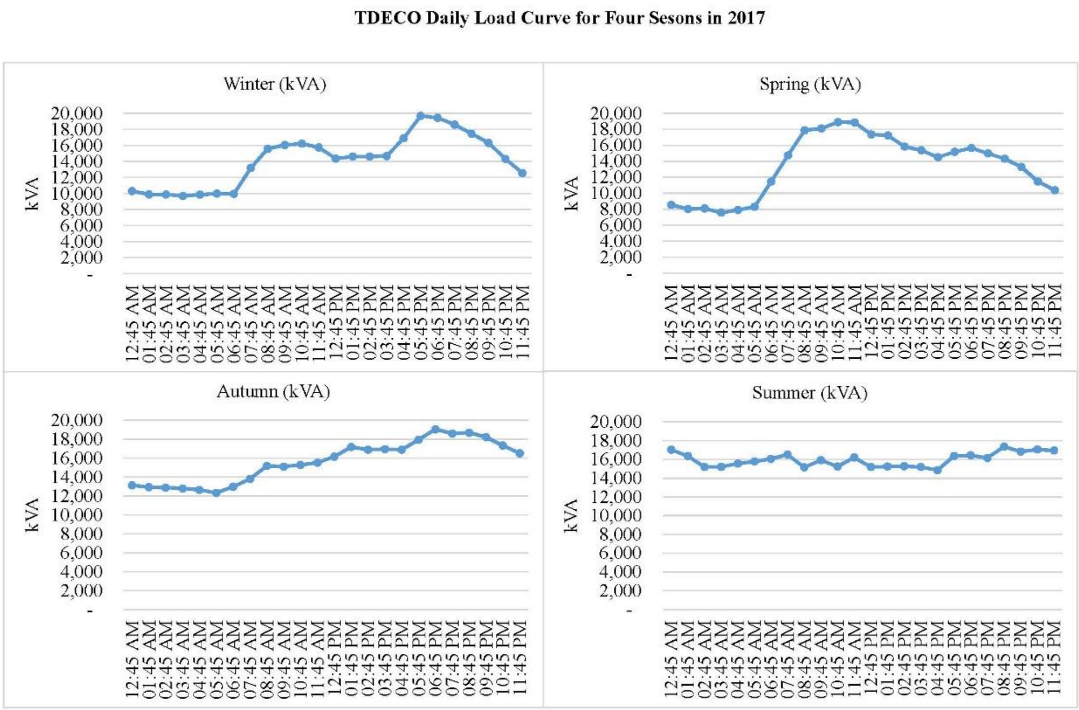


Figure (1.1): TDECO Daily Load Curves for Four Seasons in 2017

Figure (1.2) shows the annual incremental of TDECO loads during the last four years that represent 9.58% annually.

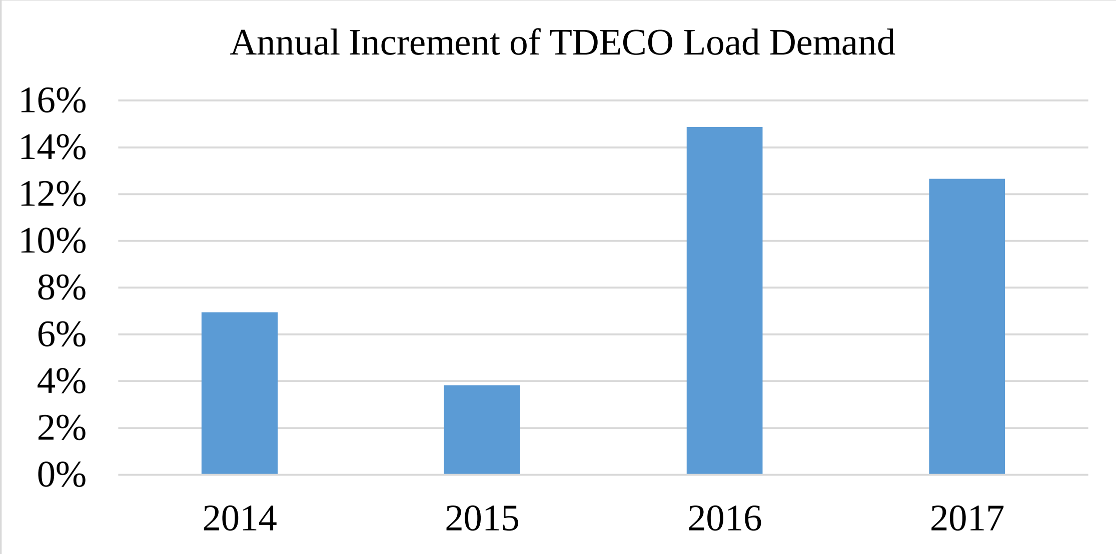


Figure (1.2): Annual Increment of TDECO Load Demand

Therefore, generating electricity by using photovoltaic technology is the only partial solution for the energy crises.

The Palestinian Energy and Natural Resources Authority (PENRA) published many legislations for renewable energy in Palestine are classified as follows:

A. Palestinian Solar Initiative (PSI) Program.

This initiative has been published since 2012 according to declaration of cabinet 16/127/13 that allows the first 1000 domestic consumers in the west bank install Photovoltaic (PV) power stations on their rooftops up to 5kWp and sell the generated electricity to Distribution Electricity Companies (DESCOs) with the following incentive tariff:

- First incentive tariff for the first 100 residential rooftop PV stations in the west bank is 1.07 NIS in 2012.

- Second incentive tariff for the second 300 residential rooftop PV stations in the west bank is 0.8 NIS in 2013.
- Third incentive tariff for the rest residential rooftop PV stations in the west bank is 0.54 NIS in 2015.

B. Net Metering Program

This program has been published since 2015 according to declaration 17/77/04 that allows any electrical DESCO's subscriber to install PV power stations that generates up to 100% of its own electrical consumption, and the 75% of extra generated power it will be transferred to the next month (this transfer is allowed for only one year).

C. Power Purchase Agreement (PPA)

This program has been published since 2015 that named ("Direct Power Purchase Award of Renewable Energy Generation Station" according to declaration of Palestinian cabinet [2]). This allows the investors to build PV power stations as electrical generation investment and connect it with Palestinian Electricity Transmission Ltd (PETL) grid with tariff of 10% less than the electricity tariff that generated from traditional generation according to renewable energy and energy conservation law Annex1 of statement 5 and 11.

In view of the above PENRA strategy, beside to the electrical shortage, TDECO seeks to consume as large as possible from PV systems in covering the energy demands by the end of 2020, there will be 24019 kWp PV stations connected to TDECO grid; 20480 kWp of them will be connected to Medium

Voltage (MV) grid and 3539 kWp will be connected to Low Voltage (LV) grid.

Table (1.1): Grid Connected PV Stations within TDECO Grid (Installed and Proposed)

Year	PSI (kWp)	Net Metering (kWp)	PPA(kWp)	Total
2013	385	15	120	520
2014	555	127	120	802
2015	555	127	470	1152
2016	640	127	470	1237
2017	800	286	2348	3435
2018	880	420	3470	4771
2019	880	10658	8470	20009
2020	880	12668	10470	24019

Table (1.1) shows the grid connected PV stations connected with TDECO grid classified as follows:

1. Feed in Tariff initiative which has started in 2012 ,as part of Palestinian solar Initiative (PSI) which was divided in three tariffs :
   A. Fist tariff was 1.07 NIS/kWh where 48 of our residential customers subscribed in it at 5kWp for each one (48% of the subscriber in the west bank).
   B. Second tariff was 0.8NIS/kWh where 64 of our residential customers subscribed in it at 5KWp for each one. (21.3% of the subscriber in the west bank).

C. Third tariff was 0.54NIS/kWh where 65 of our residential customers subscribed in it at 5KWp for each one. (9% of the subscriber in the west bank).

2. Net metering program, 420.35kWp PV stations connected to TDECO grid now that cover owners' electrical energy consumption like (17 agricultural projects ,20 schools,8 public buildings, many water pumps, Arab American University (AAUJ), cow farm, … etc.), some of these projects were donated by Czech Republic, ministry of finance, Agency France Development (AFD)...etc. and others financed by their owner account. The first net metering PV stations were installed in 2013 through first stage of Czech donation or on grid PV station or agricultural purposes and some privet projects that were before issuing the net metering program from PEA.
3. PPA program, 3000kWp private sector PV station follow PTEL that were connected to TDECO grid and there are 2 other licenses (7000kWp) that will be connected in the next two years.
4. TDECO's PV station[1], 470kWp PV power station that is donated from Czech Republic as shown in Figure (1.3)

[1] Included in PPA PV power station

Figure (1.3): 470kWp TDECOs’ PV Power Station

The geographical coordination is 32.30257° latitude 35.39138° longitude and the altitude is 400m above sea level in Tubas-Anon – near transformer maintenance center as shown in Figure (1.4).

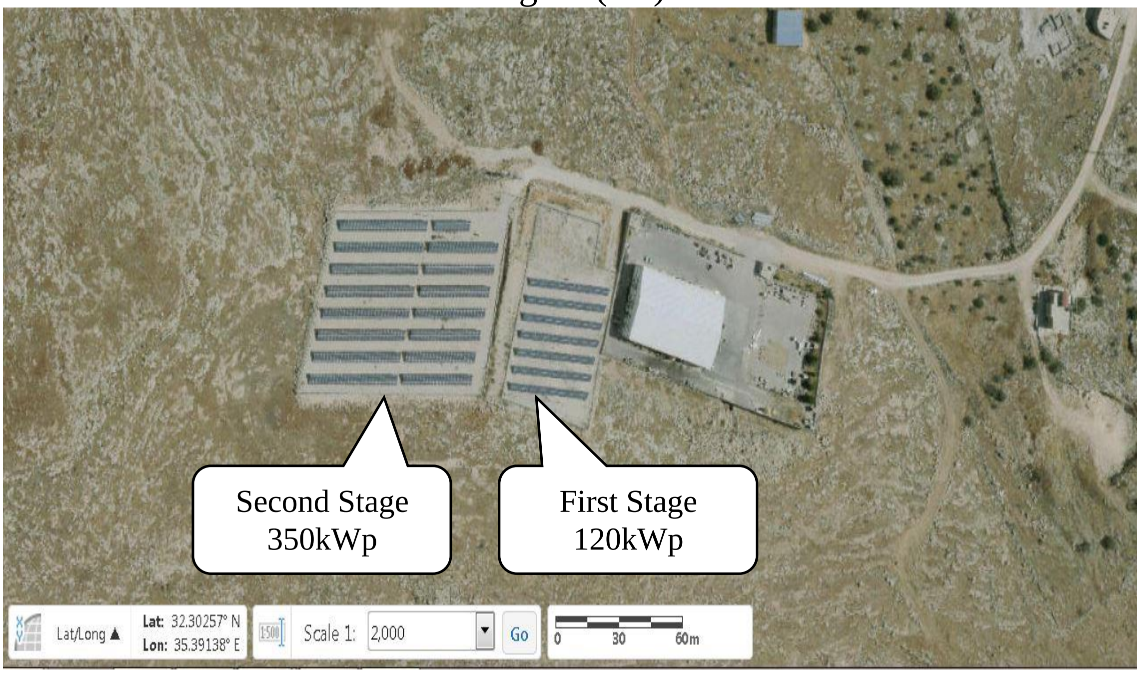


Figure (1.4): Ortho-photo of 470kWp TDECOs' PV Power Station

It is divided in two following stages:

1 First stage operated in Jun2013, under the auspices of prime Minister Dr. Salam Fayad and supported by the Czech Government represented by the Czech Development Agency .Its capacity is about 120kWp installed on 3000m^2 area .This cost of this station is $286000 (2.38$/Wp), the estimated production is 208800 kWh/year.

2 Second stage was operated in Feb2015, under the auspices of Prime Minister Dr. Rami Al-Hamdallah and supported by the Czech Government represented by the Czech Development Agency. Its capacity is 350kWp installed on 6000m^2 area western of the first stage as shown in Figure (1.4) the cost of this stage is 685000$ (1.96$/Wp) and the estimated production is 609000kWh/year.

This thesis discusses and evaluates this stage of the PV power station.

TDECO continues to install and encourage new PV power stations as shown in Figure (1.5) and Figure (1.6).

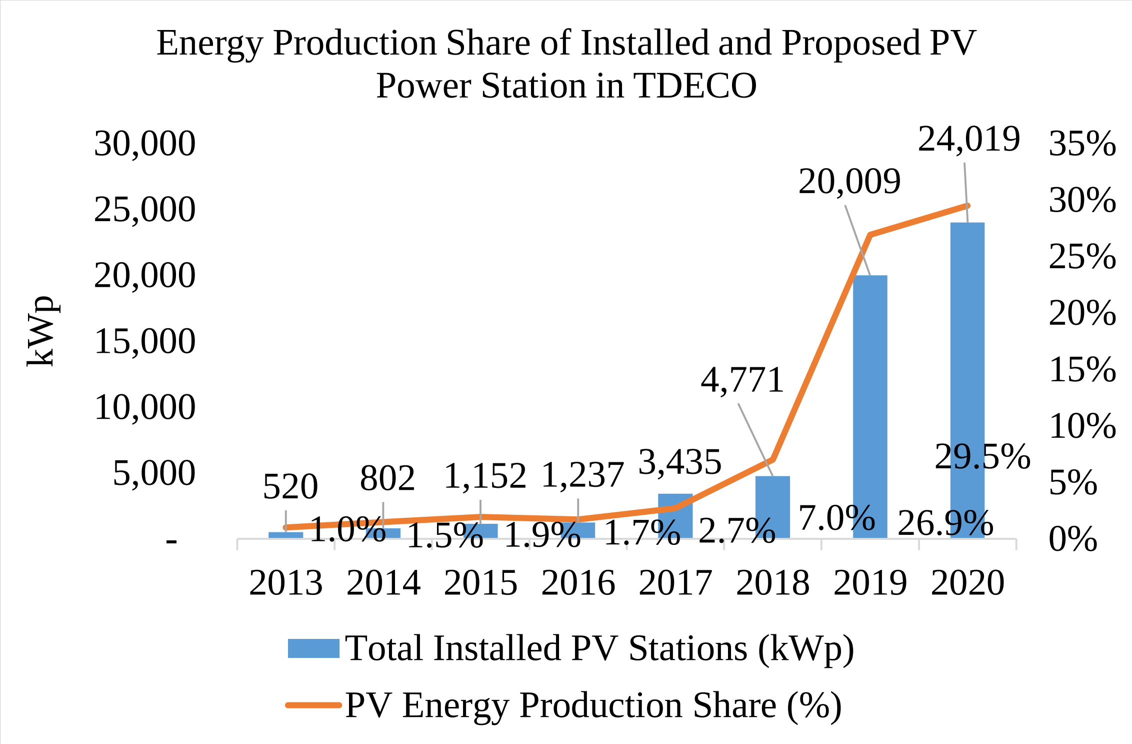


Figure (1.5): Installed and Energy Production Share of PV Power Station in TDECO

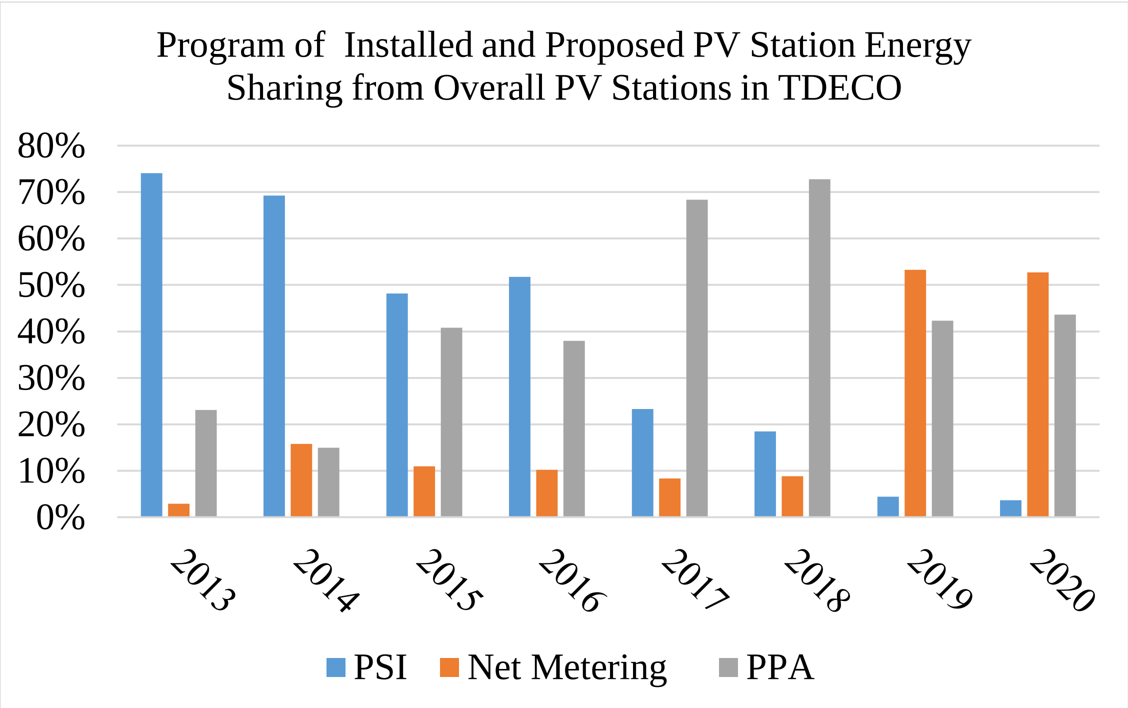


Figure (1.6): Program of PV Station Energy Sharing from Overall PV Stations in TDECO

1.2. Objectives of the Study

The main goal of this thesis is the technical, financial and environmental evaluation of the 350kWp PV power station. Thesis objectives can be pointed as the followings:

- Measuring and analysis the environmental parameters like solar irradiance on horizontal and tilted surfaces, wind speed and ambient and cell temperature in the location of PV power station in 2016.
- Describing and technically evaluate PV power station equipment according to national and international codes.
- Investigating the possibility of modifying the system performance and safety.
- Finding out the actual and expected efficiency and losses for this PV power station.
- Finding out system performance figures like performance ratio, specific yield, capacity factor and
- Investigating the impact of irradiance, inverter loading on inverter efficiency.
- Investigating the temperature effect, dirt and the number of inverters' MPPT on PV power station production.
- Determination the economic feasibility of installing this PV power station with different financing methods.
- Investigating of optimizing DC cables and transformer.

- Studying the financial impact of using power factor correction, high meter accuracy and cleaning the PV power station.
- Studying the environmental positive and negative impacts and mitigation measures in this PV system.

1.3. Thesis Structure

This thesis is divided to nine chapters, the followings illustrate those briefly:

Chapter One: TDECOs' Electric Grid History

This chapter as an introduction talks about electricity history in TDECO, the general situation of producing electricity from solar energy in Palestine and the current situation of renewable energy in TDECO.

Chapter Two: Literature Survey

Chapter Three: Solar and Energy Potential in Tubas

This chapter discuss the weather data in Tubas; solar irradiance, wind and temperature by using local weather station, installed within the second PV power station donated from Czech Republic on 2015.

Chapter Four: The Construction of the 350 kWp PV Power Station

In this chapter, the 350 kWp PV power station administrative phases in the installation process, general geometrical and electrical construction description are discussed.

Chapter Five: Detailed Description of the 350 kWp PV Power Station Components and Evaluation

This chapter discuss the site selection criteria, technical evaluation for all components this PV power station that according to national and international codes. The checklist for each component are prepared to facilitate system installation evaluation.

Chapter Six: System Performance

This chapter discusses system efficiency and losses, system operational parameters, the energy production actual and expected, irradiance, temperature, dust, number of maximum power point impacts on PV power station.

Chapter Seven: Economic Analysis and Optimization

The aim of this chapter is to predict the income of this PV power station during its lifetime, which is considered as 20 years. The feasibility study of replacing transformers to reduce the running cost of this PV power station. Studying the cables selection to optimize the cost, studying the feasibility of installing new capacitor bank to this PV power station, commercial comparison between using class 0.5 and class 1 meters and finally studying the economic impact of cleaning this PV power station from the dust are considered in the study.

Chapter Eight: Environmental Impacts and the Proposed Mitigation Measures

This chapter presents the environmental positive and negative impacts and mitigation measures in this PV system.

Chapter Nine: Conclusion and Recommendations

This chapter represent the main conclusion and recommendations in this thesis.

Chapter 2

Literature Survey

2. Literature Survey

Exact knowledge of the sun's path is important for calculating irradiance values and the yields of solar energy systems. The sun's altitude can be described at any location by the solar altitude and the solar azimuth.

When talking about solar energy systems, due south is generally given as (a = 0°).

Angles to the east are indicated with a negative sign (east: a = -90°). To the west, angles are given without a sign (or with a positive sign) (west: A = 90°) [3].

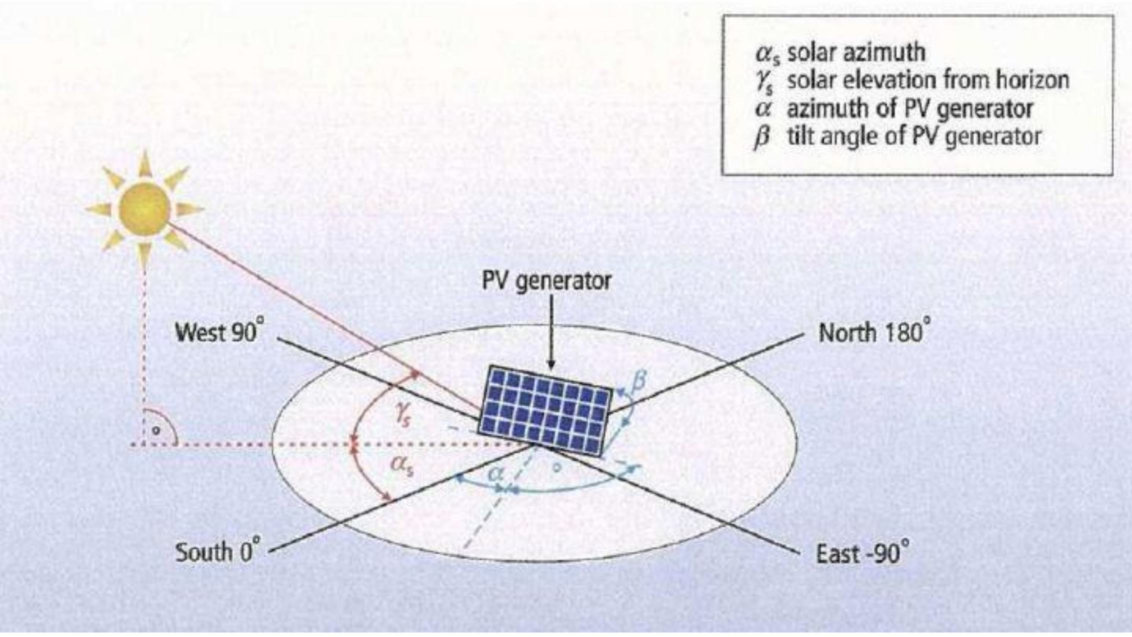


Figure (2.1): Defining Angles in Solar Technology

Literature Survey of the PV Power Station Classification

The PV power station classification that according to National Energy Regulator of South Africa (NERSA) [4] “Compliance with this grid connection code shall be applicable to the Renewable Power Plants (RPP) depending on its rated power and, where indicated, the nominal voltage at the point of coupling (POC). Accordingly, RPPs are grouped into the following three categories:

(a) Category A: 0 – 1 MVA

This category includes RPPs with rated power of less than 1 MVA and connected to the LV voltage (typically called 'small or micro turbines'). This category shall further be divided into 3 sub-categories:

(i) Category A1: 0 - 13.8 kVA

This sub-category includes RPPs of Category A with rated power in the range of 0 to 13.8 kVA.

(ii) Category A2: 13.8 kVA – 100 kVA

This sub-category includes RPPs of Category A with rated power in the range greater than 13.8 kVA but less than 100 kVA.

(iii) Category A3: 100 kVA – 1 MVA

This sub-category includes RPPs of Category A with rated power in the range 100 kVA but less than 1 MVA.

Note: For RPPs connected to multi-phase supplies (two- or three-phase connection at the POC), the difference in installed capacity between phases may not exceed 4.6 kVA per phase.

(b) Category B: 1 MVA – 20 MVA

This category includes RPPs with rated power in the range equal or greater than 1 MVA but less 20 MVA.

(c) Category C: 20 MVA or higher

This category includes RPPs with rated power equal to or greater than 20 MVA”.

Literature Survey of Inverter

According to [5], Inverters work by converting DC voltage and current into AC voltage and current to be used to meet electricity demand for various appliances. The most common types of Inverters are:

a) Stand-alone Inverters are used in isolated or decentralized systems not connected to the utility grid, where the Inverter receives its DC current and voltage from batteries that are charged by PV system.

b) Grid connected inverters regulates the amount of voltage and the current that is received from DC and then converts it into an alternating current by ensuring that the power will be in phase or synchronized with the grid-power. This will allow the exportation of any excess power generated by the PV system to the utility grid.

Grid connected inverters; in addition to its basic functionality of DC to AC, conversion should perform the following functions:

a) Synchronize its output voltage and frequency with the AC mains.

b) Disconnect from the grid if the voltage and frequency deviate from the allowable limits or there is a loss of gird.

c) Ensure the output AC waveform is within the specified harmonic and flicker limits

d) Adjust the PV array operating voltage to ensure maximum power is extracted from the PV Array.

e) Monitor earth and isolation faults on the DC side of the solar PV system.

Inverters typically come in two classifications that will have an impact on the design process of the Solar PV System. These are:

a) Isolated inverters with at least simple separation between the AC and DC sides.

b) Non-isolated inverter without at least simple separation between the AC and DC sides, also known as transformer-less inverter.

According to [6], when considering the most appropriate inverter size, the following oversizing/ under sizing considerations should be considered.

Why Undersize the Inverter?

a. PV modules in UK operate for much of the time below the nominal rated power. Nominal rated power is the output of the module under STC reached relatively infrequently in the UK. Consequently, inverters will spend much of their time operating at power levels below the nominal array rating.

b. Inverter efficiency is generally lower when operating at low power levels. With a degree of inverter under sizing, it is possible to take the normal operating regime higher up the efficiency curve and hence decrease inverter losses at times of normal irradiance levels.
c. The array is located in a sub- optimal location, orientation or pitch and such as is expected to produce a lower than normal output.
d. When grid connection limit is imposed on a site it may be beneficial to considerably undersize the inverter to gain maximum generation. An example would be a domestic inverter of 3.68 kW with a 6 kW array connected so as to produce more power when in sub-optimal conditions Manufacturers will provide guidance on the maximum under sizing possible.
e. While a larger inverter may provide a system with a higher output power, the increased annual yield may not be justified by the extra cost (i.e. the system has a lower IRR).

Why Oversize the Inverter?

a. Limited inverter selection
b. A system with an inverter smaller than the array will, on occasions of high irradiance, have the output clipped- the inverter will simply not be able to deliver all the available power to the grid. Oversizing the inverter prevents this happening.
c. May increase inverter life.
d. The array is expected to produce significant power – for example, an array on a solar tracker or located in a very sunny location.

Literature Survey of Photovoltaic Modules

Solar PV Modules typically come in three safety classes as per IEC 61730 according to [5] :

a) Class A modules meet the safety class II, these are mandatory.

b) Class B modules meet the safety class 0, these are not permitted.

c) Class C modules meet the safety class III, these are not permitted.

Consideration should be given to Modules installed in coastal environments, in such locations compliance with IEC.

Potential Induced Degradation (PID), according to the Institution of Engineering and Technology [6], to reduce the power output of a cell. It occurs when the voltage between the cell and the ground drives ions from the module glass (and other parts of PV laminate) into the semiconductor and reduce its effectiveness. The presses is amplified by increased humidity, temperature and system voltage.

Certain types of PV modules are more prone to PID and the manufacturers may specify particular grounding arrangement for PV system. Some PID effects can be reversed, and the full output of a module restored, by connecting one of the DC current currying conductors to earth (connecting DC negative to earth for the P-type module). This is termed ‘functional grounding’.

IEC are currently working on a standard for module manufacturers to test for the impact of PID on a particular module (IEC 62804 (Draft)) system voltage durability qualification test for crystalline silicone modules.

Literature Survey of Spacing between Modules' Rows

The spacing between module rows according to the Institution of Engineering and Technology [6], is dictated by the site topography and the degree of inter row shading that is deemed acceptable. Providing sufficient access between rows for cleaning or grass cutting vehicles also needs to be considered. Table (2.1) shows that the advantages and disadvantages either larger gap or smaller gap between rows.

Table (2.1): Comparison between Larger and Smaller Gaps between Rows

	Larger gap between rows	smaller gap between rows
Shading	Less inter row shading	more inter row shading
KWh/KWp performance	Better KWh/KWp	worse KWh/KWp
Installed capacity(KWp)	Smaller array (KWp) can be installed	larger array (KWp) can be installed

In general, foundation options for ground-mounted PV systems include the following that according to International Finance Cooperation [7]:

- Concrete piers cast in-situ: These are most suited to small systems and have high tolerance to uneven and sloping terrain. They do not have large economies of scale.

- Pre-cast concrete ballasts: This is a common choice for manufacturers with large economies of scale. It is suitable even at places where the ground is difficult to penetrate due to rocky outcrops or subsurface obstacles. This option has low tolerance to uneven or sloping terrain, but requires no specialist skills for installation. Consideration must be given to the risk of soil movement or erosion.
- Driven piles: If a geotechnical survey proves suitable, a structural steel profile driven into the ground can result in low-cost, large-scale installations that can be quickly implemented. Specialist skills and pile driving machinery are required, but may not always be available.
- Earth screws: Helical earth screws typically made of steel have good economics for large-scale installations and are tolerant to uneven or sloping terrain. These require specialist skills and machinery to install.
- Bolted steel baseplates: In situations where the solar plant is located over suitable existing concrete ground slabs, such as disused airfield runway strips, a steel baseplate solution bolted directly to the existing ground slabs.

Literature Survey of Grounding System

The international standard IEC60364 explain the five basic methods of grounding and providing the neutral of an electrical installation where it is required. The five methods are abbreviated TN-C, TN-S, TN-C-S, TT and IT.

The first letter denotes the source of power from a star-connected winding.

T denotes that the star point of the source is solidly connected to earth, which is usually at a location very near to the winding.

I denotes that the star point and the winding are isolated from earth. The star point is usually connected to an inductive impedance or resistance. Capacitive impedance is never used.

The second letter denotes the consumer. The consuming equipment needs to be earthed. There are two basic methods that can be used to earth the body of electrical equipment. These methods are denoted by the letters T and N. The letter N is sub-divided into other letters, S and C, thus giving N-S, N-C and N-C-S.

T denotes that the consumer is solidly earthed independently of the source grounding method.

N denotes that a low impedance conductor is taken from the earth connection at the source and routed directly to the consumer for the specific purpose of grounding the consuming equipment.

S denotes that the neutral conductor (N) routed from the source is separate from the protective earthing (PE) conductor, which is also routed from the source. This implies that five conductors need to be routed for a three-phase consumer.

C denotes that the neutral conductor and the protective earthing conductor are one and the same conductor. This means that four conductors need to be routed for a three-phase consumer.

TN-C-S denotes that combined PEN conductors from transformer to consumer distribution point, but separate PE and N conductors in fixed indoor wiring and flexible power cords

The different earthing (grounding) types are illustrated in Figure (2.2):

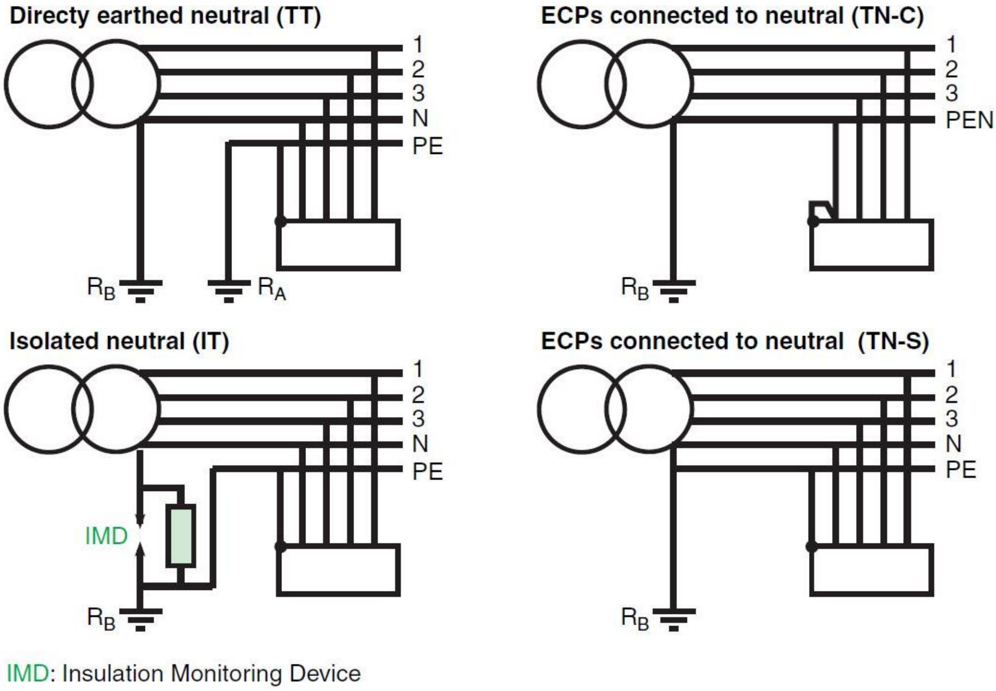


Figure (2.2): Grounding Configurations

Literature Survey of Protection System

Combiner boxes have protective and isolation equipment, such as string fuses and disconnects (also known as load break switches), and must be rated for outdoor placement using, for example, ingress protection (IP). An explanation of the IP bands is provided in Table (2.2) depending on the solar PV plant architecture and size, multiple levels of junction boxes can be used [7].

Table (2.2): Ingress Protection

First Digit	Protection from Solid Objects	Second Digit	Protection from Moisture
0	Non-protected	0	Non-protected
1	Protection against solid objects greater than 50mm	1	Protected against dripping water
2	Protection against solid objects greater than 12mm	2	Protected against dripping water when tilted
3	Protection against solid objects greater than 2.5mm	3	Protected against spraying water
4	Protection against solid objects greater than 1.0mm	4	Protected against splashing water
5	Dust protected	5	Protected against water jets
6	Dust tight	6	Protected against heavy seas
		7	Protected against immersion
		8	Protected against submersion

According to [8], installing Type B earth leakage protection units ensures the safety of individuals and correct functioning for alternating current (AC), direct current (DC) or mixed current (AC/DC) intensities up to frequencies of 1 kHz. Type A and AC earth leakage protection units do not detect smooth residual direct currents. Moreover, Type A units become more sensitive when a pulsating earth leakage current is accompanied by a smooth direct current. In these cases, protection is not as effective and compromises the expected safety levels.

All protection elements installed upstream must have the same or higher rating than those installed downstream, never lower, in order to guarantee the correct operation of the selective classification process. Therefore, if Type B is the maximum protection level of an element, a Type A or AC unit cannot be installed downstream.

Where an electrical installation includes a PV power supply system without at least simple separation between the AC side and the DC side, an RCD installed to provide fault protection by automatic disconnection supply shall be type B according to IEC 62423.

According to [9], Where the PV converter is, by construction, not able to feed DC fault currents into the electrical installation, RCD of type B according to IEC62423 is not requires.

RCDs are classified into different categories, as follows, in according with their ability to ensure protection against various types of earth fault currents:

1.Type AC

- for residual sinusoidal alternating currents

2.Type A

- as for type AC; and
- for residual pulsating direct currents

3.Type B & F (MS IEC-62423)

- as for type A; and
- for smooth DC

Selection of RCDs according to the type of protection RCDs can be used where it is necessary to protect a circuit or an installation against dangerous residual currents. The three main areas for such protection are as follows according to [10] :

1.Protection against fire.

Tracking currents are linked to ageing of installations where a reduction in humidity and drying out of pollution at the surface of isolating materials may lead to a degradation of the isolating material and the deposit of carbon. This may cause fire. Recommended to use RCDs having $I\Delta n$ not higher than 300 mA at the beginning of installations. In domestic applications, where installations are not maintained, the use of such RCDs is highly ecommended. For fire protection, the RCD must break all phase(s) and neutral. It may be an S Type RCD in order to allow discrimination with other RCDs downstream.

2.Fault protection (protection against indirect contact)

Fault between a live part and earth

- May cause exposed metal parts to reach a dangerous voltage.
- A person touching such live parts may be exposed to a potentially fatal
- Shock risk, so the fault must be eliminated.
- This is referred to as protection against indirect contact.
- Choice of RCD must follow recommendations made in MS IEC 60364.

In general, a medium sensitivity RCD can be selected for this type of fault protection.

e.g. An RCD with a rated residual operating current of up to 300 mA. If this value is appropriate it is possible to use a single RCD for fire protection and fault protection (protection against indirect contact)

3.Basic protection (protection against direct contact)

- Direct contact between a person and a live conductor, a residual current will flow through the body of the person.
- This current may cause a fatality if not eliminated quickly.
- An RCD having /Δn not higher than 30 mA will provide adequate protection in this situation (additional protection against electric shock).

In a domestic application, a 30 mA RCD used at the origin of the installation can provide efficient protection covering fire protection, fault protection and basic protection. For basic protection the RCD should not be a delayed type (selective type).

Literature Survey of Power Factor Correction in PV Systems

Solar PV Plants Generation starts when sun shining is active generation period. Solar Inverter Designed to produce power at unity power factor meaning they only produce active power; so the reactive power needed from loads will be consumed from utility grid In effect this reduces the power factor, as the grid is then supplying less active power, but the same amount of reactive power. Therefore total power factor during the month will be decreased, could be cause some penalties from IECo to solve this problem we should install Capacitor Bank in solar Plant Substation.

Project developers should maintain a power factor close to unity; there are other states that charge for the reactive power consumed by the PV plant. Although most modern central inverters can be made to operate at leading power factor, supplying the reactive power during hours of high irradiance, there may be a need to include a capacitor bank to compensate reactive power during periods of low irradiance. It is advisable to select inverters that can compensate the reactive power [7].

Main benefits of correct Pf is

- Avoid Penalty
- Increased Efficiency in the System Capacity.
- Reduces Voltage Drop
- Reduces System Losses.

Chapter 3

Solar and Wind Energy Potential in Tubas

3. Solar and Wind Energy Potential in Tubas

This chapter discusses the weather data in Tubas; solar irradiance, wind and temperature by using local weather[1] station, installed within the second PV power station donated from Czech Republic on 2015.

3.1. Solar Radiation

Palestine is located within the global solar belt countries, which have high solar energy potential Figure (3.1) [11]

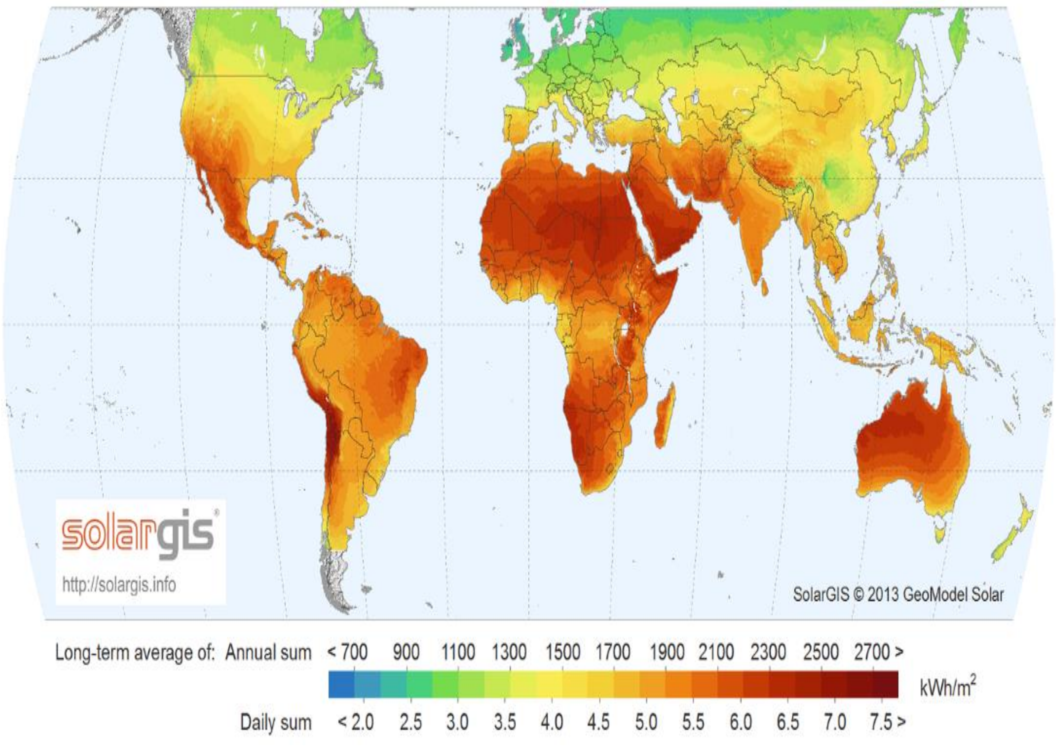


Figure (3.1): Solar Irradiance of the World

[1] The detailed specifications of this weather station is presented in section 5.10

The photovoltaic power potential in west bank is shown in Figure (3.2) [12]. Tubas is located in the northern part of Palestine distinguished with very good solar irradiance amounting to about 5.4 kWh/m^2-day [1] .

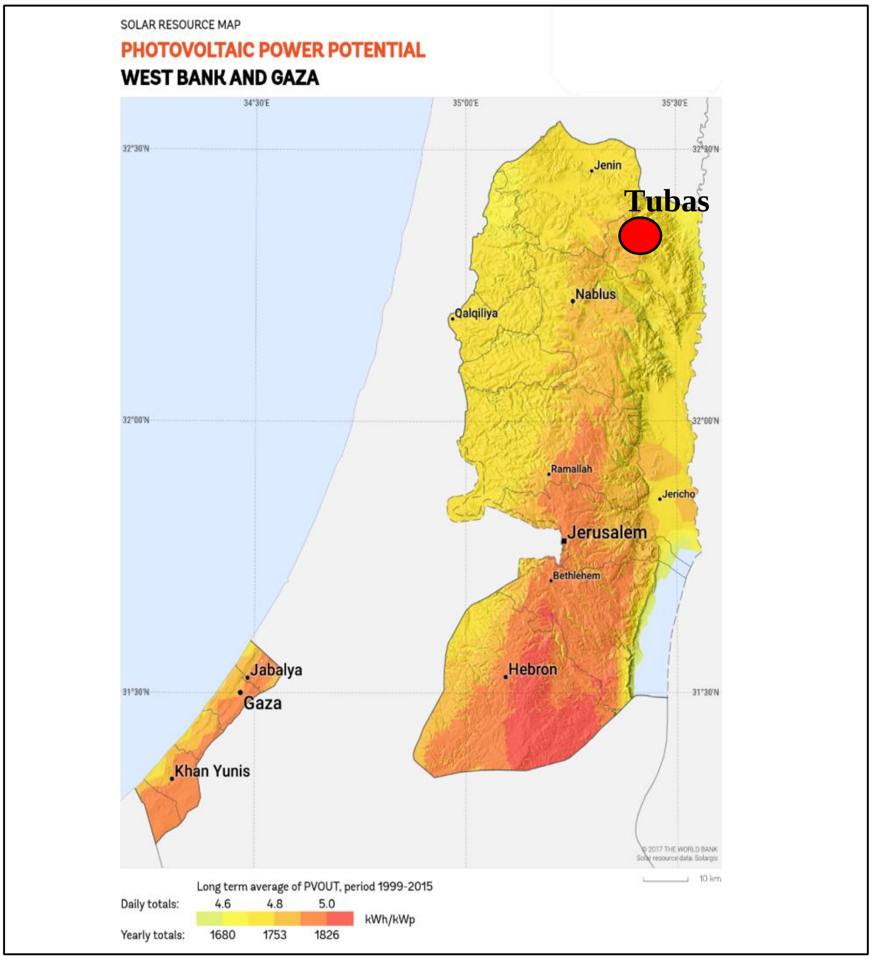


Figure (3.2): Photovoltaic Power Potential in West Bank and Gaza

This section discusses the irradiance data from TDECOs' weather station, which has 22° titled and horizontal irradiance sensor. From the data have been collected in 2016, the total yearly irradiance was 2171 kWh/m^2 and 1866 kWh/m^2 on tilted plane and horizontal plane respectively.

Table (3.1) shows the measurements of the maximum solar radiation of typical clear day for each month on tilted surface $G_{t(max)}$ and horizontal surface $G_{h(max)}$, at solar noon time that were measured on 15 minutes interval basis.

Table (3.1): Maximum Solar Radiation of Typical Clear Day for Each Month

Date	$G_{t(max)}$ W/m^2	$G_{h(max)}$ W/m^2	Solar Noon Time for Tilted
Jan.6.2016	806	574	11:30 AM
Feb.4.2016	902	678	11:30 AM
Mar.1.2016	1011	790	11:45 AM
Apr.1.2016	1070	908	12:30 PM
May.11.2016	1026	945	12:45 PM
Jun.1.2016	1008	950	12:30 PM
Jul.1.2016	1002	950	12:30 PM
Aug.3.2016	987	907	12:30 PM
Sep.1.2016	965	843	12:45 PM
Oct.2.2016	958	772	11:15 AM
Nov.3.2016	838	608	11:15 AM
Dec.9.2016	833	562	11:30 AM

From the previous table and Figure (3.3) [1] the solar noon in Tubas is between 11:30am and 12:45pm around the year. The maximum solar irradiance for horizontal surface was 950 W/m^2 on Jun and July, the maximum solar irradiance for tilted surface was 1070W/m^2 on April, the lowest solar irradiance for horizontal surface was 562 W/m^2 on Dec and the lowest one for tilted surface was 806W/m^2 on Jan.

[1] See Appendix E1 for high resolution figure

Usually the irradiance of horizontal surface is greater than tilted surface during noon time in Jun, July, August and September because the altitude angle of the sun is higher, this is dispute these readings because uncalibrated equipment.

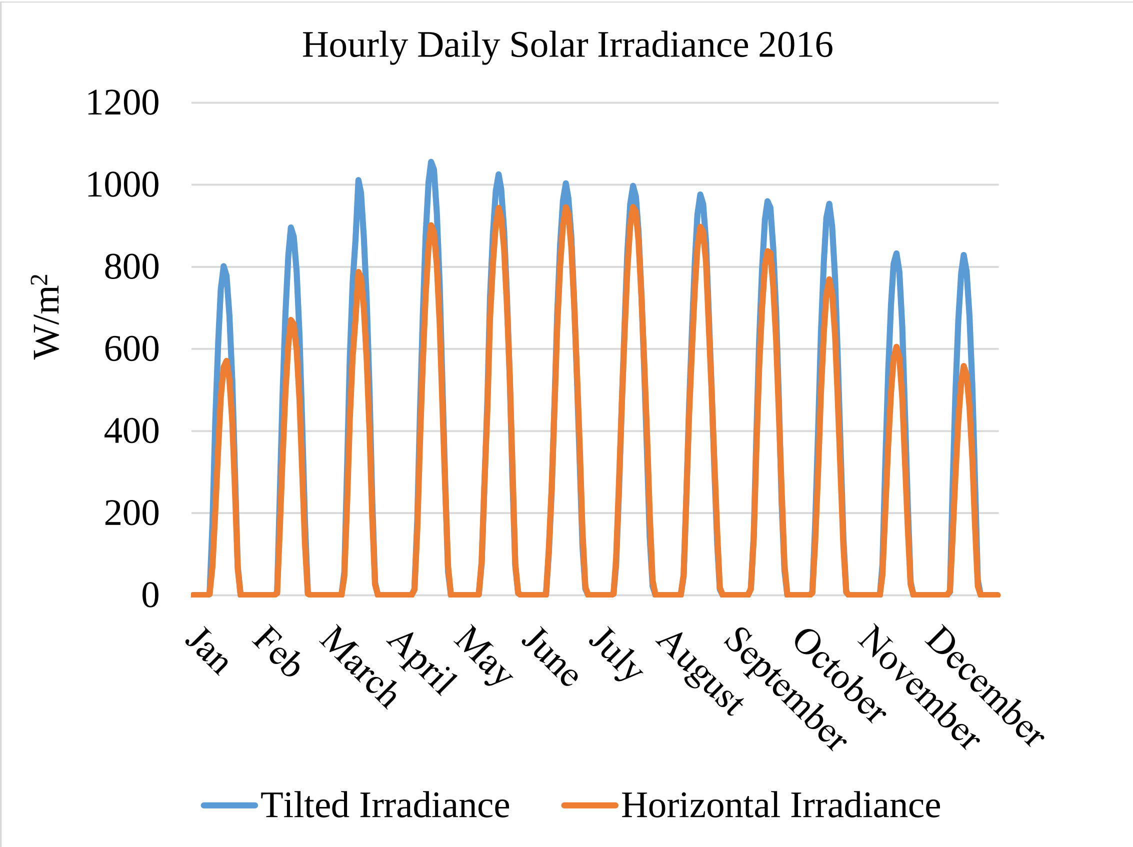


Figure (3.3): Hourly Daily Solar Irradiance 2016

In 2016[1], the sun was shining for 4576 hours and 45 minutes, which represents 52% of the year. Table (3.2) shows the sunrise, sunset and the sun shine time for a typical clear sky day of each month. The average daytime was 12 hours and 30 minutes; the maximum daytime was 14 hours and 30

[1] 2016 was leap year

minutes in Jun and July while the minimum daytime was 10 hours and 15 minutes in Jan.

Table (3.2): Sun Rise, Sun Set and Day Time for a Typical Clear Sky Day

	Sun Rise time (t_s)	Sun Set time (t_{ss})	Day Time (t_d)	Day Time for each month
Jan.6	6:30 AM	5:00 PM	10:30	325:30:00
Feb.4	6:15 AM	5:15 PM	11:00	319:00:00
Mar.1	5:45 AM	5:45 PM	12:00	372:00:00
Apr.1	6:15 AM	7:00 PM	12:45	382:30:00
May.11	5:30 AM	7:30 PM	14:00	434:00:00
Jun.1	5:15 AM	7:45 PM	14:30	435:00:00
Jul.1	5:15 AM	7:45 PM	14:30	449:30:00
Aug.3	5:30 AM	7:45 PM	14:15	441:45:00
Sep.1	6:00 AM	7:00 PM	13:00	390:00:00
Oct.2	5:15 AM	5:30 PM	12:15	379:45:00
Nov.3	5:45 AM	4:45 PM	11:00	330:00:00
Dec.9	6:15 AM	4:30 PM	10:15	317:45:00
Min			10:15	317:45:00
Max			14:30	449:30:00
Avg			12:30	381:23:45

Table (3.3) shows the average monthly solar irradiance for each tilted and horizontal surface and the monthly tilt correction coefficient calculated according to Equation 3.1.

$$K = \frac{G_{t(avg)}}{G_{h(avg)}} \quad (3.1)$$

Where,

K: Tilt correction coefficient.

$G_{t(avg)}$: Average monthly solar irradiance per day for tilted surface (kWh/m^2-day).

$G_{h(avg)}$: Average monthly solar irradiance per day for horizontal surface (kWh/m^2-day).

Table (3.3): Average Monthly Solar Energy on Horizontal and Tilted Surface at 22° for Tubas and Correction Coefficient

	$G_{t(avg)}$ kWh/m^2-day	$G_{h(avg)}$ kWh/m^2-day	Tilt Correction Coefficient (K)
Jan	3.70	2.70	1.372
Feb	4.38	3.32	1.320
Mar	5.52	4.39	1.256
Apr	6.38	5.55	1.151
May	7.09	6.60	1.076
Jun	7.58	7.39	1.027
Jul	7.51	7.41	1.013
Aug	7.22	6.89	1.047
Sep	6.68	5.95	1.122
Oct	6.20	5.03	1.233
Nov	5.11	3.74	1.365
Dec	3.72	2.59	1.434

The average solar irradiance during 2016 was 5.13 kWh/m^2-day and 5.925 kWh/m^2-day for horizontal and tilted surface respectively. Despite $G_{t(max)}$ has the maximum value on April as discussed previously on Table (3.1).

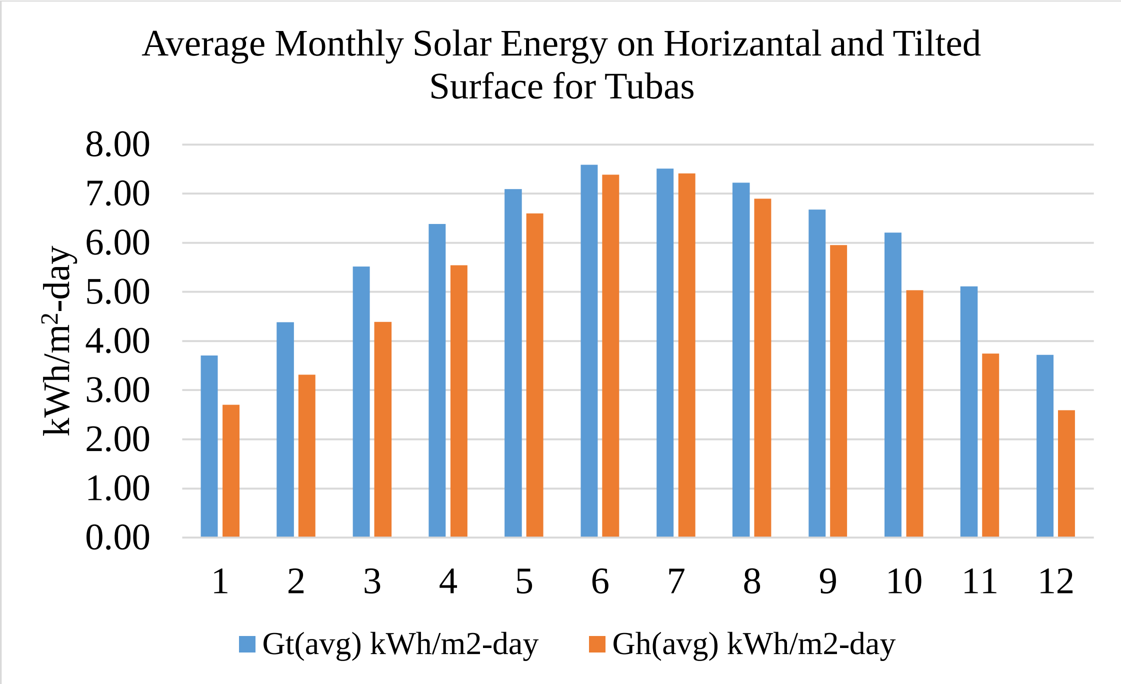


Figure (3.4): Average Monthly Solar Energy on Horizontal and Tilted Surface for Tubas

3.2. Wind Speed

The anemometer[1] has been installed at the height of 4m from the ground, which measures the wind speed and direction. The measuring data is not suitable to study the wind energy potential necessary to perform a feasibility study. This needs an installation height, which is not less than 12 meter. Table (3.4) shows the average and maximum wind speed for the year 2016. The average wind speed during the year was 2.21m/s and the maximum wind speed was 15m/s.

Table (3.4): Average and Maximum Wind Speed for Tubas in 2016

	Average Wind Speed (m/s)	Maximum Wind Speed (m/s)
Jan	1.98	15
Feb	1.87	8
Mar	2.41	13
Apr	2.06	11
May	2.58	13
Jun	2.25	9
Jul	2.52	9
Aug	2.37	9
Sep	2.15	9
Oct	1.98	9
Nov	2.42	12
Dec	1.90	12

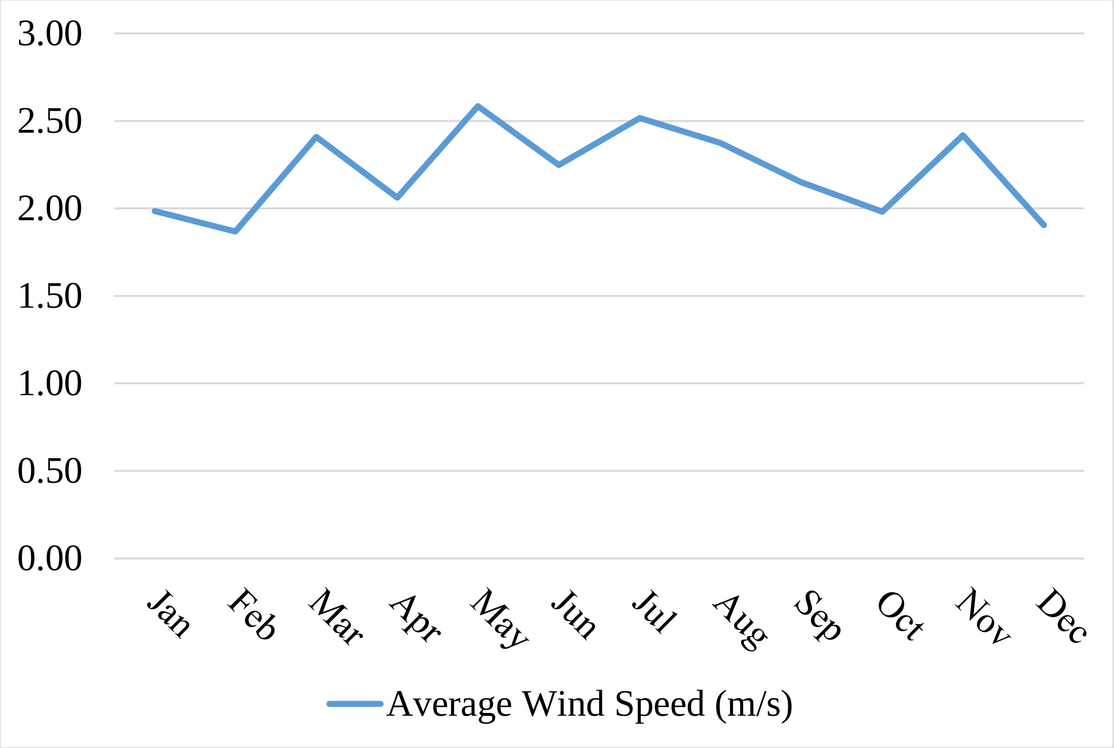


Figure (3.5): Average Wind Speed at 4m height in Tubas during 2016

The representation of the statistical repartition of the wind directions of this site is shown on the Figure (3.6) “wind rose diagram” that shows wind direction frequency and its direction in degrees. We notice that the wind comes mainly from the west and to a lower extent from the south in this particular site.

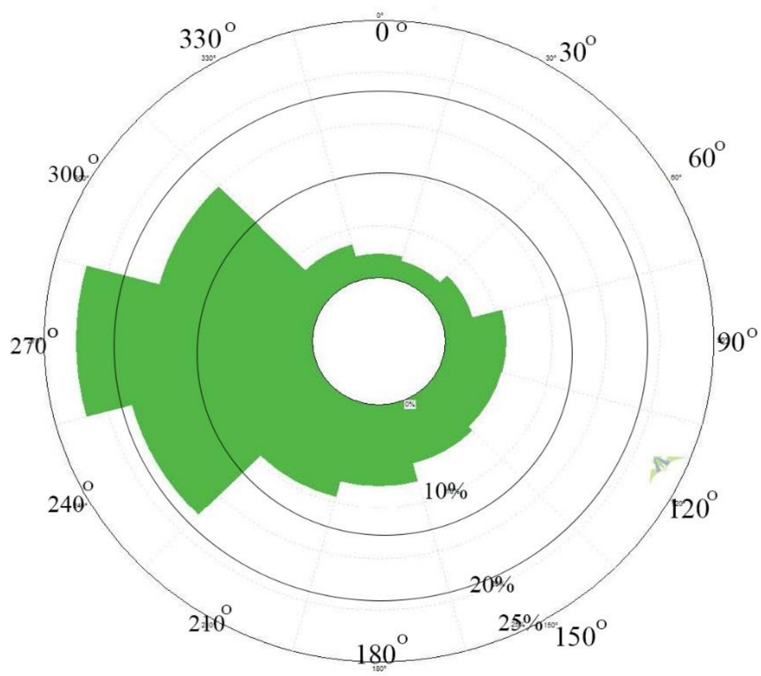


Figure (3.6): Wind Rose

The hourly data was taken to draw the wind duration curve shown in Figure (3.7), the repetition was for the wind speed is less than 4m/s and the maximum repetition was 10% for 2m/s.

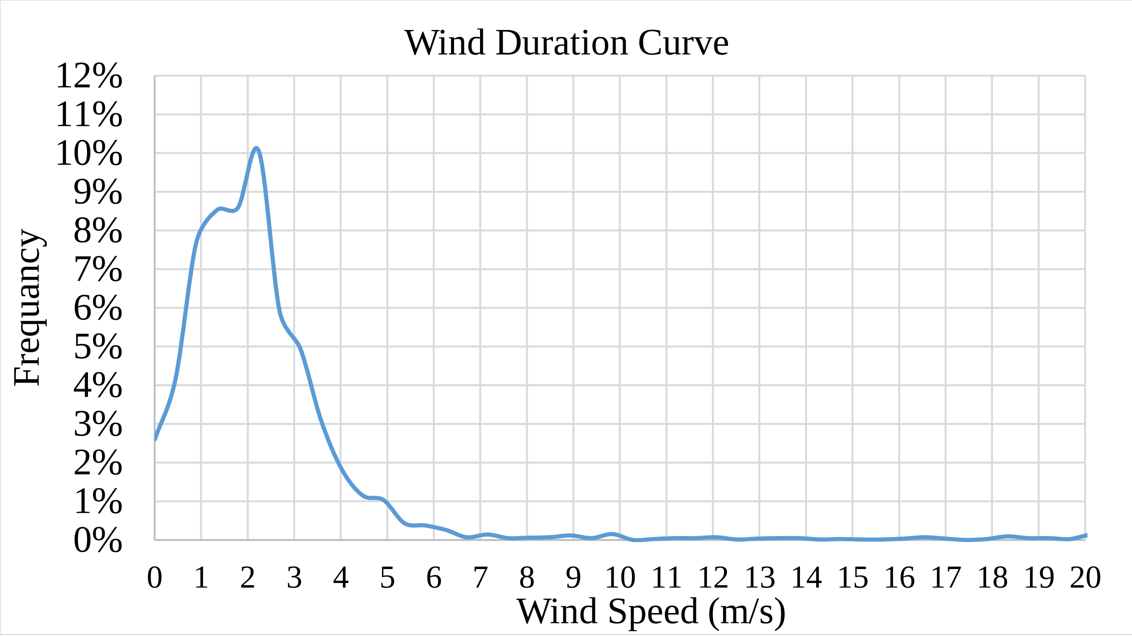


Figure (3.7): Wind Duration Curve

The data were fitted to small wind turbine 3.5kW from roam energy with the specifications shown in Table (3.5).

Table (3.5): Wind Speed Categories During the Year According to Roam Wind Turbine Specifications.

Status	Speed Ranges of Roam Wind Turbine	Hours Repetition on This Site	Frequency During the Year
off	less than 2.8m/s	7359	84.06%
Cut-in wind speed	from2.8m/s to 11m/s	1179	13.47%
Rated wind speed	from11m/s to 22m/s	89	1.02%
Cut-out wind speed	more than 22m/s	127	1.45%

Figure (3.8) shows this turbine will operate during 14.49% (more the 2.8m/s and less than 22 m/s) from the year. Therefore, this site with this installation height not suitable for installing wind turbine with cut in wind speed 2.8m/s.

If there is another wind turbine with cut in wind speed less than 2m/s, it could be more suitable.

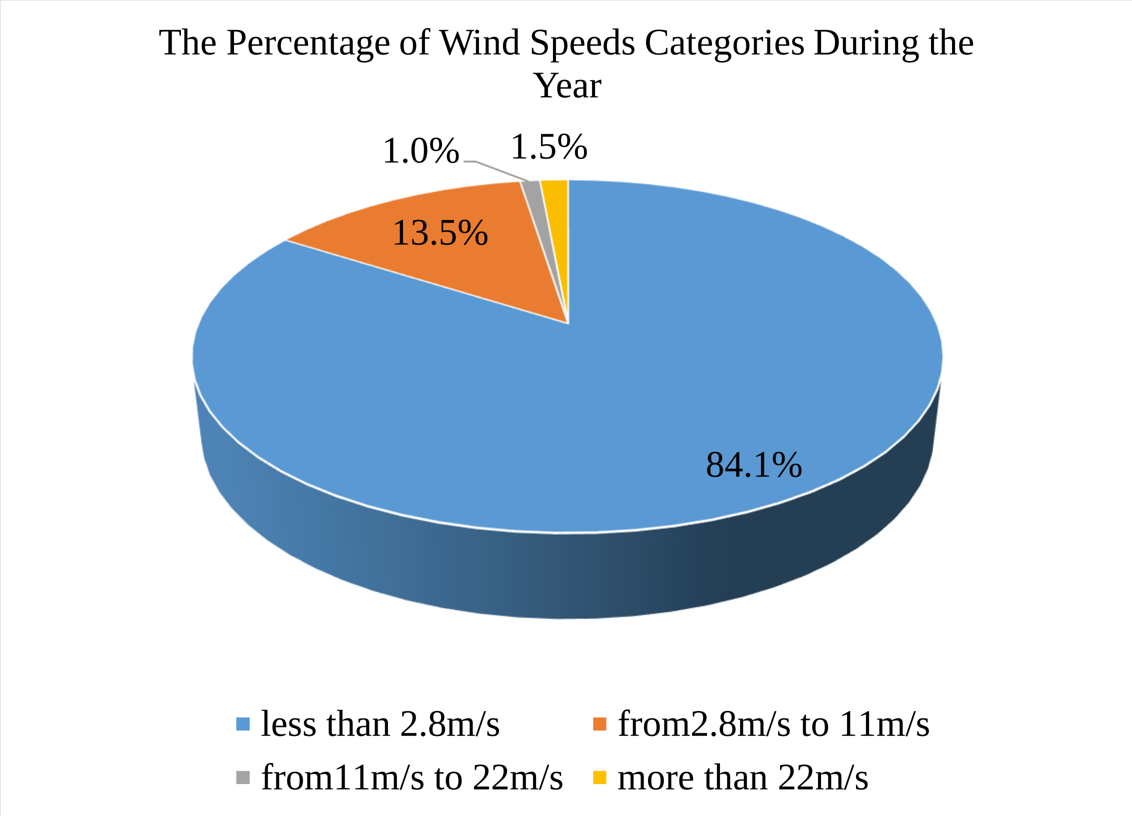


Figure (3.8): The Percentage of Wind Speeds Categories During the Year

3.3. Temperature

The ambient temperature is an important factor affects the PV output power. This section discusses the obtained data for specified site; ambient temperature, cell temperature and make a comparison between the real and calculated cell temperature. All measured data is based on 5-minute interval taken from temperature sensor[1] in 2016.

Table (3.6) and Figure (3.9) show that the highest ambient temperature is 42°C in May, the lowest ambient temperature is 0.1°C in Jan and the average is 20.5°C.

Table (3.6): Ambient Temperature in Tubas

Month	Temperature Max °C	Temperature Avg. °C	Temperature Min °C
Jan	19.6	10.4	0.1
Feb	27.5	14.7	6.6
Mar	28.0	16.1	8
Apr	36.0	21.9	10.4
May	42.0	22.4	13
Jun	39.5	27.8	16.3
Jul	37.2	27.3	19.8
Aug	36.8	27.0	20.2
Sep	36.6	25.3	17.6
Oct	37.4	23.6	15.2
Nov	29.9	18.0	5.9
Dec	19.8	10.9	2.8

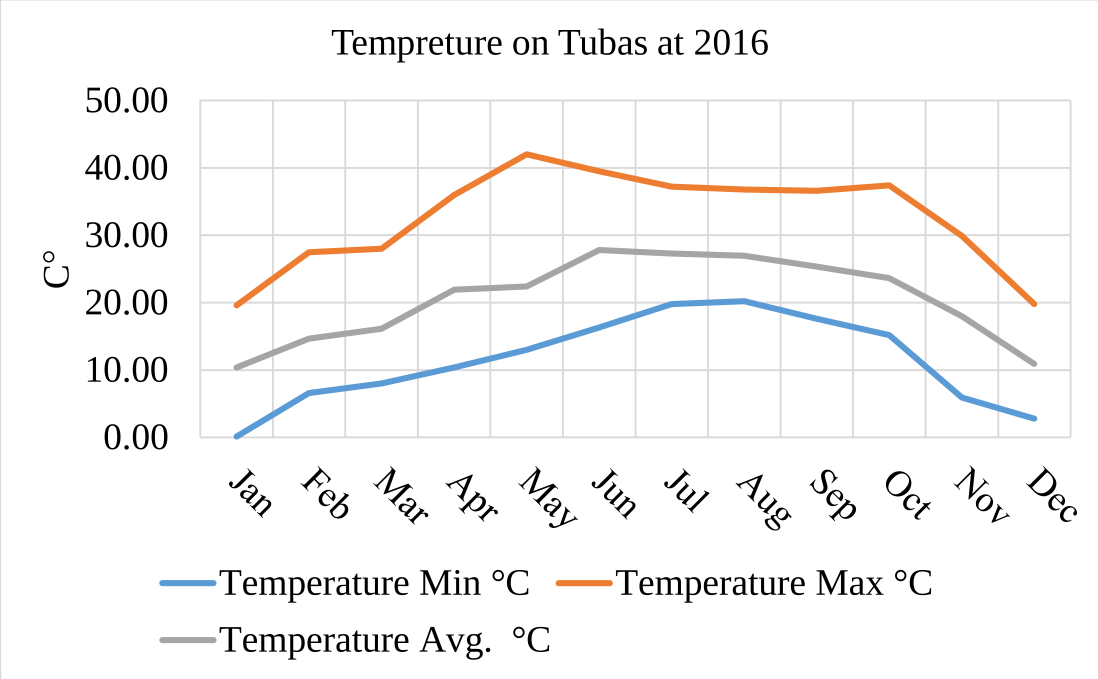


Figure (3.9): Temperature on Tubas at 2016

Table (3.7) and Figure (3.10) show the monthly maximum, average and minimum cell temperature during 2016, which were 69.1°C in Jun and -4.7°C in Jan respectively.

Table (3.7): Cell Temperature on 2016

Month	Maximum Cell Temperature °C	Monthly Average Cell Temperature °C	Minimum Cell Temperature °C
Jan	46.3	12.2	-4.7
Feb	55.1	18.1	2.0
Mar	53.8	20.0	7.5
Apr	63.4	27.1	6.0
May	68.4	27.6	10.0
Jun	69.1	33.6	12.3
Jul	66.2	32.6	15.0
Aug	66.7	31.0	17.5
Sep	67.6	30.7	12.0
Oct	67.1	28.1	11.4
Nov	57.7	20.7	3.0
Dec	49.6	13.3	0.0

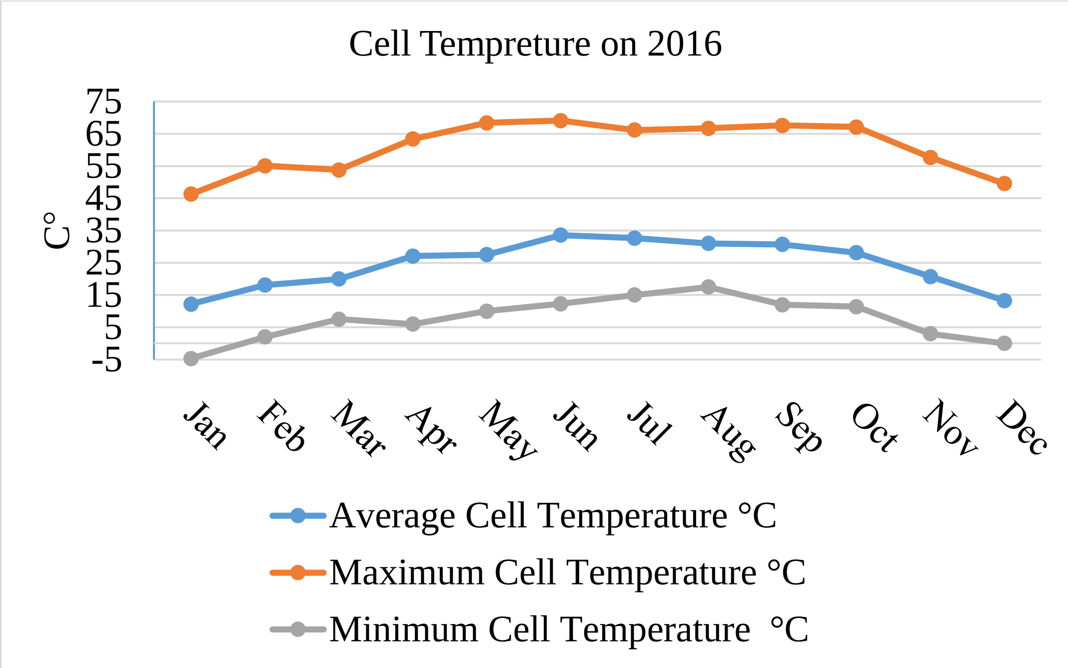


Figure (3.10): Cell Temperature on 2016

The approximate cell temperature can be calculated by using Equation3.2 [13].

$$T_C \approx T_{amb} + 0.0256 * G_h \tag{3.2}$$

Where,

T_c : Cell Temperature (°C).

T_{amb} : Ambient Temperature (°C)

G_h : Horizontal Solar Irradiance (W/m^2)

Table (3.8) shows the actual and calculated cell temperature on July.1st.2016, which is a typical summer day.

Table (3.8): Daily Ambient, Actual and Calculated Cell Temperature on a Typical Summer Day

Date/Time	Horizontal Irradiance (W/m^2)	Ambient Temp.(C°)	Actual Cell Temp.(C°)	Calculated Cell Temp.(C°)
12:00 AM	0	22	20	22
1:00 AM	0	22	20	22
2:00 AM	0	22	20	22
3:00 AM	0	21	19	21
4:00 AM	0	21	19	21
5:00 AM	4	22	19	22
6:00 AM	89	22	21	24
7:00 AM	275	24	28	32
8:00 AM	469	27	38	39
9:00 AM	647	28	46	45
10:00 AM	792	30	50	50
11:00 AM	900	31	51	54
12:00 PM	946	32	54	56
1:00 PM	934	32	54	56
2:00 PM	863	32	50	54
3:00 PM	731	31	46	50
4:00 PM	565	31	41	45
5:00 PM	385	30	34	40
6:00 PM	198	28	30	33
7:00 PM	36	26	25	27
8:00 PM	0	24	22	24
9:00 PM	0	23	21	23
10:00 PM	0	23	21	23
11:00 PM	0	23	20	23

Figure (3.11) shows that there is slight difference between the real and calculated cell temperatures.

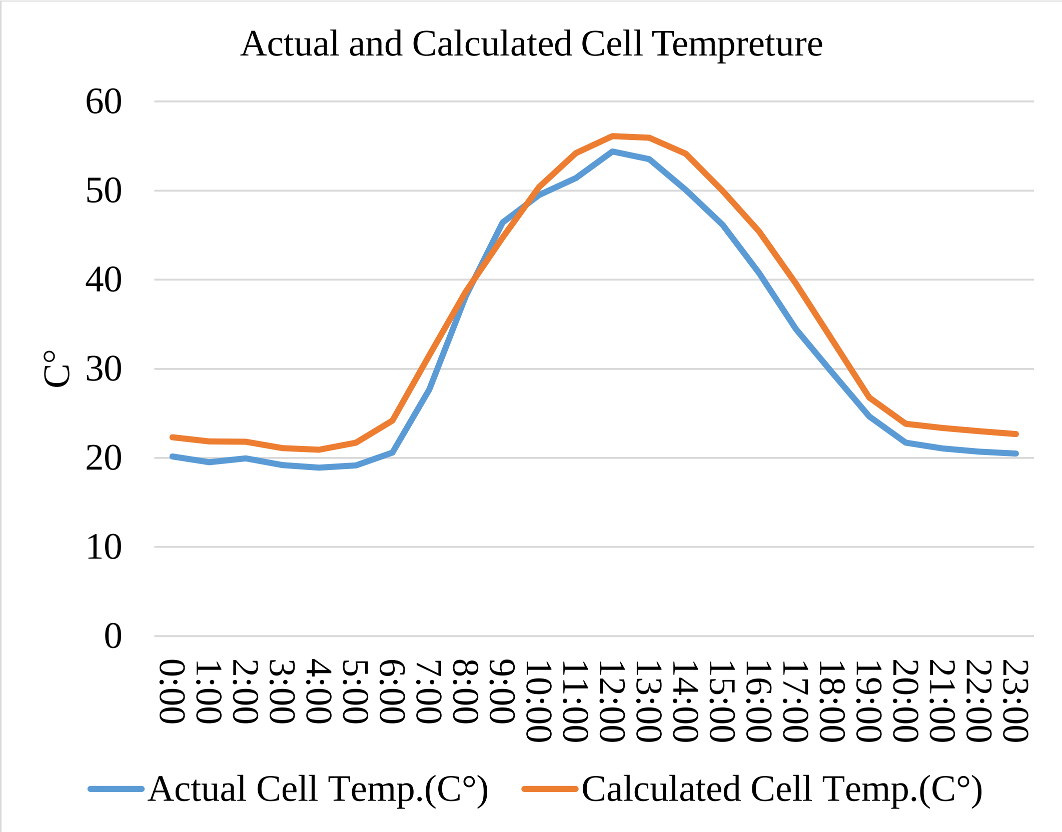


Figure (3.11): Actual and Calculated Cell Temperature

Chapter Four

The Construction of the 350kWp PV Power Station

4. The Construction of the 350 kWp PV Power Station

The PV power station consists of PV modules, inverters, DC and AC electrical protection equipment, grounding system, lightning protection system, galvanized steel structure, monitoring system, weather station, MV transformer, DC and AC cables.

In this chapter, the 350kWp PV power station administrative phases in the installation process, general geometrical and electrical construction description are discussed.

4.1. Administrative Phases in the Installation Process

This PV station classified as (“Direct Power Purchase Award of Renewable Energy Generation Station” according to declaration of Palestinian cabinet [2]) go through following administrative process.

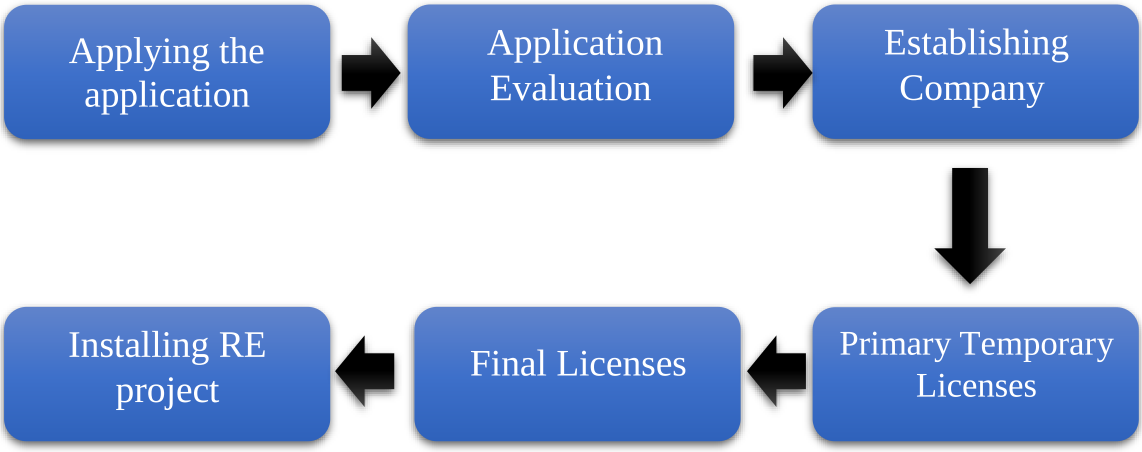


Figure (4.1): Administrative Process Flow Chart

Figure (4.1) shows the 6 installation stages. This station was the second largest PV station in the West Bank in 2013, and the Palestinian Electricity Transmission Ltd (PETL) was not established yet. Unfortunately, no clear administrative regulations published then, so some of these stages were not completed. The detailed description of each stage is as follows:

1. Applying the application of new PV power station to Palestinian Energy and Environment Research Center (PEC) and PETL includes the followings:

a. Technical study including station capacity, station technology, site location, land ownership and electrical grid availability.

b. Financial study and capability, including local and international partners information, company registration and its official financial documents, feasibility studies and financial studies of the project.

Note: we skipped point 1.b from this PV power station because it is a grant from the Czech Republic Development Agency. TDECO apply the importance of this project and their suffering from electricity shortage without it.

2. Application evaluation, that includes the followings:

   a. Technical approval from PEC (to check their strategic compatibility).
   b. Technical approval from PTEL (to check electrical grid and connection point compatibility).

This PV power station was, according to PEC strategy at that time and it was already compatible with the electrical grid and the connection point because it was the first PV station on this site.

3. Establishing the company according to corporation Law

This PV power station follows TDECO so it was no need to establish a new company.

4. Primary temporary licenses

It was not completed for this PV power station because the regulation was not published yet.

5. Final licenses

It was not completed for this PV power station because the regulation was not published yet.

6. Installing RE project

This PV power station was installed as mentioned in the next chapter.

4.2. Geometrical Description

This station lies in approximately 6000m^2 rocky area with parallelogram shape area that has been rounded by a fence that has one main gate in the northeastern corner.

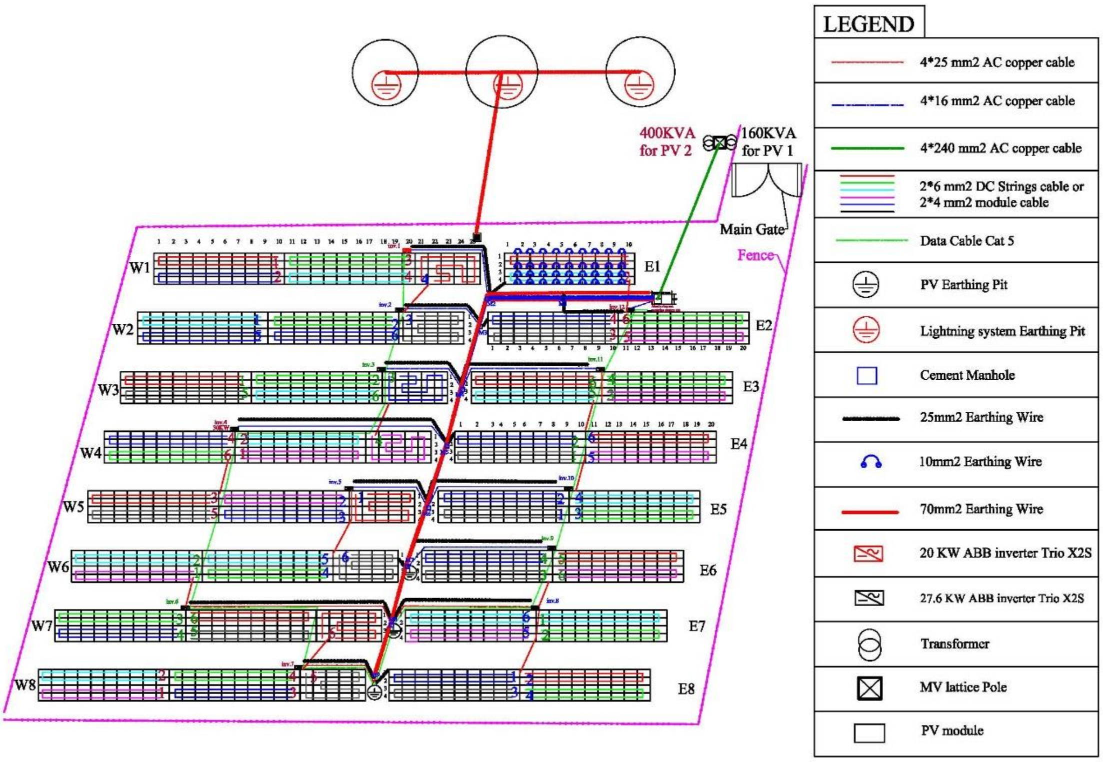


Figure (4.2): Top View of the 350kWp PV Power Station

Figure (4.2) [1] shows the 1400 PV modules in this PV power station divided into two areas western and eastern sides denoted by 'W' and 'E' respectively, are separated by 3m width, 75 meter long service road for maintenance purposes.

The PV modules are fixed on eight galvanized steel tables at each side that oriented directly to the south with 22° tilt angle. Each western table has 100 PV modules (4 rows x 25columns) and each eastern table has 80 PV modules

[1] See Appendix E3 for high resolution figure

(4 rows x 20columns) except one table in the far north of eastern area that has 40 PV modules (4rowsx10columns). The Inverters have been fixed on the structure behind the PV modules that distributed in all PV power station tables.

All DC cables were either fixed in structure or inserted in suitable conduit that has been buried underground between tables as shown in Figure (4.2).

All inverter AC cables lies between inverters and Main Distribution Board (MDB) are inserted in conduits and buried underground through service road. Each 7.5m the concrete manholes are inserted for cabling maintenance and grounding checkpoints. The first three manholes from the far south contains pure copper electrodes for the station grounding system.

The main cable lies between MDB and transformer are directly buried underground.

We can see also in the far north MDB which is fixed on (2.5x1.3x0.15m) reinforced concrete surface and a monitoring system distribution board (DB) is located there about two meters away from the MDB.

The weather station is fixed above before last table in area E near monitoring system DB in the far north.

The lightning protection system is fixed at 12 m galvanized steel pole; we can find it on the far north of area W, which has three grounding system pits outside, the far northern fence by 20m.

The last component of this power system is the transformer, which is located outside the northern fence on the west side of the main gate.

4.3. Electrical Description

This PV power station generates electricity by converting solar irradiance to DC electrical power through PV modules that connected to inverters, which converts DC power to AC. Then this power is transferred to 33kV network through a 33/0.4kV distribution transformer. For equipment and human safety purposes, there are some necessary DC and AC electrical protection equipment like DC fuses, surge protection device (SPD) on DC and AC side, residual current device (RCD), AC circuit breakers in LV side and isolator switch on MV side, all these components are shown in Figure (4.3) [1]

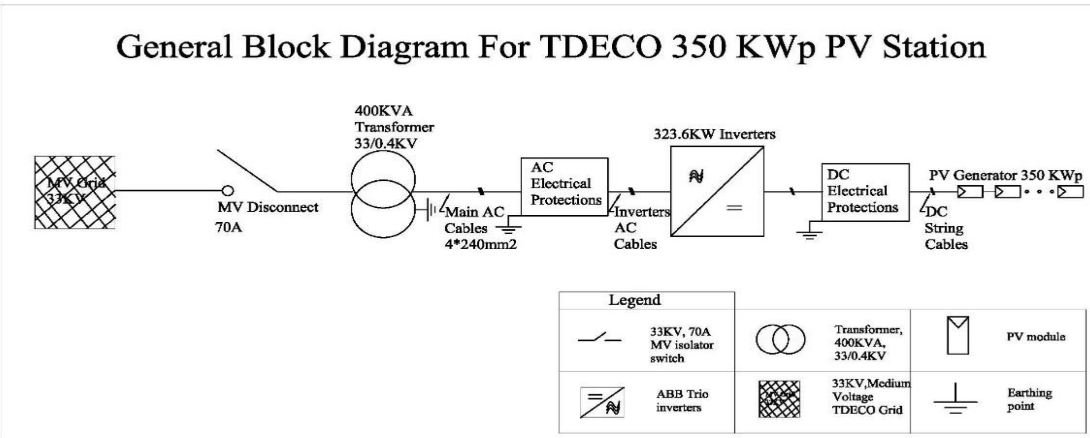


Figure (4.3): General Block Diagram for TDECO 350 kWp PV Station

This system consists 1400 PV modules (Hanwha Solar One 250Wp) connected by 4 and 6 mm^2 DC cables to 12 inverters (11inverters ABB 27.6kW and 1 inverter ABB 20 kW), which fixed behind the structure. These inverters have built in DC/AC junction box with all necessary DC fuses, DC surge protection device (SPD), AC SPD and DC/AC isolator switch.

[1] See Appendix EAppendix E4 for high resolution figure

Each 120 PV modules are connected to 27.6kW inverters, 20 modules in series and 6 strings in parallel. Regarding the 20kW inverter, 80 PV modules are connected to it where 20 modules in series and 4 strings in parallel. Then each string connected to 15A fuse inside DC/AC junction box and DC SPD connected in parallel of these fuses then goes to the inverter. The inverter output goes to DC/AC switch, while AC SPD parallel connected to this switch.

4x16mm^2 and 4x25mm^2 AC cables are connected between the inverter DC/AC switch and MDB.

The MDB contains RCDs and AC circuit breakers then goes through 4x240mm^2 underground AC cable to step up, 400kVA-0.4kV/33kV transformer, then to TDECO medium voltage (MV) utility grid.

All these parameters will be discussed in detail in the next chapter.

Chapter Five

Detailed Description of the 350kWp PV Power Station Components and Evaluation

5. Detailed Description of the 350 kWp PV Power Station Components and Evaluation

This chapter discuss the site selection criteria, technical evaluation for all components of this PV power station according to national (Palestinian Standards(PS)) and international codes as Australian Standards (AS), the National Electrical Code (NEC)-USA, the German Energy Society and the Institution of Engineering and Technology (IET)-United Kingdom[1] considering the following aspects, :

- Site selection criteria
- PV modules.
- Inverters.
- PV and inverter design
- Electrical protection system in AC and DC combiner boxes, comparison between the existing and proposed protection devices and finding the advantages and disadvantages in each case.
- MDB design, ventilation and its components (like AC inverter breakers, RCDs, busbar, main circuit breaker and G59).
- Grounding system.
- Lightning protection system.

[1] International standards are used because the absence of local standards

- Mounting structure.
- Monitoring system.
- Weather station.
- Calculating the voltage drop and power losses for AC and DC cables and summarize the main parameters that should be taken into account when selecting cables.
- Metering system.
- Transformer.
- Safety, labeling, and identification.
- Power factor correction.
- Before and after on site tests.

The checklist for each component are prepared to facilitate system installation evaluation an Appendix F.

The financial evaluation of system will be discussed in chapter 7

5.1. Site Selection Criteria

In general, the process of site selection must consider the constraints of each site and impact on the cost of the electricity generated. There are no clear-cut rules for site selection; the checklist shown in Appendix F.1 lists the basic requirements and procedures necessary to assist developers with the site selection process.

Figure (5.1) shows the land before and after preparation

Figure (5.1): The Location of PV Power Station Before and After Land Preparation

5.2. PV Modules

The system consists of 1400 PV modules, each module capacity is 250Wp, polycrystalline cell dimensions (156 mm × 156 mm), module dimensions(1636mm x 988mm x 40mm) this module contains 60(6x10) cells with 3 sets of diodes and protection class IP 67, its brand name is Hanwha Solar One which is Chinese product.

Electrical characteristics at Standard Test Conditions (STC) of this PV module is illustrated in a Table (5.1).

Table (5.1): Electrical Characteristics of Hanwha PV Module at STC

Maximum Power (P_{max})	250 W
Open Circuit Voltage (V_{oc})	37.7 V
Short Circuit Current ($I_{sc, mod@ STC}$)	8.79 A
Voltage at Maximum Power (V_{MPPT})	30.4 V
Current at Maximum Power (I_{MPPT})	8.23 A
Module Efficiency (%)	15.50%

Electrical characteristics at Normal Operating Cell Temperature (NOCT) at (NOCT, 45±3°C) defined at irradiance of 800W/m^2, ambient temperature 20°C and wind speed 1m/s are shown in Table (5.2).

Table (5.2): PV Module Electrical Characteristics at Normal Operating Cell Temperature (NOCT).

Power Class	250 W
Maximum Power (P_{max})	183 W
Open Circuit Voltage (V_{oc})	35 V
Short Circuit Current ($I_{sc\ ,mod@\ NOCT}$)	7.13 A
Voltage at Maximum Power (V_{MPPT})	27.6 V
Current at Maximum Power (I_{MPPT})	6.64 A
Module Efficiency (%)	14.20%

(See Appendix B.1 for full data sheet.)

The fill factor (FF) is an important parameter to characterize the PV module performance. For crystalline PV modules 0.75<FF<0.85 [3]. FF is obtained as follows.

$$FF = \frac{V_{mpp} * I_{mpp}}{V_{OC} * I_{sc,mod}} \quad (5.1)$$

The fill factor, according to STC (FF_{SCT}) is 0.755 and according to NOCT (FF_{NOCT}) is 0.7344.

Various standards are in place to provide safety and performance tests for PV modules according to Palestinian local standers [14] and IEC standards [6], photovoltaic modules should have the following certificates:

1 PS 2676: 2012 or IEC 61215.

2 PS 2684: 2012 or IEC 61730-1

3 PS 2685: 2012 or IEC 61730-2

This module complies Palestinian standers[1] and has other certifications as follows:

- Harsh Environment: Verified against Salt Mist and Ammonia Corrosion (IEC 61701 and IEC 62716).
- ISO 9001 quality standards and ISO 14001 environmental standards.
- OHSAS 18001 occupational health and safety standards.
- Conformity to CE (low Voltage Directive and EMI), fire tested class E (EN 13501-1).

Total effective area of PV modules is as mentioned in Equation 5.2

$$A_{PV,station} = N_{Cell} * A_{Cell} * N_{mod} \quad (5.2)$$

Where,

$A_{PV,\ station}$: PV power station area (m^2)

A_{Cell} : Module area (m^2)

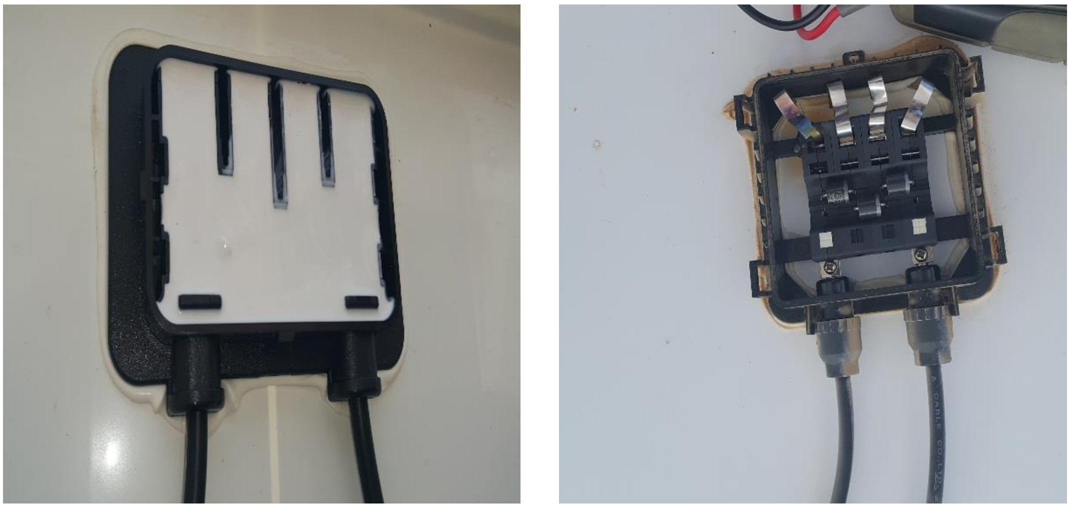
N_{Cell}: Number of cell per module

N_{mod} : Number of modules of PV power station

Then,

$A_{PV,\ station}$= 2044.224m^2

[1] This module compatible to the local standards see Appendix C1 for PSI certification



(A) (B)

Figure (5.2): (A) Sealed and (B) Non-Sealed PV Module Junction Box

This module has a good sealed junction box that sold by white suitable insulator sheet as shown in the Figure (5.2-A). On other hand, Figure (5.2-B) shows non-sealed junction box of another type. From our practice, this sealing gives the following advantages:

1. It keeps diodes and metallic strips from dust, air and wet.
2. It protects PV module junction box for long life.
3. It decreases the probability of corrosion.
4. The white insulator has good properties in heat dissipation so sealed one will dissipate the heat faster than the non-sealed.
5. It decreases the probability of loose connections inside the PV module junction box that could happen when charging, installing and maintenance the PV module.

Appendix F.2 shows us the main aspects that should be considered when we select a PV module.

Therefore, this PV module comply with all requirements.

5.3. Inverters

A power inverter is an electronic device that converts the DC voltage and current to AC, which has many classifications as mentioned in chapter 2.This PV power station contains 12 grid-tie, transformer-less inverter; its brand is ABB Italian product. One of them has 20kW rated capacity named TRIO-20.0-TL-OUTD-S2X-400 (inverter number 1), and the others rated capacity are27.6kW named TRIO-27.6-TL-OUTD-S2X-400 (inverters number 2-12)[1]. Table (5.3) shows the main inverters specifications. The S2X inverter version has additional protection options that will be discussed in section 5.5. This inverter has two connection options; one or two MPPT input connections, the last one is used in this PV power station.

Table (5.3): 20kW and 27.6kW ABB Inverter Specifications

	20kW Inverter	27.6kW Inverter
Absolute maximum DC input voltage ($V_{max,abs}$)	1000 V	1000 V
Start-up DC input voltage (V_{start})	430 V (adj. 250...500 V)	430 V (adj. 250...500 V)
Operating DC input voltage range (V_{dcmin}...V_{dcmax})	0.7 x V_{start}…950 V (min 200 V)	0.7 x V_{start}…950 V (min 200 V)
Number of independent MPPT	2	2
Rated DC input voltage (V_{dcr})	620 V	620 V
Rated DC input power (P_{dcr})	20750 W	28600 W

[1] This inverter compatible to the local standards see Appendix C.2 for PSI certification

	20kW Inverter	27.6kW Inverter
Maximum DC input power for each MPPT ($P_{MPPTmax}$)	12000 W	16000 W
DC input voltage range with parallel configuration of MPPT at P_{acr}	440...800 V	500...800 V
DC power limitation for each MPPT with independent configuration of MPPT at P_{acr} , max unbalance example	12000 W [480 V≤VMPPT≤800 V] the other channel: Pdcr-12000 W [350 V≤VMPPT≤800 V]	16000 W [500 V≤VMPPT≤800 V] the other channel: Pdcr-16000 W [400 V≤VMPPT≤800 V]
Maximum DC input current (I_{dcmax}) / for each MPPT ($I_{MPPTmax}$)	50.0 A / 25.0 A	64.0 A / 32.0 A
Maximum input short circuit current for each MPPT	30A	40A
AC grid connection type	Three-phase 3W+PE or 4W+PE	Three-phase 3W+PE or 4W+PE
Rated AC power (P_{acr} @cosφ=1)	20000 W	27600 W
Maximum AC output power (P_{acmax} @cosφ=1)	22000W	30000W
AC voltage range	320...480 V	320...480 V
Maximum AC output current	33A	45A
Total current harmonic distortion	< 3%	< 3%

All of these inverters are fixed outside on the galvanized steel structure under the photovoltaic' structure using appropriate number of bolts as shown in Figure (5.3).

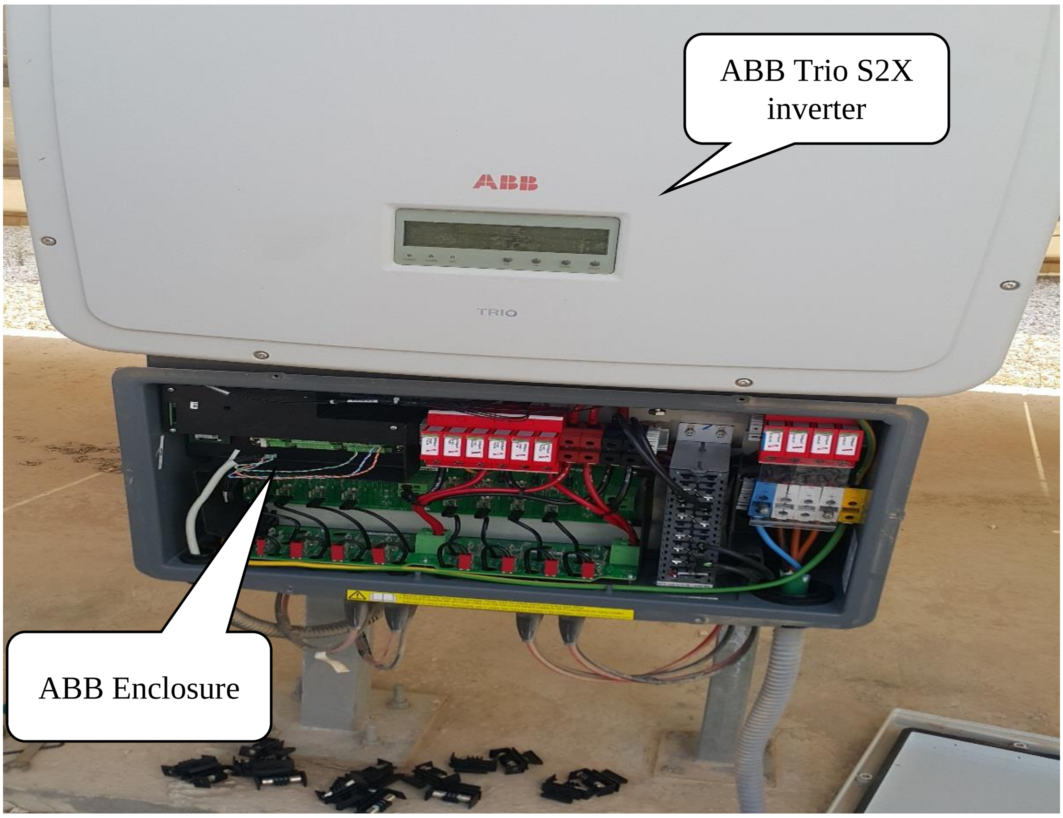


Figure (5.3): ABB Inverter

In this PV power station, the inverter input voltage at STC is determined according to Equation 5.3

$$V_{OC,string\,@T} = N_{series} * V_{OCT,mod@T} \quad (5.3)$$

Where,

$V_{OC,\,string@T}$: Open circuit voltage for string at specific temperature.

N_{serise}: number of modules in series per string

$V_{OCT,mod@T}$: Open circuit voltage for PV module at specific temperature.

$V_{OC,\,string@STC}$= 37.7 V * 20 module

$V_{OC,\,string@STC}$= 754V.

5.3.1. Inverter Efficiency

This section shows the theoretical inverter efficiency as mentioned in inverters catalogue and the actual inverter efficiency in 2016, nevertheless the irradiance impact on inverter efficiency and inverter-loading impact on inverter efficiency will be discussed in section 6.4 and section 6.5 respectively.

Theoretical Inverter Efficiency

Figure (5.4) illustrates theoretical inverter efficiency as mentioned in ABB catalogue.

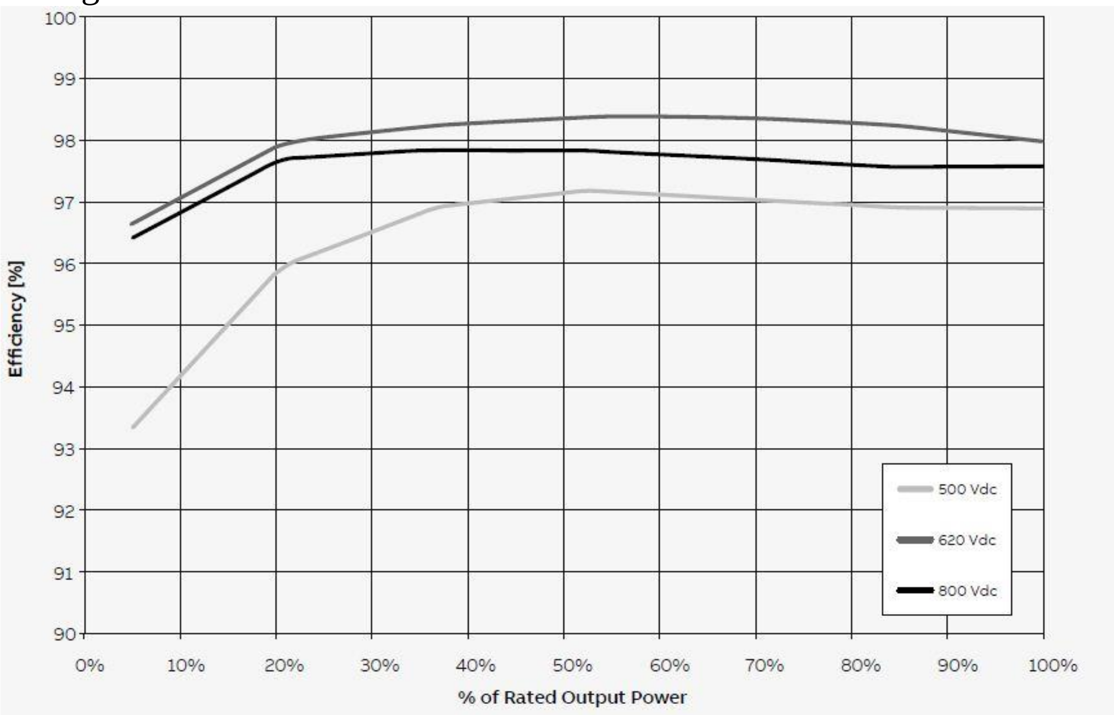


Figure (5.4): ABB Inverter Efficiency Curve according to Manufacturer

The operated voltage of the inverter at STC is 608V; so from the efficiency curve the closest two readings are 98% and 97% for 620V and 500V respectively. By using interpolation according to Equation5.4,

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1} * (x - x_1) \qquad (5.4)$$

The theoretical inverter efficiency is 97.9%.

Actual Inverter Efficiency

The actual inverter efficiency is determined by dividing the actual total output AC energy on the total input DC energy of the inverter,

$$\eta_{inv,actual} = \frac{E_{inv,AC}}{E_{inv,DC}} * 100\% \qquad (5.5)$$

$\eta_{inv, actual}$: Actual inverter efficiency

$E_{inv, DC}$: Total DC energy injected in the inverters (kWh).

$E_{inv, AC}$: Total AC energy produced from inverters and injected in AC cables (kWh).

In 2016 the $E_{inv, DC}$ was 596508kWh and the $E_{inv,AC}$ was 574040 kWh.

Therefore; the $\eta_{inv, actual}$ is 96.23%.

5.3.2. Inverter Selection

In Appendix F.3 shows the main item that should be considered in selecting and evaluating the inverter

Figure (5.5) shows the inverters' stand fixed behind the rail of support structure which has good ventilation and there is no direct sun. This stand's design was checked by structural engineer.

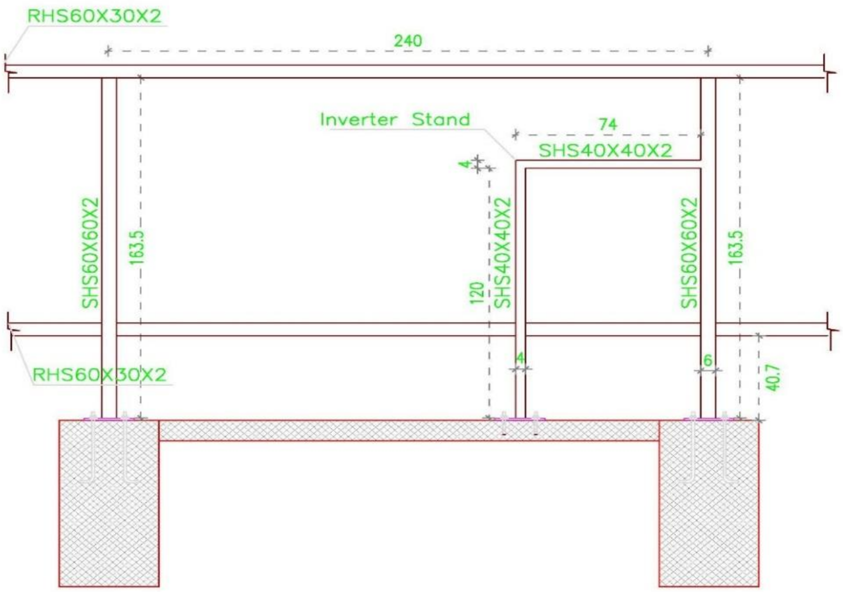


Figure (5.5): Inverter's Stand Layout

5.4. PV and Inverter Design Evaluation

This section discusses and evaluates the sizing of PV modules and inverters in the 350kWp PV power station. The sizing and evaluation of other equipment will be discussed later in this chapter.

Figure (5.6)[1]shows the detailed single line diagram in this 350kWp PV power station. There are 12 inverters in this PV power station and 1400 PV modules, each 120 PV modules are connected to 27.6kW inverters, 20 modules are connected in series and 6 strings are in parallel. Each 3 strings are connected to one MPPT input regarding the 20kW inverter. 80 PV modules are connected to it where 20 modules in series and 4 strings are in parallel, each two strings are connected to one MPPT input. These inverters have a built in DC/AC junction box with all necessary DC fuses, DC surge protection devices (SPD), AC SPD and DC/AC isolator switch. Then it is

[1] See Appendix E6 for high resolution figure

connected to the MDB, which contains main Circuit Breaker (CB), inverters' CB and Residual Current Devices (RCD) for each inverter, then it connected to MV transformer and then to TDECO's grid.

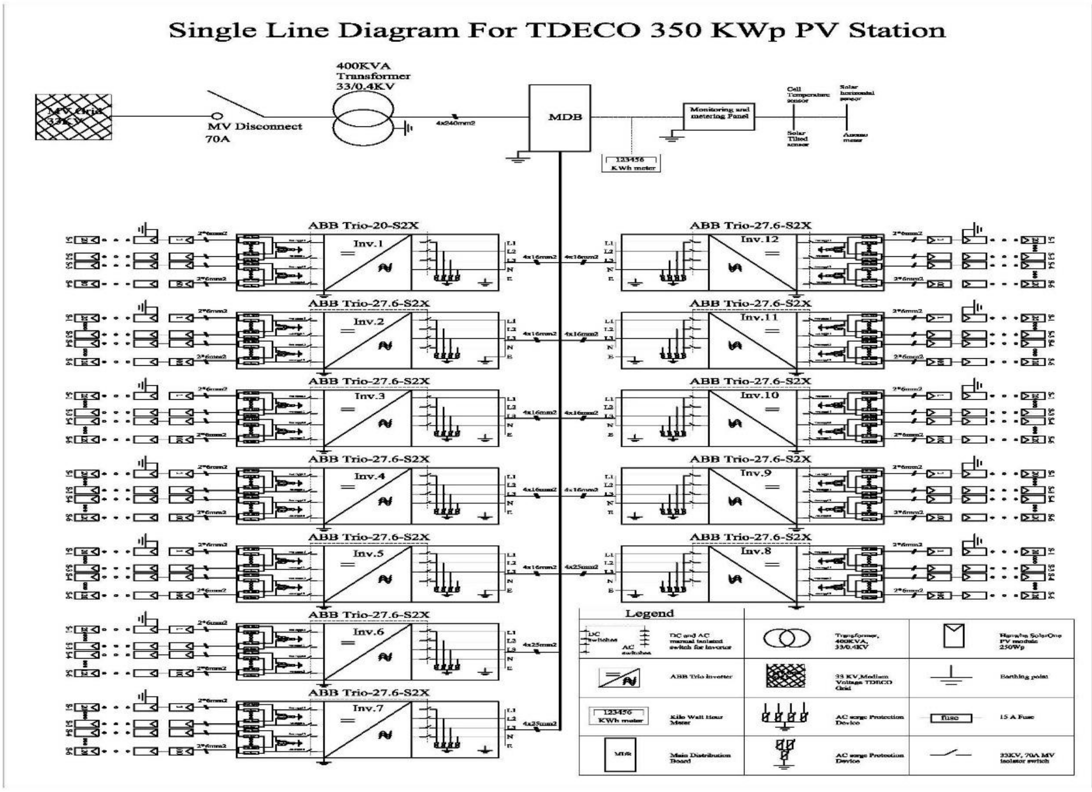


Figure (5.6): Single Line Diagram for TDECO 350kWp PV Power Station

The following points shall be assessed for sizing and evaluating the design of PV modules and inverters:

1. Maximum Inverter Input Voltage

The maximum DC input voltage of the inverter to which the string will be connected should never be exceeded; because this can damage or decrease the inverter's operational lifetime.

The highest module voltage that can occur in operation is the open circuit voltage. The coldest cell temperature reached at the PV power station is -4°C

Table 3.6 The corresponding maximum DC input voltage at the inverter inputs for this PV power station is determined according to Equation 5.3 and Equation 5.6

$$V_{OC,module@T} = V_{OC,module@STC}(1 + h_v * (T_C - 25\ °C)) \qquad (5.6)$$

Where,

$V_{OC,STC}$: Open circuit voltage of module at STC condition.

h_v: Temperature Coefficients of Voltage(% / °C).

T_c: Cell temperature (°C).

$V_{OC,module@-4°C}$ = 37.7 V*(1+ -0.31%*(-4°C-25°C))

$V_{OC,module@-4°C}$ =41.1V

Then,

$V_{OC,string@-4°C}$=20 modules *41.1V

$V_{OC,string@-4°C}$ = 821.8V which is less than 1000V (the absolute maximum DC input voltage of the inverter ($V_{max,abs}$)).

2. Minimum Inverter Input Voltage

The minimum open circuit voltage in the hottest daytime temperature must be greater than the inverter DC turn-off voltage.

The highest cell temperature recorded at the PV power station is 69.1°C Table 3.6 The corresponding minimum DC input voltage on the inverter inputs in this PV power station is determined according to Equation5.3 and Equation 5.6

$V_{OC,module@69°C}$ = 37.7 V*(1+ -0.31%*(69°C-25°C))

$V_{OC,module@69°C}$ = 32.56V

Then,

$V_{OC,\ string\ @69°C}$ = 651.15V, which is more than 430 V (inverter start-up DC input voltage (V_{start})).

3. Maximum Inverter Input Current

The inverter must be able to safely withstand the maximum PV array current, which is obtained according to Equation5.7

$$I_{max,mpp} = N_{string} * I_{sc,\ mod@\ STC} \quad (5.7)$$

$I_{max,\ MPPT}$: Maximum input current for MPPT (A).

N_{string}: Number of string per inverter.

<u>For inverters (2-12) Trio27.6 with 2 MPPT connection:</u>

$I_{max,\ MPPT}$= 3 * 8.79 A

$I_{max,\ MPPT}$= 26.37A which is less than 32A

<u>For inverters (2-12) Trio27.6 with 1 MPPT connection (in case of this connection):</u>

$I_{max,\ MPPT}$= 6 * 8.79 A

$I_{max,\ MPPT}$= 52.74A which is less than 60A

<u>For inverter (1) Trio20 with 2 MPPT connection:</u>

$I_{max,\ MPPT}$= 2 * 8.79 A

$I_{max,\ MPPT}$= 17.58 A which is less than 25A

<u>For inverter (1) Trio20 with 1 MPPT connection (in case of this connection):</u>

$I_{max,\ MPPT}$= 4* 8.79 A

$I_{max,\ MPPT}$= 35.16A which is less than 50A

Therefore; the maximum input current of PV arrays are less than the maximum allowed input current for inverter in case of 1 or 2 MPPT connection.

4. Maximum String Power for Each Inverters' MPPT Inputs

The inverter MPPT input rated power range must be sized with the power of PV array MPPT points at different temperatures.

$$P_{MPPT,inv} = P_{PV@STC} * N_{string} * N_{serise} \qquad (5.8)$$

$P_{MPPT,\ inv}$: Inverter power or each MPPT input.

<u>For inverters (2-12) Trio27.6</u>

$P_{MPPT,\ inv}$ = 250Wp * 20 modules *3 strings

$P_{MPPT,\ inv}$ = 15kWp, which is less than 16kWp.

<u>For inverter (1) Trio20</u>

$P_{MPPT,\ inv}$ = 250Wp * 20 modules *2 strings

$P_{MPPT,\ inv}$ = 10kWp, which is less than 12kWp.

5. Inverter Sizing

The optimal inverter sizing is determined according to Equation5.9 [6]

$$0.8 < \text{Power Raio} < 1.1 \qquad (5.9)$$

Where,

$$\text{Power Ratio} = \frac{P_{inv,DC}}{P_{PV@STC}}$$

$P_{inv,DC}$: Inverter DC input rated power.

<u>For inverters (2-12) Trio27.6</u>

The installed PV module capacity $P_{PV@STC}$ is 30kWp and the $P_{inv,DC}$ is 28.6kW therefore, the power ration is 0.953 which is in the acceptable limit

<u>For inverter (1) Trio20</u>

The installed PV module capacity $P_{PV@STC}$ is 20kWp and the $P_{inv,DC}$ is 20.75kW therefore, the power ration is 1.0375 which is in the acceptable limit before 9/11/2017. Then the Trio20 inverter has been replaced to

Trio27.6 inverter, the new power ratio is 1.43, therefore the new one is an oversized inverter. Therefore, inverter1 should be reinstalled to Trio20 inverter.

Appendix F.4 shows the summery of the PV and Inverter evaluation that passed all inspection points.

5.5. Electrical Protection System

Protection system in the photovoltaic system is very important that isolate the faulty parts from the rest. The objective of a protection scheme is keeping the power system stable by isolating only the faulted components, whilst leaving as much of the photovoltaic station as possible still in operation. This section discusses the followings:

- Protection system configuration (existing and suggested).
- Comparison between ABB and locally electrical panel enclosure.
- DC electrical protections.
- AC electrical protections.
- Utility grid protection.

Note: The local standard of electrical installation requirements for inverter energy systems and grid protection devices are adopted from AS4777-1, which does not apply the system ratings more than 10kVA for single phase unit or 30kVA for three phase units. Therefore this PV power station will be evaluated according IEC62548:2011.

5.5.1. Protection System Configuration (Existing and Suggested)

In general, PV power stations should have electrical protection devices for both DC and AC sides. These devices would be distributed in one or electrical panel termed hereafter enclosures. This section discusses the existing and suggested enclosure distribution in this PV power station, as shown in Figure (5.7) that would have two configurations of enclosures distribution; the existing one by using ABB S2X version of inverter enclosure (termed hereafter; ABB enclosure) and another suggested by using two locally made enclosure one for DC protections and another for AC protections (termed hereafter; locally enclosures). While the types and sizes of the electrical protection devices will be discussed in section 5.5.3.

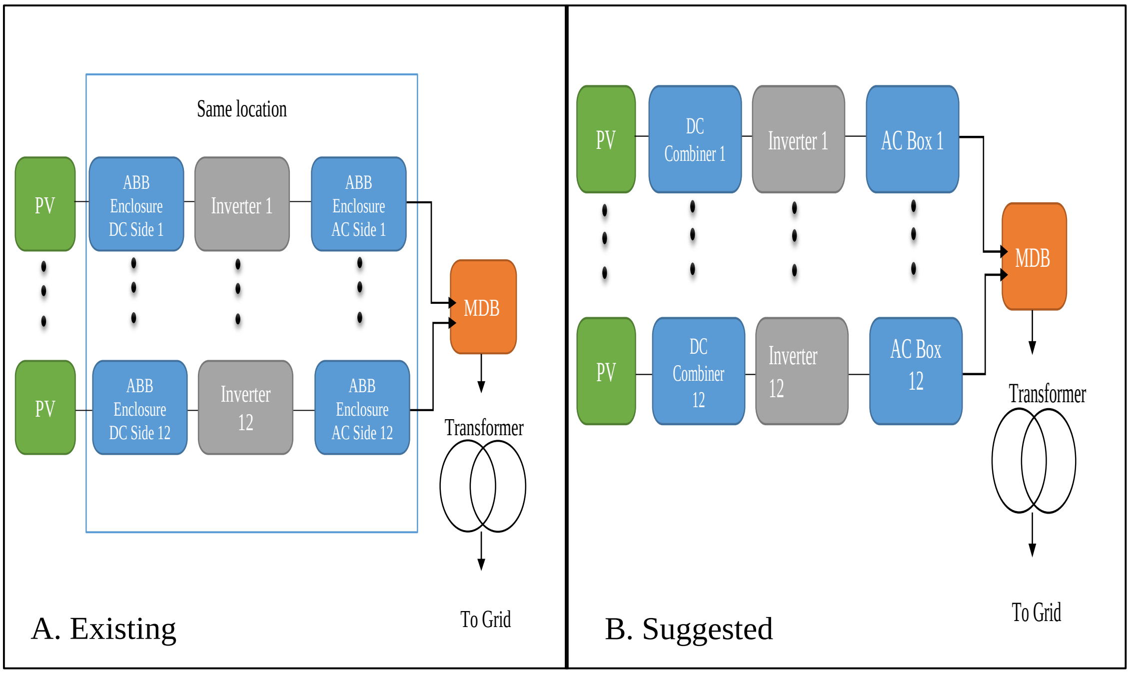


Figure (5.7): Existing and Suggested Enclosures Distribution

A. Description of ABB Enclosure (Existing Protection System Configuration)

This enclosure inputs are DC cables coming from PV modules and the output is AC inverter cable that running to MDB.

As shown in Figure (5.8), ABB enclosure is equipped by 2MPPT inputs, 4 pairs (+/-string) for each MPPT input, this system design use only 3 pairs from each MPPT input (in other words, the 6 strings are equally distributed on 2MPPT input).DC input connected to two inputs (MPPT) 4 string for each one and 3phase plus neutral output and monitoring cable. This type of enclosure has each DC and AC protections. This enclosure includes the following components:

a. Eight pieces of MC4 mail connector (formerly Multi-Contact for the 4mm diameter) which is commonly used for connecting solar modules, double insulated, IP68 and rated 1000 V.
b. Printed Circuit Board (PCB)
c. Positive and negative fuses for all string.
d. Four terminal jumpers, two for positive and two negative; for converting MPPT mode purpose.
e. DC overvoltage surge arresters.
f. AC overvoltage surge arresters.
g. AC/DC isolator switch.
h. Five pieces of AC terminals for output cable.

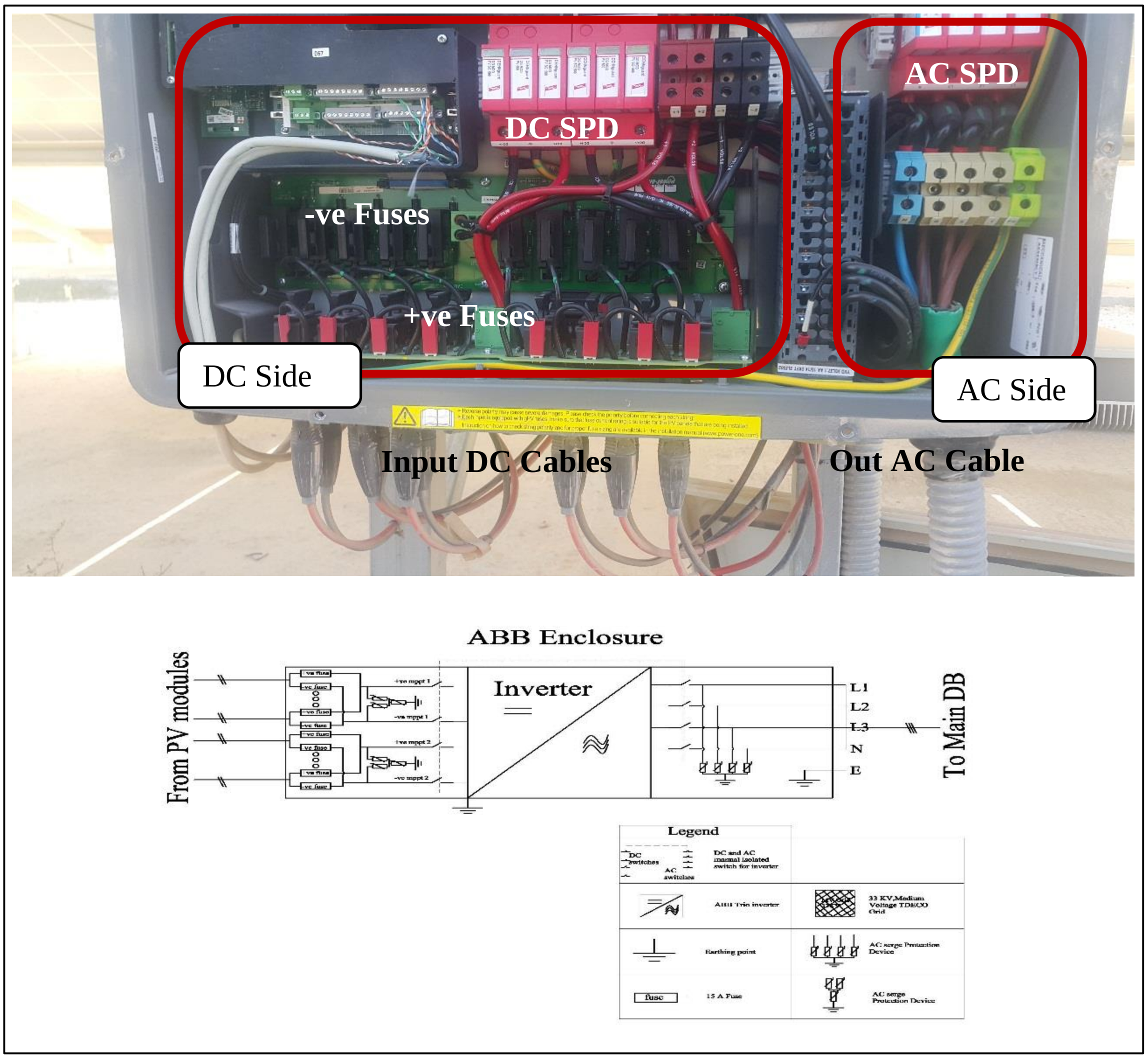


Figure (5.8): ABB Enclosure and Electrical Wiring

B. Description of Locally Enclosures (Suggested Protection System Configuration).

Two individual locally made enclosures are suggested to install them instead of ABB enclosure; one for DC protection devices and another for AC protection devices. As shown in Figure (5.9).

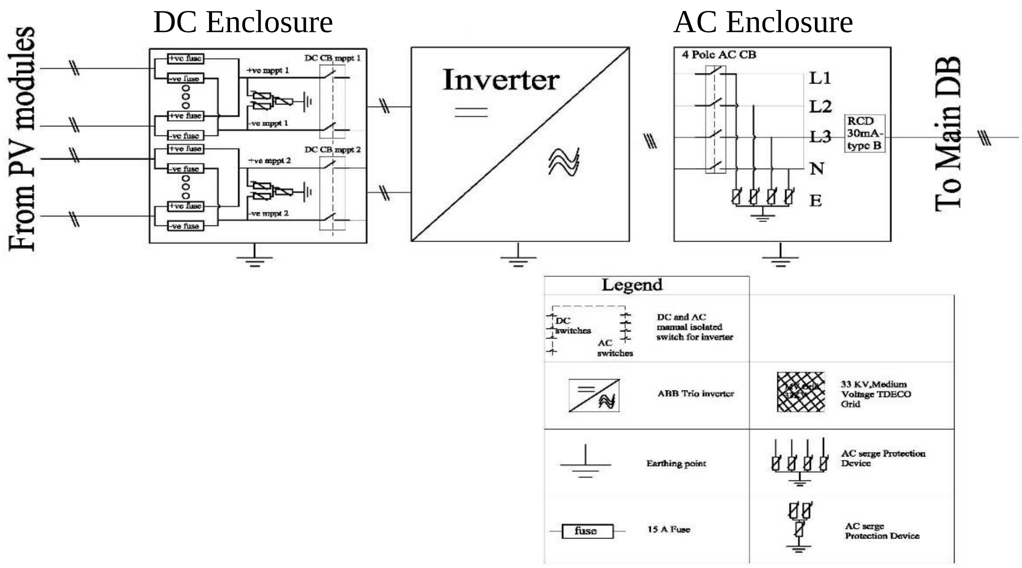


Figure (5.9): Locally Enclosures Electrical Wiring

These enclosures include the following components:

A. DC Enclosure:

1. Six pieces of 4mm^2 cable glands (for input PV cables).
2. Two pieces of 10mm^2 cable glands (for output cable).
3. Six pairs,15A DC fuses
4. Two copper bus bars (positive and negative).
5. DC overvoltage surge arresters.
6. DC isolator switch.
7. Grounding cable between door, enclosure and main grounding system.

B. AC Enclosure:

8. Four pieces of 25mm^2 cable glands(for input and output cables)
9. Five pieces of copper bus bars (3 phases, neutral and ground).
10. AC overvoltage surge arresters.
11. AC circuit breaker.

12. AC Residual Current Device (RCCD)-type B.
13. Grounding cable between door, enclosure and main grounding system.
14. Grounding cable between door, enclosure and main grounding system.

5.5.2. Comparison Between ABB and Locally Electrical Panel Enclosure.

Electrical enclosure holds all electrical protection devices from water, dust…etc. In general, there are two types of electrical enclosure used in Palestine, plastic and galvanized steel, form our practical observation, the last one is more robust to the bad weather and has a longer lifetime.

This section, from our practical observation, discusses the differences between ABB enclosures and proposed locally enclosures.

1. Location

Description:

Existing enclosure is ABB enclosure located under its inverters while two proposed locally enclosures needed instead of ABB enclosure; one contains DC protections and another for AC protections. Both enclosures should be located, 50cm near away from its inverters.

Recommended Choice:

Using two locally enclosures because if fire break out in inverter, it is necessary to shut down all beakers easily and safely by using that enclosures. Therefore, this reduces equipment damage.

2. Installation

Following table shows main three points that should be considered in installation.

Table (5.4): Installation Comparison between ABB and Locally Enclosures.

	ABB Enclosure	Locally Enclosures
Installing simplicity	Simple	Simple
Weight	Heavier (Its weight 12kg).	Lighter (Its weight 2kg).
Internet connection	Need	No need

3. Space

ABB enclosure has little bit tight for example, fuses replacement quit difficult because the narrow place on the other hand; the locally one can be designed with 40% surplus area.

4. Maintenance

- <u>Advantage of Using ABB Enclosure:</u>

ABB enclosure has good feature by detecting the problem rapidly by using monitoring system or ABB inverter appears the type of error clearly on its LCD.

- <u>Disadvantage of Using ABB Enclosure:</u>

If the problem was in Printed Circuit Board (PCB), the enclosure should be returned to the factory; this means the inverter doesn't work; because this version of inverters are programed to operate with similar types of enclosure, which is often not available in local market. In addition, this replacement needs internet connection to get ABB inverter code, otherwise the inverter refused new part. Furthermore, the DC protection enclosure cannot be added before the inverter, according manufacturer recommendation, [15] and new enclosure could not be operated if the internet not available. So lost the energy production until manufacture rehabilitation or buy a new spar part inverter to avoid energy lost which means additional cost.

- Advantage of Using Locally Enclosures:

Any protection device can be replaced at any time in locally enclosures without energy lose. Moreover measuring strings' voltages and currents are easily accessible.

- Disadvantage of Using Locally Enclosures:

The faults can't be detected rapidly because they are not supported by monitoring system.

5. Converting from 1MPPT to 2MPPT and vice versa

It is very simple when ABB enclosure is used by connecting jumpers between to channels and switching special dip switch inside that enclosure this will convert from 2 MPPT to 1 MPPT and vice versa on the other hand this conversion in locally enclosures more difficult because it needs rewiring and resizing all components.

6. Accessibility

The door of locally enclosures are easier in opening and closing than ABB enclosure because the last one needs unscrewing around six bolts by using special screwdriver to open it.

7. Safety

- All electrical devices inside both enclosure as cables, fuses busbar and isolator switches are insulated, which is good as a safety requirements, but some locally enclosures manufacturers forget adding insulated busbar .
- The ABB enclosure is adjacent inverter ;so in case fire breakout in inverter the probability of damaging more than locally one because the last one should be installed 50cm at least far from inverter.
- Enclosures grounding.

All metallic parts in both enclosures are connected in grounding system except the door in ABB enclosure.

Therefore from safety point view, we find locally enclosures safer than ABB one in fire breakout case

8. Environmental Protection Rating

ABB enclosure has IP65, while locally enclosures have IP54; so ABB enclosures have higher environmental protection rating than locally one.

9. Ventilation

The heat is one of the bad factors that cause degradation or damage of electrical devices. Keeping these devices away from heat is necessary that could be achieved by magnifying enclosure, good ventilation or cooling system.

Air temperature, electrical protection devices, wire, connections and busbar dissipate heat that will increase the temperature inside electrical enclosure.

ABB enclosure haven’t any type on ventilation, while fans or some ventilations holes can be added to the locally type.

In this design case, both ABB and locally enclosures don’t need cooling system or ventilation holes because the size of enclosure is enough to dissipate the heat.

10. Price

The price of ABB enclosure with all protections is around 1290$per inverter, so 12 inverters cost is 15480$. While 2 locally enclosures needed instead of ABB enclosure for each inverter that cost around 1000$per inverter, so 12 inverters cost 12000$.Therefore locally enclosures saving is 3480$.

5.5.3. Sizing DC and AC Electrical Protection Devices.

Figure (5.10) shows that PV cells are combined to create a PV module, PV modules are connected in series to create a PV string and PV strings are connected in parallel to create a PV array. Each PV stings and array should be protected by external protection devices that will be discussed in this section.

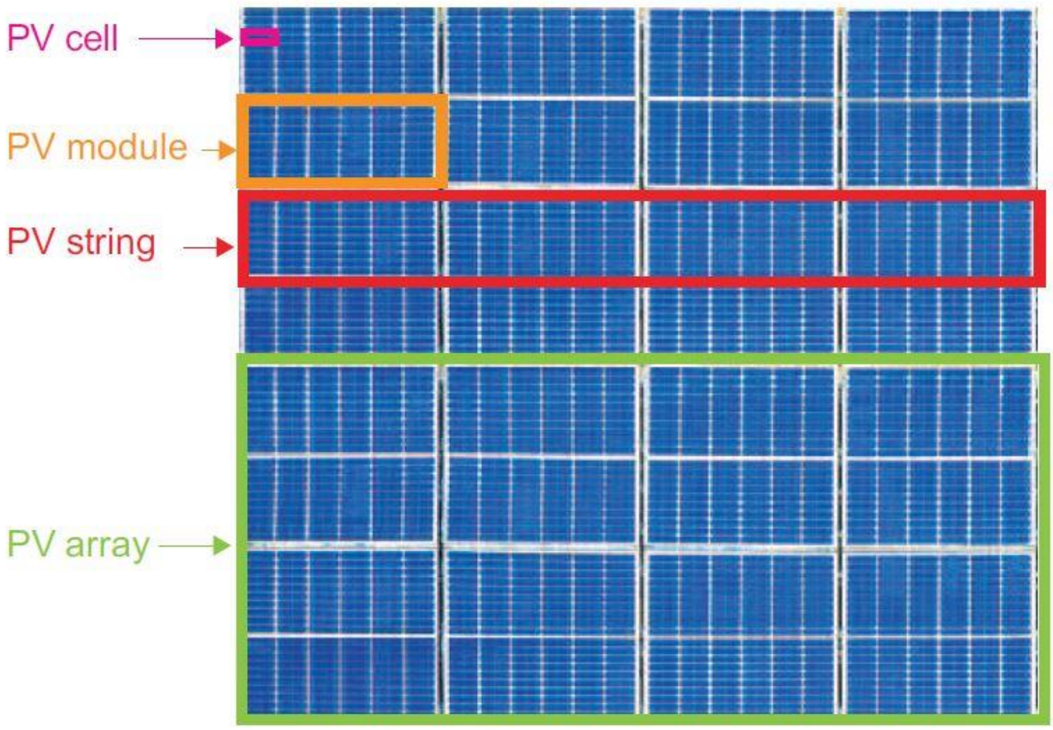


Figure (5.10): PV Array Construction

5.5.3.1. Sizing DC Over Current Protection Device (OCPD) and Disconnector Switch.

Circuit breaker and fuse are electrical safety devices that operate to provide overcurrent protection of an electrical circuit.

The OCPDs should be specifically designed and tested to protect PV systems with high DC voltages and low fault currents, because PV modules are current limited sources, so the available short-circuit current within PV systems is limited, and the overcurrent protective devices need to operate effectively on low levels of fault current.

The IEC and Underwriters Laboratories (UL) recognize that the protection of PV systems is different than conventional electrical installations. This is reflected in IEC 60269-6 (gPV), IEC62548 and UL 248-19 for fuses and UL

489B for breakers that define specific characteristics an OCPD should meet for protecting PV systems.

Figure (5.11): shows the OCPDs locations of PV string, array and array switch disconnector that is according IEC62548

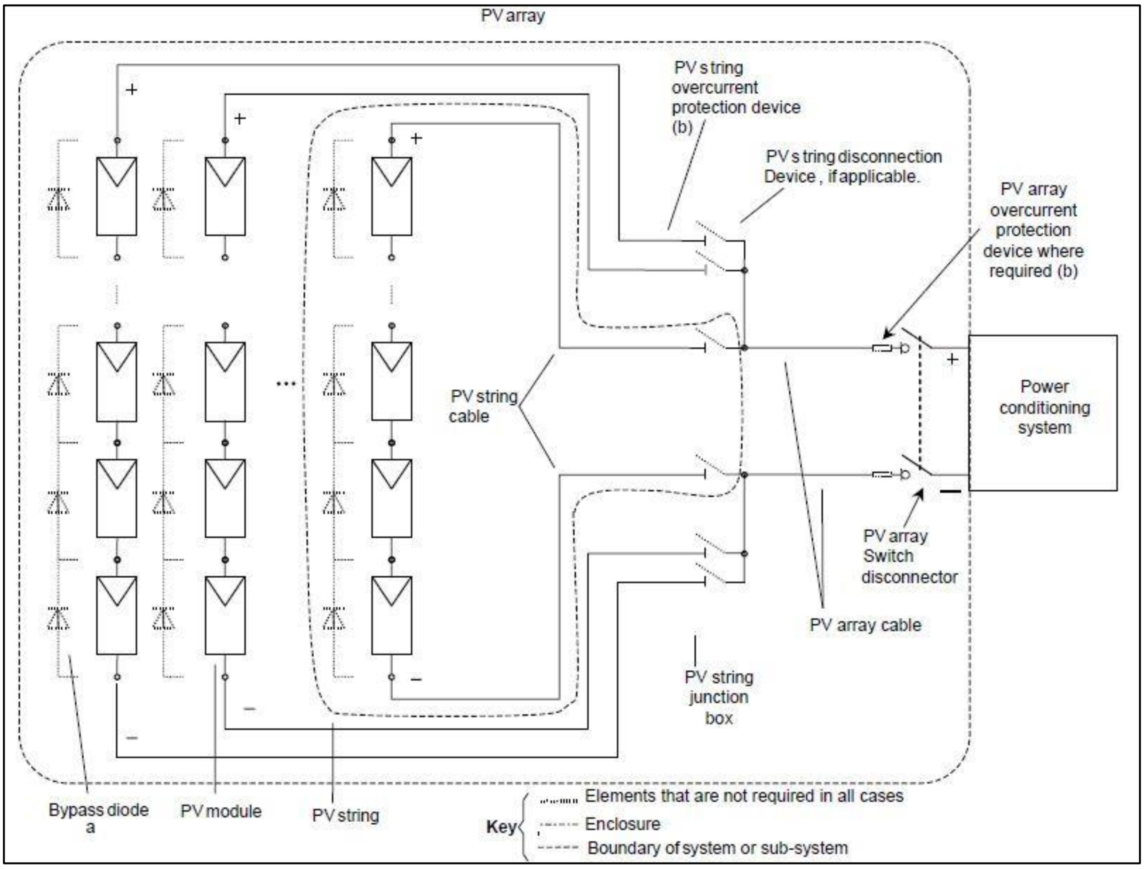


Figure (5.11): OCPDs Needed in PV Array

a) PV String Overcurrent Protection Requirements

In case of conductive defective bypass diodes: The module is short-circuited and the voltage in the affected string is reduced. The total current of the other strings can ignite the PV module. For this reason a string fuse is urgently recommended with three or more parallel strings.

The string overcurrent protection device is typically used to isolate PV string from the PV array that shall be used if:

$$\{(N_{String} - 1) \times I_{sc,\ mod@\ STC}\} > I_{mod\_max\_ocpr} \quad (5.10)$$

Where,

$I_{mod\_max\_ocpr}$: the PV module maximum overcurrent protection rating determined by IEC61730-2.

Note: This is often specified by module manufactures as the "maximum series fuse rating"

In this PV power station the $I_{mod\_max\_ocpr}$ is 15A.

Both 27.6kW and 20kW inverters have two MPPT inputs, 6 strings (3 strings per MPPT) and 4 strings (2 strings per MPPT) respectively therefore,

(3-1) x 8.79 A $>^?$ $I_{mod\_max\_ocpr}$ → 17.58A is greater than 15A for 27.6 kW inverters.

(2-1) x 8.79 A $>^?$ $I_{mod\_max\_ocpr}$ → 8.79A is less than 15A for 20 kW inverter.

Therefore, each PV strings in 27.6kW inverters shall be protected with an overcurrent protection device according the following relations

$$1.5 \times I_{sc,\ mod@\ STC} < I_{n,string} < 2.4 \times I_{sc,\ mod@\ STC} \quad (5.11)$$

$$I_{n,string} \leq I_{mod\_max\_ocpr} \quad (5.12)$$

Where,

$I_{n,\ string}$: The nominal overcurrent protection device rating of the string.

Therefore,

13A < $I_{n,\ string}$ < 21A and $I_n \leq$15A

So,

$13A < I_{n,\,string} \leq 15A$

This PV power station have 15A string fuses, which are accepted.

b) PV Array Overcurrent Protection Requirements

PV array isolation is typically achieved by the use of a switch-disconnector or a suitably rated circuit breaker.

The PV array OCPD shall be rated as follows

$$1.25 \times N_{string} \times I_{sc,mod\ @STC} < I_{n,Array} \leq 2.4 \times N_{string} \times I_{SC,mod\ @STC} \quad (5.13)$$

Where,

$I_{n,\,Array}$: The nominal overcurrent protection device rating of the array.

Note: The array multiplier (1.25) is lower than the string multiplier (1.5) to allow for design flexibility. However, this approach may result in nuisance tripping and should be avoided for sites with high irradiance level [6].

Therefore,

$33A < I_{n,\,string} < 63A$ for each MPPT input in 27.6 kW inverters.

$22A < I_{n,\,string} < 42A$ for each MPPT input in 20 kW inverter.

Both PV string and array overprotection devices voltage should be rated as the following formula [7].

$$V_{OCPD,raing} = V_{OC@STC} \times N_{serise} \times 1.15 \quad (5.14)$$

Where,

$V_{OCPD,\,rating}$: String Fuse Voltage Rating.

Therefore,

$V_{OCPD,\,rating} = 867.1V$.

This PV power station doesn’t have any PV array OCPDs. The above calculations should be followed, If the locally enclosures installed.

c) DC Switch-Disconnector Requirements

The DC switch disconnector provide a manual means of electrically isolating entire PV arrays, which is required during installation and maintenance. DC switches must be:

- Double-pole to isolate both the positive and negative PV array cables.
- Rated for DC operation according to Equation5.13.
- Capable of breaking under full load.
- Rated for the system voltage and maximum current expected according to Equation5.14.
- Equipped with safety signs.

This PV power station have DC/AC switch disconnector that built in inverter if locally enclosures would be installed.

5.5.3.2. Sizing AC Electrical Protection

This section discusses the AC electrical protection for inverters’ electrical panel (hereafter AC box), MDB and utility grid protection.

5.5.3.2.1. AC Electrical Protection in Inverters’ Electrical Panel

This section describe suggested AC box that mentioned in Figure (5.7-B).

The suggested AC box contains inverter’s OCPD, RCD and AC SPD

- AC SPD will be disused in section 5.5.3.3.

- The AC OCPDs' are usually installed when the decentralized inverters are used. Both the AC box for each inverters and in the MDB are installed that would be sized according to inverter manufacturer recommendations and Equation5.15.

$$I_{inv,OCPD-max} \geq I_{inv,OCPD} \geq 1.25 \times I_{inv,AC-max} \quad (5.15)$$

Where,

$I_{inv,\ OCPD}$: The AC OCPD for inverter.

$I_{inv,\ AC-max}$: Maximum AC output current from inverter

$I_{inv,OCPD-max}$: Maximum external AC overcurrent protection from inverter manufacturer.

In this PV power station, the maximum external AC overcurrent protection recommended for 27.6kW and 20 kW ABB inverter are 63A and 50A respectively.

$63A \geq^{?} I_{inv,\ OCPD} \geq^{?}$ (45A*1.25= 56A) →the existing inverters CB rating is 50A therefore it should be replaced by 63A CB for the 27.6 kW inverters.

$50A \geq^{?} I_{inv,\ OCPD} \geq^{?}$ (33A*1.25= 41A) →the existing inverters CB rating is 50A which is suitable for the 27.6 kW inverters.

- Residual Current Device (RCD) should be installed in this PV power station; because it hasn't a simple separation between the AC side and the DC side (the transformerless inverters are used), RCD installed to provide fault protection by automatic disconnection supply shall be type B according to IEC 62423.

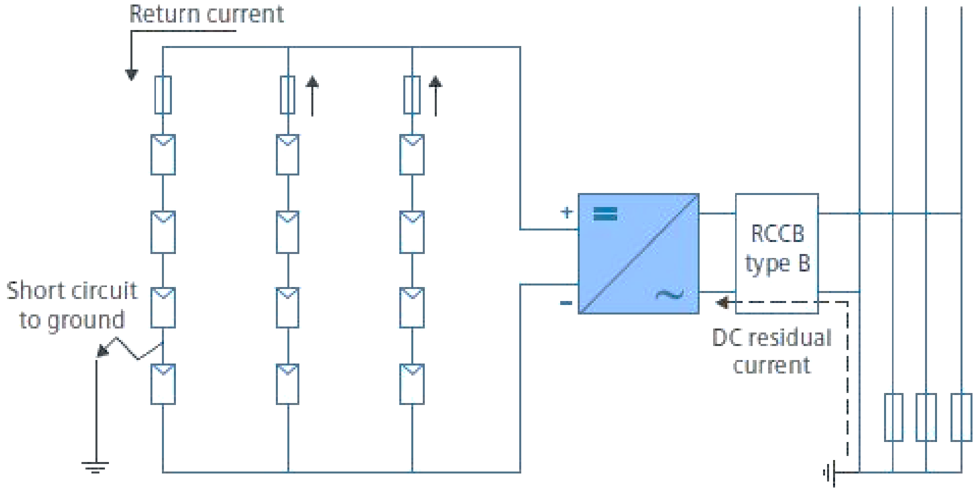


Figure (5.12): Inverters without Simple Isolation: a Type B RCD Protection Device is Required.

Figure (5.12) shows transformerless inverters. If there is not at least one simple isolator implemented between the AC side and the DC side, a type B residual current protection device is required. With transformerless inverters, the lack of simple (galvanic) isolation between the DC input side and the AC output side can cause smooth DC residual currents to go through the AC side, which makes additional measures for personal and fire protection necessary. Type A residual current protection devices cannot detect these smooth DC residual currents. For this reason the devices do not trip in the event of a fault and the intended protective function is not provided. In contrast, type B and B+ universal current-sensitive residual current circuit breakers offer optimal protection in case of smooth DC residual currents. An additional transformer ensures that the intended protective function is provided. Type B+ also offers advanced preventative protection against fire by limiting the tripping value to 420 mA.

This PV power station has 300mA RCD type A that located in MDB; therefore it should be replaced by another type B. Unfortunately, this type of RCD is importing prevented by Israel.

5.5.3.2.2. AC Electrical Protection in MDB.

Figure (5.13) shows the last electrical protection board connected between the PV station and grid is main distribution board.

Figure (5.13): MDB in This PV Power Station.

MDB usually has the following components:

1. Inverters CB

The existing inverters CB description: 50A, 4pole MCB for each inverter

The suggested inverters CB description: New inverters CB would be sized according to section 5.5.3.2.1.

2. RCD (it should connected in AC box but in this PV station installed in MDB)

   The existing RCD description: 300mA, 4pole RCD type A

   The suggested RCD description: New RCDs would be sized according to section 5.5.3.2.1.

3. Main circuit breaker

   The existing main CB description: 650A, 3poles main CB

   The suggested main CB description:

Main CB should be sized according to Equation 5.16 and Equation 5.17

$$I_{CB} \geq 1.25 \times I_{PV,station} \tag{5.16}$$

Where,

$$I_{PV,station} = \frac{P_{PV,station}}{\sqrt{3} \times V_{grid}} \tag{5.17}$$

Where,

I_{CB}: Main circuit breaker current

$I_{PV,station}$: Total current produced from PV power station

$P_{PV,station}$: Total rated power of PV power station

$I_{CB} \geq 1.25$ x (350kW/(1.732* 0.4kV))

$I_{CB} \geq 505A$, the existing CB is suitable.

4. G59 decoupling relay with contactor

New G59 decoupling relay according to section 5.5.3.2.2

4 poles, not less than 505A contactor should be connected to G59 controlling port.

5. Ventilation

The existing ventilation system is air forced that contains the followings:

- Fan specifications are ,220-240V,50/60hz ,0.14/0.10A
- Tempreture sensor
- Electrical protection system(fuse or CB), which is not connected properly now. Figure (5.14) shows the existing AC power supply is connected from inverter 6 RCD without suitable OCPD, while it should be connected to the main MDB buspar through 6 A CB or fuse.

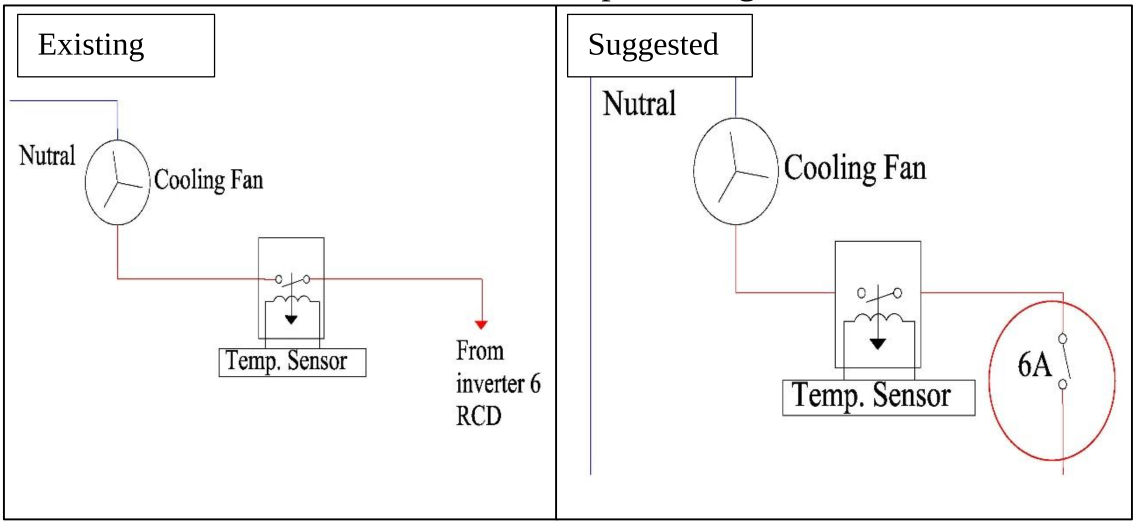


Figure (5.14): Electrical Wiring for Air Forced Ventilation System

Figure (5.15)[1]shows the modifications in the red circles

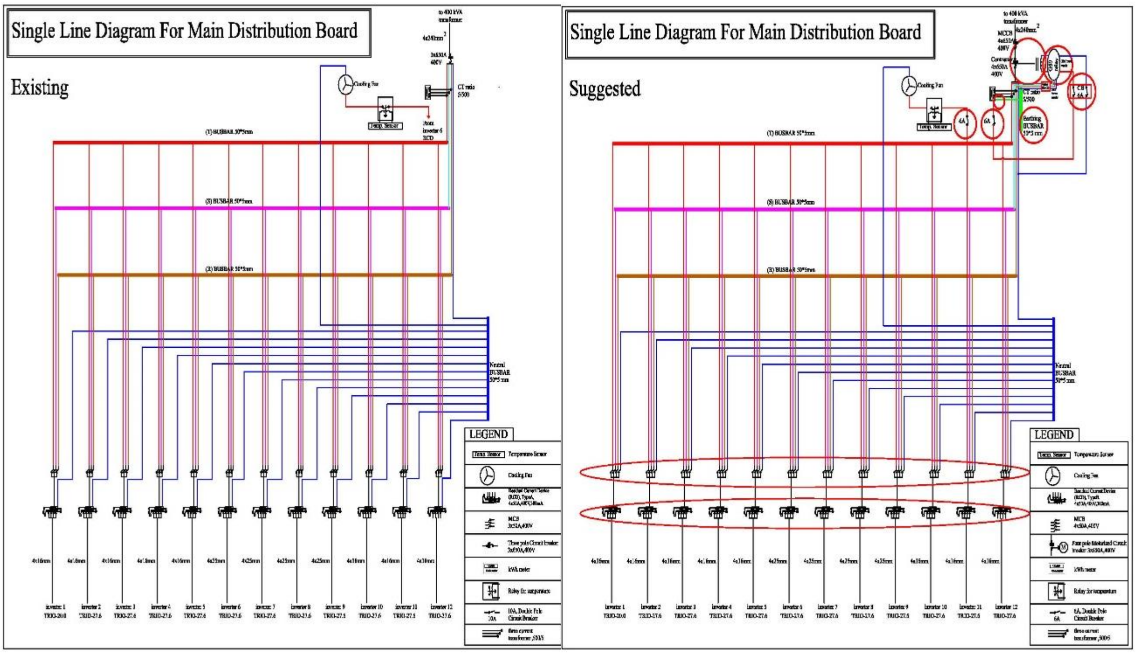


Figure (5.15): SLD for Existing and Suggested MDB

5.5.3.2.3. Utility Grid Protection

PV power plants need to meet the requirements of the grid company of the network onto which they will export power. Technical requirements for connection are typically set out in grid codes, which will be published by the PERC and cover topics including planning, connection and operation of the plant. Grid codes will vary by country but unfortunately, it is not published yet.

The following items would be included in the grid code with recommended limits:

1. Voltage limits (according to Israel code)

[1] See Appendix E9 for high resolution figure

33 ± 10% kV for 33 kV customers.

2. Frequency Limits (according to Israel code)

The frequency range allowed:

95% of the time: 49.5-50.5 Hz.

100% of the time: 47-52.5 Hz.

3. Limits on harmonic emission. (according toEN50160)

LV: THDU ≤ 8%, each harmonic/U1 ≤ 5%

MV: THDU ≤ 5%, each harmonic/U1 ≤ 3%

4. Limits on voltage flicker. (according to EN50160 as shown in Appendix E.8)

5. Limits on frequency variation. (according to EN50160 as shown in Appendix E.8)

6. Reactive power export requirements.

7. Fault level requirements.

8. System protection.

G59 Decoupling Relay

A G59 relay is a monitoring device that controls a contactor or other isolation means that sits between the PV system and the connection to the grid. The G59 relay monitors the grid voltage and frequency. If it detects a fault, it de-energizes the contactor disconnecting the PV system from the grid.

G59 relays are typically only required on larger systems (systems of over 16A per phase).

Unfortunately, The G59 decoupling relay absence in this PV system that main functions ensures that a mains (utility) failure is detected and that the mains (utility) supply is disconnected from the local source in line with common international requirements. Figure (5.16) shows the recommended connection

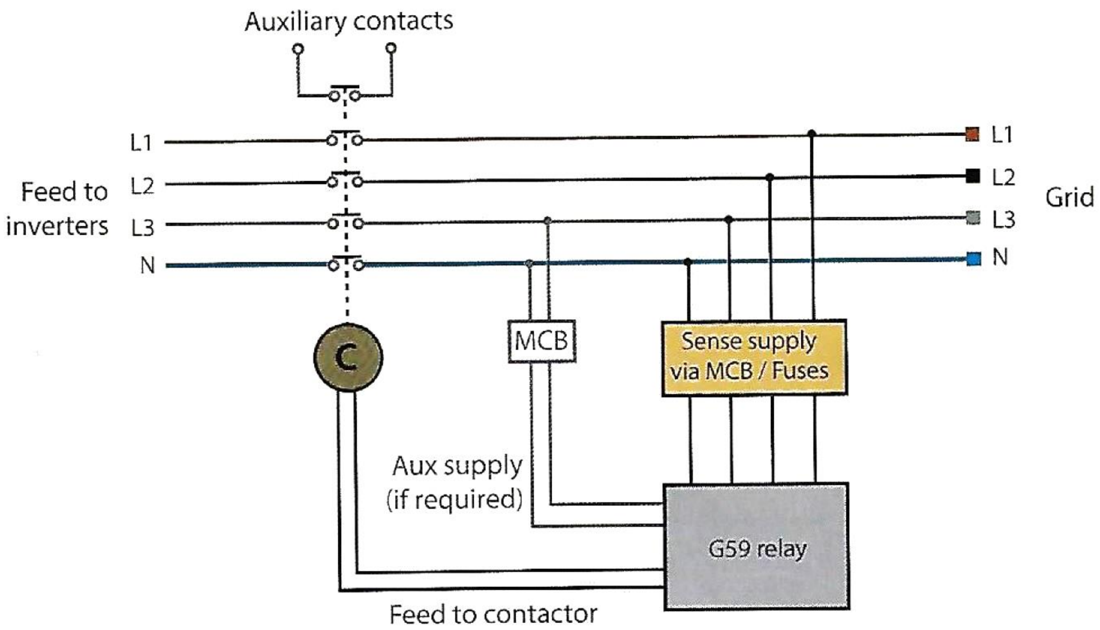


Figure (5.16): G59 Decoupling Relay Connection

G59 decoupling relay eliminates the possibility that power is supplied into an islanded grid, providing a safe, reliable protection solution when in parallel with the mains (utility) supply following specifications shall contain in this device:

- Two stage under & over voltage protection
- 10 second rolling average over voltage protection
- Two stage under & over frequency protection.

- Voltage asymmetry protection.
- Vector shift protection.
- Rate of Change of Frequency (R.O.C.O.F) protection.
- Incorrect phase sequence protection.
- Positive sequence under voltage protection.
- Negative sequence over voltage protection.
- Zero sequence over voltage protection (NVD Protection).
- Loss of mains occurs.
- Lockable security tab to prevent configuration changes after commissioning.
- MODBUS communication via RS485 with additional DSE857 interface.
- Power up in trip position
- True 3 phase mains (utility) RMS measurement
- According to BS EN 61000-6-2, BS EN 61000-6-4, BS EN 60950, BS EN 60068-2-1, BS EN 60068-2-6 BS EN 60068-2-30, BS EN 60068-2-27, BS EN 60529 standards

5.5.3.3. Sizing DC and AC Overvoltage Surge Protection Device (SPD).

If no shielded cables are used, surge arresters with a nominal leakage current of around 10 kA must be connected to the active conductors. With shielded cables, it is sufficient to use surge arresters with a nominal leakage current of around l kA.

Surge arresters are used to protect PV systems and downstream electronic devices from capacitive and inductive coupling and from grid overvoltage. Usually, the DC surge arresters are installed in the PV array combiner/junction box and AC surge arrester is installed at the point of coupling with TDECo grid, the systems with higher risk of lightning, other surge arresters are installed before and after the inverter.

DIN VDE 0675 Part 6 (Germany) differentiates between two classes of arresters; I and II.

Class I arresters can discharge direct lightning currents and are used when there is an increased risk of lightning.

Class II surge arresters are usually used on the DC and AC side with surge current capabilities of l k A (standard surge 8/20) per l kWp.

The operating voltage UC (DC) of the surge arresters must correspond to at least the open-circuit voltage of the PV array.

Table (5.5) shows the types and the rated voltages for AC and DC surge arresters.

Table (5.5): The Types and the Rated Voltages for AC and DC Surge Arresters.

Type	K (AC)	
75	75V	100V
150	150V	200V
275	275V	350V
320	320V	420V
440	440V	585V
600	600V	600V

A surge arrester must be connected between each pole and the earth/ground. Class II surge arresters, the inception and build-up voltages should be 1.4 times the maximum PV voltage (E VDE 0126 Part 31, Germany). With systems at risk of lightning, it is important to install only types with thermal isolating devices and fault indicators. The system operator should make a visual inspection of the surge arresters after every thunderstorm, at least, or once every six months.

Appendix F.5 shows that the main items that should be considered in evaluating electrical protection system.

5.6. Grounding System

All electrical systems should be connected to grounding systems that is for personnel safety and equipment protection by providing a path to safely dissipate any unwanted charges or potentials, ensure equipment performance and protection, and satisfy manufacturer’s warranty issues.

Poor grounding not only contributes to unnecessary downtime, but a lack of good grounding is also dangerous and increases the risk of equipment failure. Without an effective grounding system, we could be exposed to the risk of electric shock, not to mention instrumentation errors, harmonic distortion issues, power factor problems and a host of possible intermittent dilemmas. If fault currents have no path to the ground through a properly designed and maintained grounding system, they will find unintended paths that could include people.

TDECO has TNC-S grounding configuration, so to prevent any problem could be reflected from PV station to TDECO grid or vice versa; therefore This PV station is connected to grid according to IT configuration as shown in Figure (2.2):.

There are two separate grounding systems in this PV station; one in the out of the northern fence for lightning system (termed hereafter; lightning grounding) and the second in the last three southern grounding manholes that connect non-current carrying metal parts to ground, such as PV module frames, racks, enclosures, junction boxes, conduit and other metallic components (termed hereafter; PV grounding) as shown in Figure (4.2):. Both grounding systems, neutral and grid grounding are separated according to TDECO requirements.

The lightning grounding has three grounding pits; each one contains 1.5m, 19 inch pure copper electrodes and connected to each other by 70 mm^2 uninsulated copper cable. Another 70mm^2 insulated underground copper cable connects these grounding pits by lightning rod that was installed over the 12m steel pole. The lightning grounding pits kept far away from the closest point to metallic part (fence) about 20 m.

The PV grounding has three grounding pits contains 1.5m, 19 inch pure copper electrodes connected to each other by main grounding cable (70mm^2 uninsulated copper cable).

Each PV tables and inverters are connected by 25mm^2 insulated copper cable to the main grounding cable.

Between PV modules and frames, 6mm^2 copper cable are connecting each other's then connected to the structure.

Main grounding cable and AC cables are installed in the same conduits and manholes.

There are a physical connection between the mesh steel inside the PV concrete foundation bases and the main grounding cable.

Section 4.13.1.2 shows the grounding tests for each PV and lightning.

Figure (5.17) shows a photo taken for another PV power station that illustrates the proper hardware can be misused. Here, the stainless-steel isolation washer has been installed in the wrong sequence and the copper grounding wire is being pushed against the aluminum frame; this is a condition sure to cause corrosion and loss of electrical contact in the future.

Figure (5.17): Improper Grounding PV module

Appendix F.6 shows that the main items that should be considered in evaluating grounding systems.

The following main modifications should be done in grounding system:

- Each manholes of PV and lightning grounding pits should be connected to grounding check point with appropriate copper busbar.
- Grounding check point should be installed for each table with suitable electrical panel and suitable grounding busbar.
- The fence and the main door should be connected to the PV grounding system.
- MDB and monitoring DB should be connected to the PV grounding system.

5.7. Lightning Protection System

Lightning causes two major types of accidents:

a. Accidents caused by a direct stroke when the lightning strikes a specific zone. This can cause considerable damage, usually by fire. Protection against this danger is provided by lightning air terminal systems

b. Accidents caused indirectly, as when the lightning strikes or causes power surges in power cables or transmission links.

A lightning protection system is designed to protect the system from damage due to lightning strikes by intercepting such strikes and safely passing their extremely high currents to ground. This lightning protection system includes the air terminal, bonding conductors, and ground electrodes designed to provide a low impedance path to ground for potential strikes. Figure (5.18) shows the lightning protection system in this PV power station that the air terminal (Pulsar 60µs from ABB) installed at the top of 12 meter steel pole,

$70mm^2$ down conductor inside that pole and the three grounding pits behind the fence (grounding pits does not appear in the figure).

The distance between the lightning system and the farthest equipment in this PV power station is 81 meters.

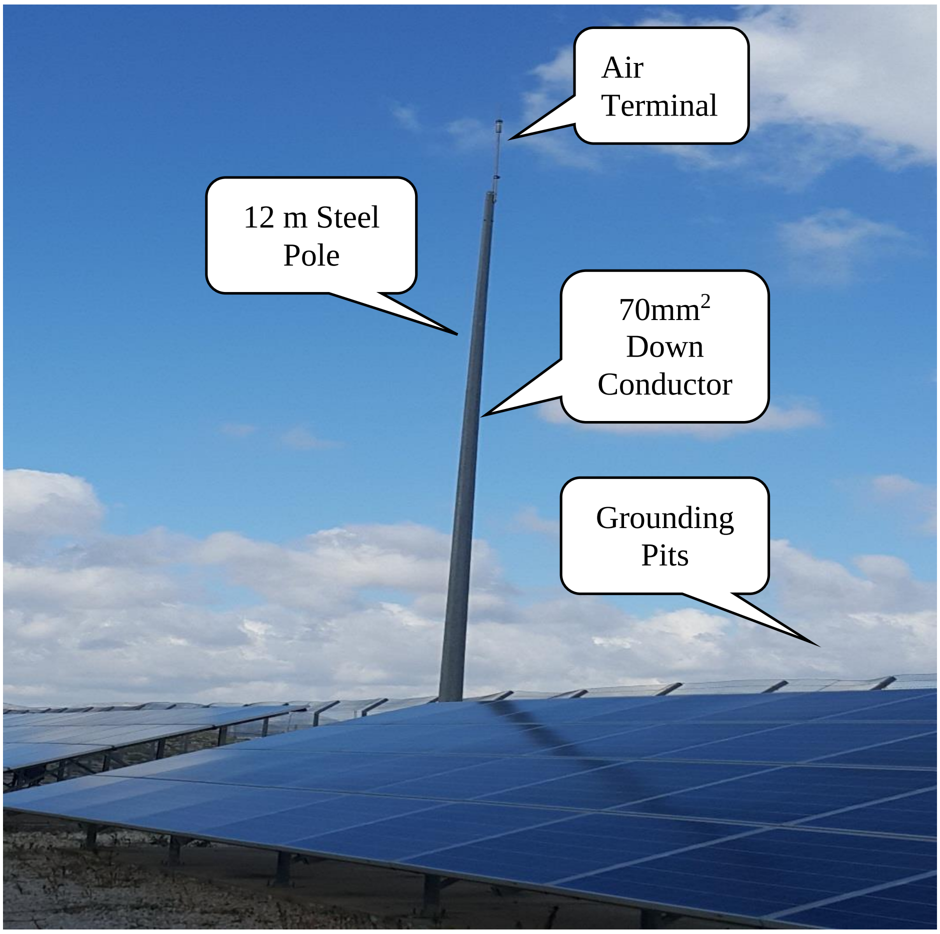


Figure (5.18): Lightning Protection System in 350kWp PV power Station

According to TDECO's requirements, lightning arrestor should be installed for each PV station above 10kWp; because there is no specific map showing lightning density in Palestine.

The lightning protection system coverage area is calculated according to Equation 5.18 for installation height greater than 5m.

$$R_p = \sqrt{2 * r * h - h^2 + \Delta * (2 * r + \Delta)} \quad (5.18)$$

Where;

R_p: The protection radius (m).

h: The height of air terminal(m);12m steel pole + 2 meter air terminal.

r: 20m for protection level I; 30m for protection level II; 45m for protection level III; 60m for protection level IV.(II protection level is used)

Δ: $\Delta T * 10^6$

ΔT: Initiation advance measured during efficiency test according to Annex C of NFC17-102

$$R_p = \sqrt{2 * 30 * 14 - 14^2 + 60 * (2 * 30 + 60)}$$

R_p = 88.5 meter which is more than 81m. Therefore, this lightning protection system covers this PV power station.

Appendix F.7 shows the main item should be considered in evaluating lightning protection system.

The lightning protection system installation complies with all requirements. The grounding system installation is discussed in section 5.6 and the onsite test is discussed in section 4.16.1.2.

5.8. Mounting Structure

This section will describe the structure shape, the shading location and types of this PV power station and the checklist of main items should be considered in evaluating galvanized steel structure. Detailed fixing and structural design are beyond the scope of this thesis.

General Description

Bolted steel base plates foundation type[1] were used in this PV power station where is located over suitable existing 10cm concrete ground slabs as shown in Figure (5.19), a 20x20cm steel baseplate bolted directly to the existing ground slabs.

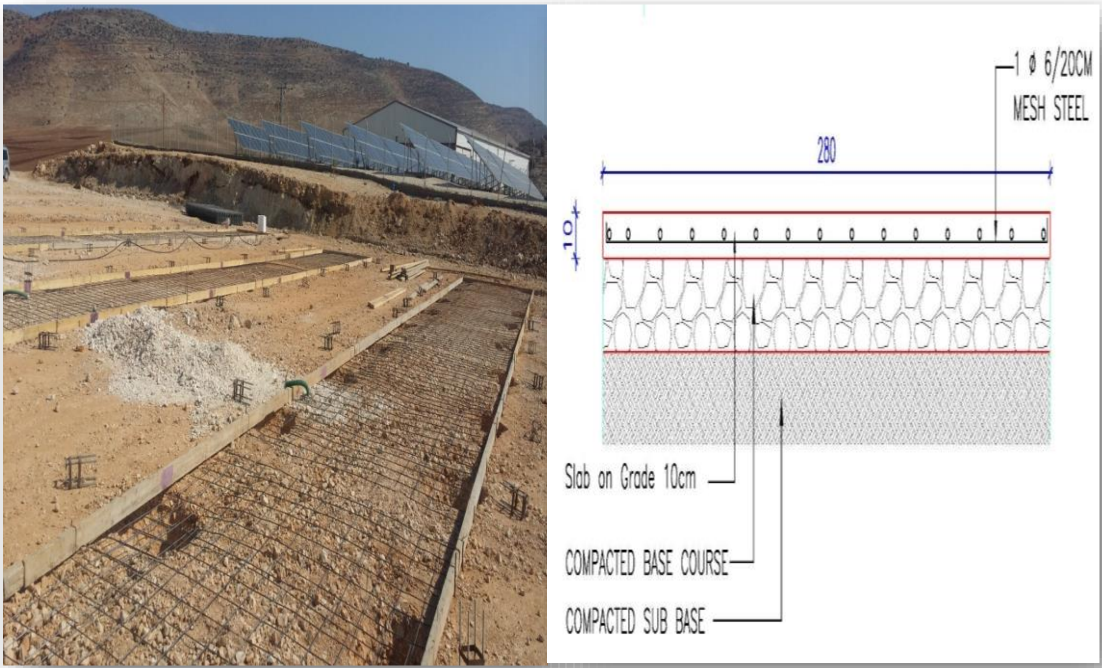


Figure (5.19): Slab on Grade Details

Figure (5.20) shows in the frame details and the trusses fixing where all trusses members' connections are welded connections, the highest point in this structure is 189cm and the lowest point is 40.7cm and the distance between two adjacent legs it 240cm. Four PV modules are fixed landscape

[1] Foundation types mentioned in chapter 2

on the 30mmx60mm rail by using omega, which is fix the back and long side of PV module frame.

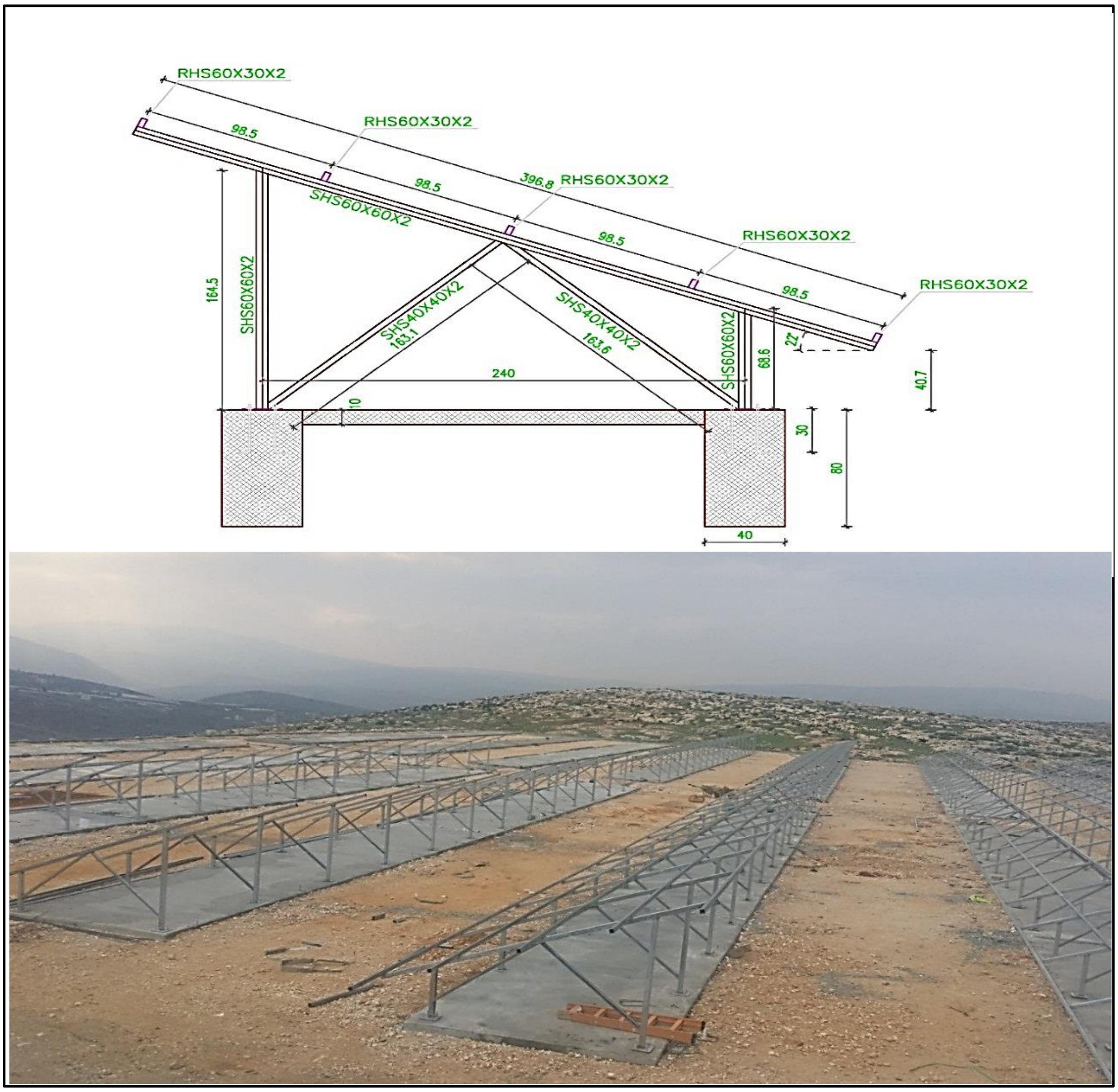


Figure (5.20): Frame Details and Trusses before PV Modules Fixing

Shading

A small degree of shading on part of an array can have a very significant impact on the overall array energy output. Two types of shading is checked in this section for 350kWp PV power station; the inter-row shading and the fence shading.

1. Inter Row Shading

The choice of row spacing is made by compromising between reducing inter-row shading, keeping the area of the PV plant within reasonable limits, reducing cable runs and keeping ohmic losses within acceptable limits. Inter row shading can never be reduced to zero: at the beginning and end of the day, the shadow lengths are extremely long. The inter row spacing in this PV power station is 7.5m, the minimum distance between the rows is determined according to Equation 5.19 [13]as shown in Figure (5.21)

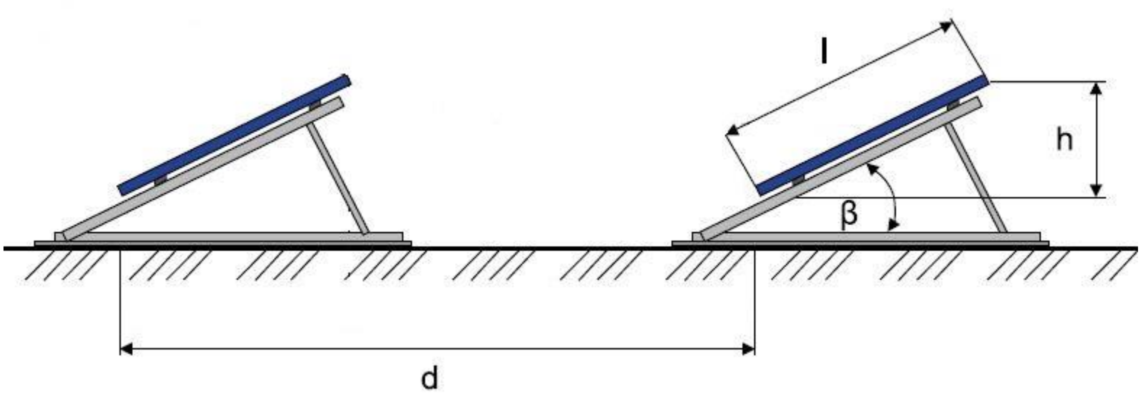


Figure (5.21): Inter Row Spacing

$$d = l * \{\sin(\beta) * \tan(23.5 + Lat.) + \cos(\beta)\} \quad (5.19)$$

α: Sun altitude; the lowest altitude, which is give the longest shading at 23.5°.

d: Distance between rows(m).

l: Length of PV array (m).

ß: Tilt angle.

Lat.: Location latitude.

d = (0.985 m* 4 modules) * {sin 22 * tan(23.5+32.32) + cos 22}= 5.83m which is less than the 7.5m, therefore no significant inter row shading in this PV power station.

2. Fence Shading

The galvanized steel wire mesh fence with anti-climb protection was installed around this PV power station with 2 meters height.

This fence make shadow that could reach the PV module especially in the southern and the western parts that will be discussed below. The shadow length will be determined according to Equation 5.20.

$$\tan\alpha = \frac{\text{Fence Hieght}}{\text{Fence shading length}} \quad (5.20)$$

Where,

$\alpha = 90° - \theta$

α: Altitude angle.

θ: Zenith angle

$\theta = \text{Lat.} - \delta$

δ: Declination angle at the longest shading day in Dec.21

θ = 32°-(-23.5°) =55.5°

Then,

$\alpha = 90° - 55.5° = 34.5°$

Then,

tan 34.5 =2 m / Fence shading length

Therefore,

Fence shading length =2.91m

Figure (5.22) [1]shows the all last PV modules locates on the far western from each row (denoted by red circle) and almost the southern row in the east side (denoted by red rectangular) will be shaded by the fence.

Number of shaded modules in the southern part are 68 modules, which is 17kWp.

Number of shaded modules in the western part are 32 modules, which is 8kWp.

[1] All dimension in the figure is centimeter

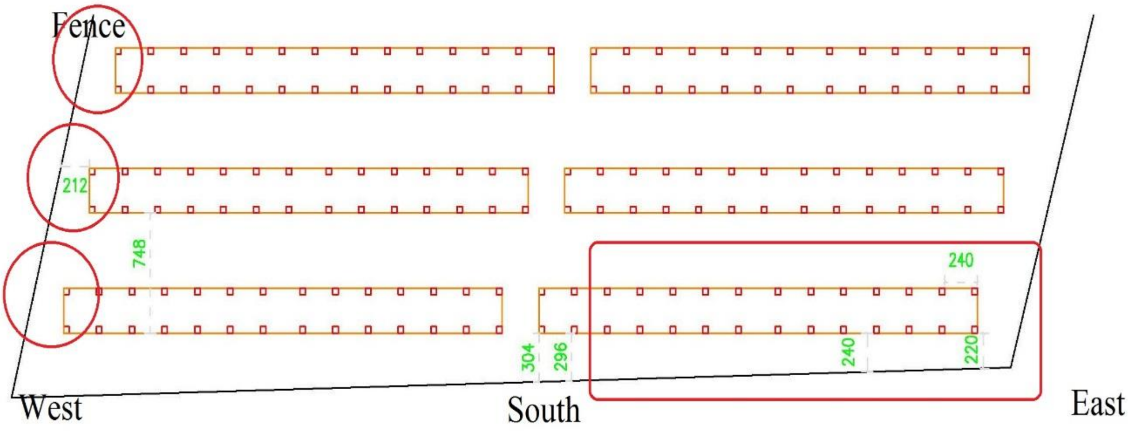


Figure (5.22): Fence Shadow Location

Other things should be considered in evaluating mounting structure mentioned in Appendix F.8.

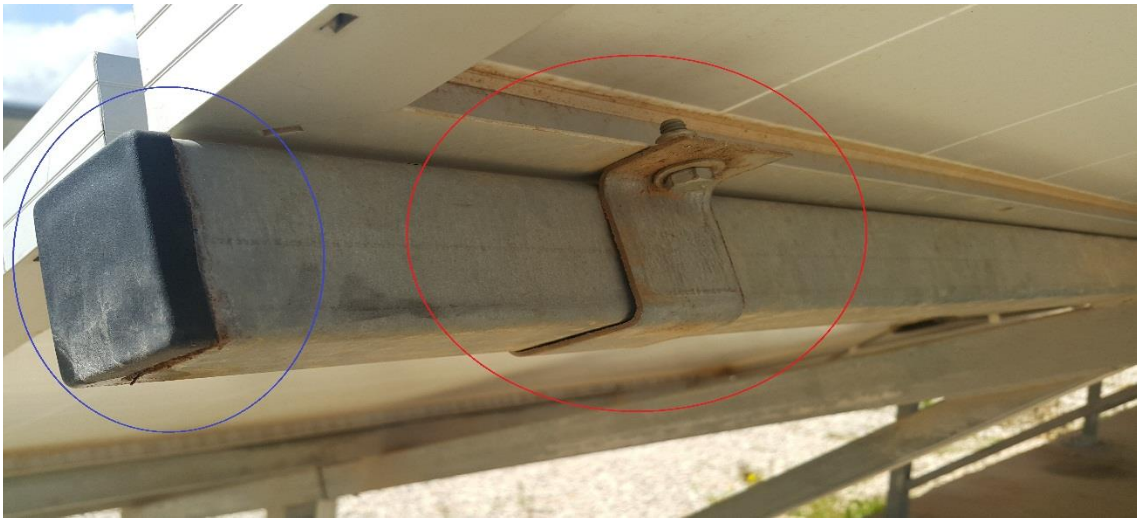


Figure (5.23): Effect of Metals Dissimilarity of Bolts and Insulating Washers

Therefore, the mounting structure should be checked using galvanic tester, bolts fixing should be tested using torque wrench according to Table (5.6), and there are corrosion in many holes' edges and welding points that should be treated.

Table (5.6): Bolts' Size and Torque

Bolt Size	Torque (N.m)
M6	4.8
M8	12
M10	23
M12	40
M14	63
M16	100

5.9. Monitoring System

A monitoring system is an essential part of a PV plant. Automatic data acquisition and monitoring technology is also essential during the operational phase in order to maintain a high level of performance, reduce downtime and ensure rapid fault detection.

Appendix F.9 shows the main item should be considered in evaluating monitoring system

Therefore; The electrical panel for monitoring needs 16A circuit breaker and 16A with 30mA sensitivity RCD.

5.10. Weather Station

This PV power station type ABB contains anemometer, ambient temperature sensor, pyranometer for tilted surface (termed hereafter Plane-of-Array (POA) Irradiance), pyranometer for horizontal surface and cell temperature sensor as shown in Figure (5.24):. For this weather station specifications, see Appendix B.5

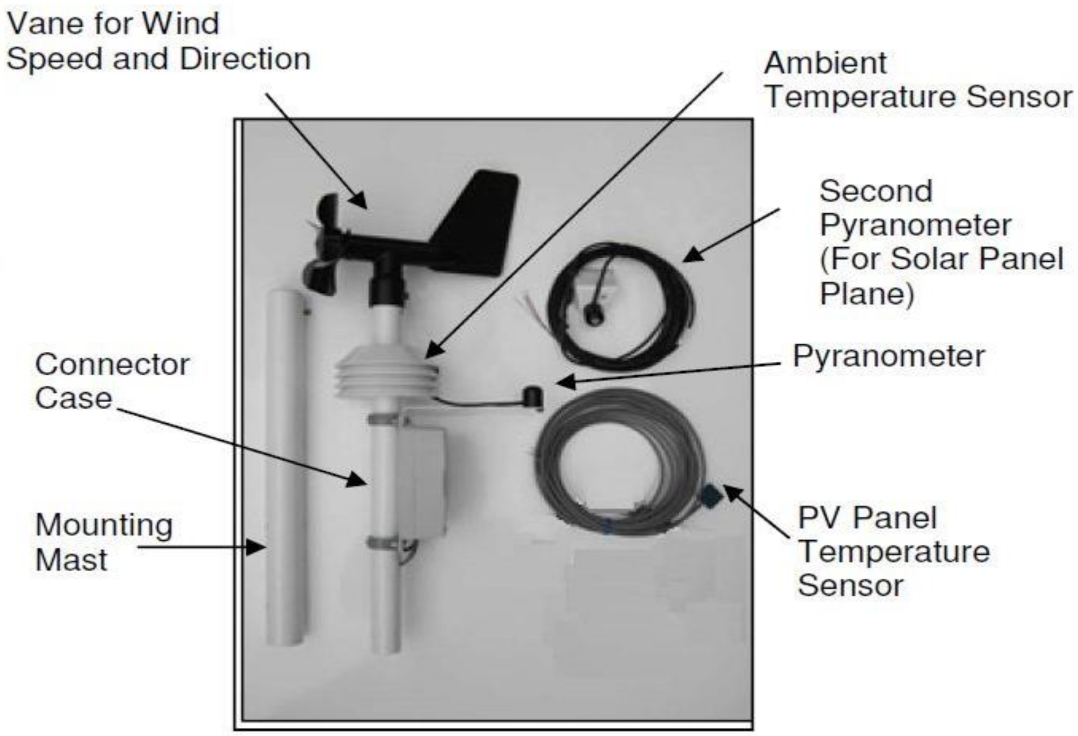


Figure (5.24): ABB Weather Station

The weather station is an important device for making performance test for the PV power station, which gives the following data:

1. Global Irradiance

   The pyranometer is attached to the sensor assembly and is oriented to measure global irradiance; (measuring range is 0 to 1750W/m^2 and its accuracy +/- 5 %). To accurately measure this quantity the sensor must be level, orientated to TRUE SOUTH and objects above 10° above the horizontal plane must not block the sensor.

2. POA Irradiance

   The POA pyranometer is mounted on the side of the solar array; this device measuring range is 0 to 1750W/m^2 and its accuracy +/- 5 %. The sensor should be at the same zenith and azimuth angle as solar array to correctly measure the plane-of-array irradiance.

3. Wind Speed and Direction

The anemometer is directly attached to the top of the sensor assembly; (measuring range is 0 to 67m/s and its accuracy > 0.45m/s). For correct wind direction, operation of the anemometer must be oriented correctly.

4. PV Cell Temperature

This sensor is designed to be attached directly to any solar panel; (measuring range is -40°C to 80°C and its accuracy +/- 0.3°C). When placed on the center back side of the panel, it accurately measures the temperature of the panel. Prior to installation of the PV temperature sensor onto the PV panel, the installation area of the panel back should be thoroughly cleaned. This cleaning will ensure a good bond between sensor and panel and allow for accurate panel temperature readings [16].

Appendix F.10 shows the main item that should be considered in evaluating the weather station.

The weather station complies all requirements.

5.11. Cables

This section discusses the types of cables used in this PV station, which divided into DC and AC cables, and how to evaluate each type according to specific criteria.

From our practice, there are six essential criteria that should be respected in cable selection and installation; cable voltage rating, cable current carrying capacity, voltage drop, power losses, cable cost and wiring measures discussed in each DC and AC cable.

5.11.1. DC Cables

The DC cables used in this station are insulated tinned copper wires used for transmitting the DC electrical power from photovoltaic modules to DC combiner box. There are 2752 meters of 4 mm^2 DC PV cables included in the modules. Hereafter termed "module cable", and 1105 meters of $6mm^2$ DC cable up to inverter, these cables, hereafter termed "string cable", are fixed to structure with special ties or lays 50 cm under ground level inside 35cm flexible conduit. Table (5.7) shows the cable specifications while detailed specifications are in Appendix B.2.

Table (5.7): DC Cable Specifications

General:
• Brand: EUPEN cable
• Origin: Belgium
• Conductor: tinned copper, flexible
• Insulation: halogen free, cross-linked polyolefin- compound
General Technical data:
• Ambient temperature: -40 °C up to + 90 °C
• Rated voltage DC: 0.9/1.5kV
• Outstanding UV- resistance
• Very low water absorption
Technical data for $4mm^2$:
• Conductor resistance at 20°C : 5.09 ohm/km
• Current carrying capacity according to installation method "single cable on surface": 52A
• Conversion factor at ambient temperature up to 60°C : 1
Technical data for $6mm^2$
• Conductor resistance at 20°C : 3.39 ohm/km

• Current carrying capacity according to installation method "single cable on surface": 67A
• Conversion factor at ambient temperature up to 60°C : 1
Standards:
• IEC/EN 61034 "Low smoke emission"
• IEC/EN 603332-1-2 "flame redundant"
• EN 50267-2-1 "Halogen free"
• EN 50267-2-2 "Low corrosive of gases"
• NFX 70-100-1-2 "Low toxicity of gases"

The general DC layout shown in the Figure (4.2), was notified by continuous red, green, cyan, magenta, blue and black lines. Each module cable and string cable have the same symbol to keep drawing evidently. All of DC cables shown are module cables except that lies between tables are string cables. Some string cables have not been drawn where located between the ends of module cables and inverters.

To maximize the output of the solar PV system; the losses in the PV array DC cables need to be minimized. Nevertheless, the voltage drop on the PV array cables also needs to be considered, particularly for large sites with long cable runs. An excessive voltage drop may affect the matching of the PV array to the MPPT input range of the inverter [6]

1. Cable Voltage Rating

There are three methods to find cable voltage ratings; the first method is according to German Energy Society [3], voltage rating of the cable should be checked taking into account the maximum open circuit voltage at the coldest cell temperature reached in our PV power station, which is -4°C according to Table (3.6) and Equation 5.3 and Equation 5.6

$V_{OC,\ string@-4°C}$ =20 modules *41.1V

$V_{OC,\ string@-4°C}$ = 821.8V

The second method, according to IET [6] is the voltage ratings of crystalline silicon modules to be applied a multiplier to the STC module parameter as follows:

$$V_{OC-max,string} = 1.15 * V_{OC,module} * N \quad (5.21)$$

$V_{OC-max, string}$ = 1.15 * 37.7V* 20 modules

$V_{OC-max, string}$ = 867.1 V

The third method, according to NEC [17](see Appendix A.c), which gives temperature correction factor tables using the following equation:

$$V_{OC-max,string} = C_T * V_{OC,module} * N \quad (5.22)$$

Where,

C_T : temperature correction factor according to NEC table ; where the lowest expected ambient temperature could be available in Tubas is -4 °C according to Table (3.7), so we select the second row (-1°C to -5°C)

$V_{OC-max,string}$ = 1.12 * 37.7 * 20

$V_{OC-max,string}$ = 844.5 V

Therefore, the calculations in the three methods in our PV power station are approximately the same; the first method for German Energy Society is 821.8V, the second method for IET is 867.1 V and the third method for NEC is 844.5 V; the highest value here according to IET method 867.1 V.

According to cable specifications, mentioned in Table (5.7) the suitable size is selected, where the cable voltage ratings is 1000V, which is more than 867.1 volts.

2. Cable Current Carrying Capacity

The maximum current of these cables could be considered as mentioned in Table (5.7) respecting the de-rating factors method of installation and temperature. The maximum ambient temperature measured in Tubas, according to Table (3.6), is 45°C. According to the cables specification in Appendix B.2 the temperature conversion factor is one up to 60°C.

In some places, we installed two cables 4 mm^2 and 6 mm^2 carrying 44A and 57A respectively.

Generally, the cable design depending on the existing protection devices or not:

A. Cable Design without Using Protection Devices:

This method calculates the maximum current the may flow through the module cables and string cables when the fuses or any protection devices are absent by using the following equation.

$$I_{max,cable} = (M - 1) * I_{SC,string} \quad (5.23)$$

Where,

$I_{max,\ cable}$: Maximum current may flow through the cable (A).

M: Number of strings per inverter.

$I_{sc,\ string}$: Short circuit current for one string (A).

Note: this method is not used in this PV power station; because we have ABB enclosure contains 15A fuse per each string. The following calculation will ensure cables capability, if one or more of ABB enclosure are canceled.

Case 1: For inverter number 1 (20 kW-4 strings)

$I_{max,\ cable} = (4-1) * 8.79$

$I_{max, cable} = 26.37$ A

The weak point locates in 4mm^2 cable that can carry the maximum current.

Case 2: For inverters number 2 to 12 (27.6 kW-6 strings)

$I_{max, cable} = (6-1) * 8.79$

$I_{max, cable} = 43.95$ A

The weak point locates in 4mm^2 cable that can carry the maximum current.

B. Cable Design Using Protection Devices:

This method shall be used when string fuses or any protection devices are installed to protect the cables from overloading,

$$I_{max,cable} \leq I_Z \quad (5.24)$$

$I_{max, cable}$: Maximum current may flow through the cable (A).

I_Z: The current carrying capacity of the protective device (A).

In this case, the protection device is used so, Equation 5.25 is used according to [6]

$$I_Z = 1.25 * I_{SC,string} \quad (5.25)$$

$I_Z = 1.25 * 8.79$ A

$I_Z = 10.99$A

The maximum current allowed for 4mm^2 cable is 43.95 A (as calculated in the case 2 of the previous point).

$I_Z \leq 43.95$A, therefore the selected cables are accepted.

3. Voltage Drop

The voltage drop in the PV array cables needs to be considered because an excessive voltage drop may affect the matching of the PV array to the MPPT input range of the inverter.

To minimize the voltage drop the cable cross-section area should be increased.

The allowed voltage drop in DC circuits is less than 1% according to VDE 0100 Part 712 which recommends: “The voltage drop in the direct voltage circuit should be no greater than 1% of the nominal voltage of the PV system at standard test conditions (STC).” This limits the power loss through all DC cables to 1% at STC [3].

Voltage drop in DC systems is given by the following equations:

$$\Delta V = b * R * I_{MPPT} \quad (5.26)$$

$$R = \rho * \frac{L}{A} \quad (5.27)$$

Where,

ΔV: Voltage drop in DC cables in Volt (V).

Note: DC voltage drop calculation for photovoltaic system should equal number of modules in series multiplied by V_{MPPT} for one module.

b: Length cable factor, b=2 for DC wiring.

R: Resistance of cables given in cables datasheet see Table (5.7).

ρ: Specific resistance of conductor material, ρ =0.023 for copper at ambient temperature of 25 C° (in ohm.mm).

L: Distance between the PV modules and inverter, in meters (m).

A: Cross section area of the cable, in mm^2.

I_{MPPT}: Maximum power point current for PV array.

Voltage drop in percent for DC systems is given by the following formula:

$$\Delta V = \frac{\Delta V}{V_0} * 100\% \quad (5.28)$$

Where,

$\Delta V(\%)$: Voltage drop in DC cables in percent (%) where maximum allowed 1%.

V_0 : voltage between positive and negative poles in DC system

The table in Appendix A.a.i shows the DC cables in this PV power plant and the voltage drop in each cable section.

We find from the this table that all strings are less than 1% where the maximum voltage drop in inverter 4 string 3 is 0.49% and the minimum voltage drop is in inverter 10 was 0.33%.

If we install 4mm^2 DC cables instead of 6mm^2, the voltage drop would be less than 1% as shown in Appendix A.a.ii table. Maximum voltage drop in inverter 4 string 3 is 0.54% and the minimum voltage drop is in inverter 10 was 0.37%.

As a result, we find using both 4mm^2 and 6mm^2 DC string cables are accepted, the better choice will be discussed in section 7.3.

4. Power Losses and Efficiency

Power losses in a cable are mainly due to resistive heating of the cable. Good design practice for PV system is to minimize DC cable losses in acceptable range (1% to 3 %) [6].This could be achieved by increasing the cross section area of cables.

The power losses in DC cable is obtained as follows:

$$P_{\text{losses in DC cables}} = b \times R \times I^2 \quad (5.29)$$

Where;

$P_{\text{losses in DC cables}}$: Power losses in DC cables, (W).

b: Length cable factor, b=2 for DC wiring.

R: Resistance of one active line (Ω).

I: Current in Ampere (A).

The power losses in percent for direct current is equal to the voltage drop in percent and in any case, must not exceed 3%.

The table Appendix A.a.iii shows the DC cables in this PV power plant and the power loss in each cable section.

We find from this table that all strings have power losses less than 1% where the maximum power losses in inverter 4 string 3 is 0.49% and the minimum power losses in inverter 10 is 0.33%.

The total power losses in this PV station at STC amounts to 1203W.

The efficiency can be calculated by the following equation:

$$\eta_{DC,cable} = \left(\frac{P_{PV,Station@STC} - P_{DC\ cable,total\ loss}}{P_{PV,Station@STC}}\right) * 100\% \qquad (5.30)$$

Where,

$\eta_{DC,cable,\ theoretical}$: Overall DC cable theoretical efficiency.

$P_{PV,Station@STC}$: Total power of PV station at STC(W).

$P_{DC\ cable,\ total\ loss}$: Total power losses in DC cables at STC (W).

$$\eta_{DC,cable\ theoretical} = \left(\frac{350000W-1203W}{350000W}\right) * 100\%$$

$$\eta_{DC,cable\ theoretical} = 99.656\%$$

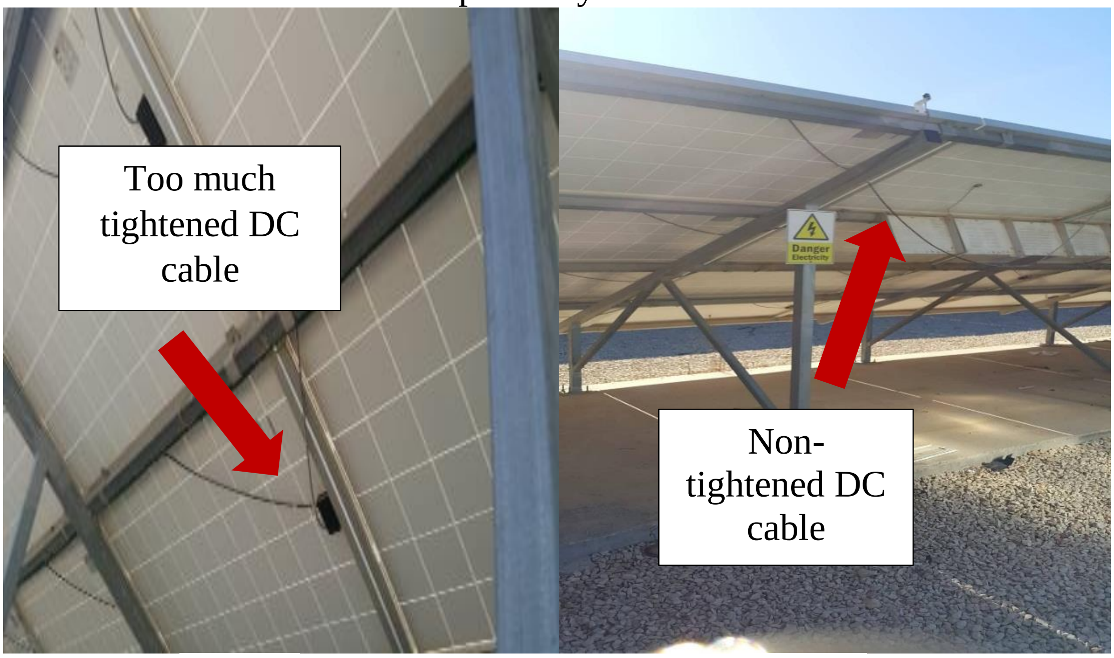
5. Cable Cost

Reducing string cable cost is one of the main issues. It is more cost effective to increase cable size so that the losses and voltage drop remain small. Nevertheless, in larger systems, cable size may need to be influenced by financial return calculations, this increasing costs money; this will be discussed in section 7.3

6. Wiring Measures

Practically, the following points should be considered in DC cable wiring:

A. Cables routing. Modules or string cable must be routed along the structural members (beams, rafters, trusses, and columns) by using suitable cable ties without tightening it too much, that could cause tension on the PV module junction box. In this PV power station, as shown in Figure (5.25), there are many cables not fixed to the structure and others are tightened too much as shown in A and B respectively.



(B) (A)

Figure (5.25): Tightened and Too Much Tightened DC Cables

B. Reducing induced voltage surges. Figure (5.26) shows two drawings the first is the current situation sample of poor module wiring for inverter 1 and 2. The second for better module wiring “Proposed case”, in order to reduce induced voltage surges in the module cables, we adopt the following wiring measures:

1. Each string's positive and negative cables (+ and -) should be routed as close as possible to each other to prevent loops formation.
2. Keeping DC cable as short as possible.

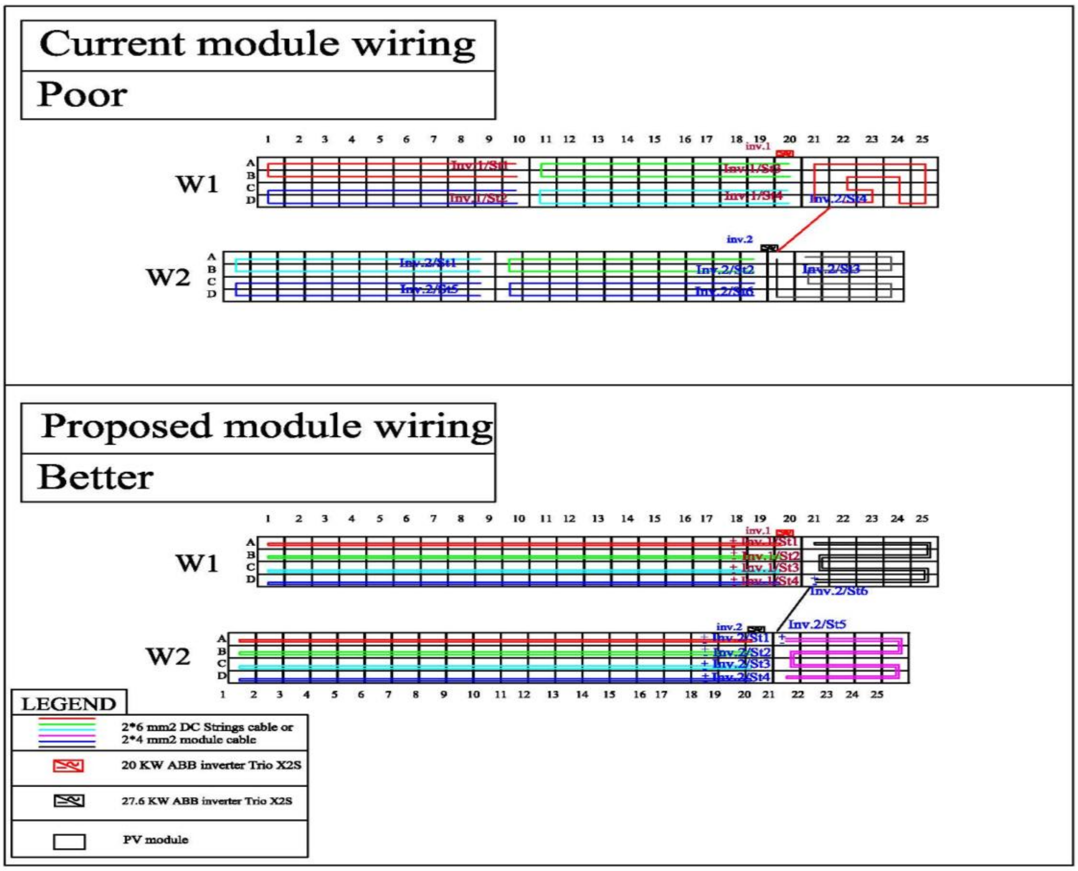


Figure (5.26): PV Module Wiring in Order Protection against Lightning and Overvoltage on the DC Side

C. Inserting mains and string cables in suitable conduit if existing. This is expressed as a percentage or ratio called “Conduit fill”, used to determine the appropriate conduit size or to determine how many cables can be inserted inside existing conduit, to ensure system safety and performance. This percentage is based on the cable outside diameter and the conduit inside diameter. Maximum recommended ratio can be affected by several factors including application type, number of cables in the conduit, and number of conduit bends. The maximum fill ratio is specified as the followings:

1. Less than two 90° bends by NEC [17] table shown in Appendix A.c.2.
2. More than two 90° bends by NEC [17] table shown in Appendix A.c.3 fill must be reduced by 15% for each bend above two to find the proper maximum fill.

In our case, there are 2x6mm^2 string cables (+&-) inserted inside 35cm conduit in all locations of this PV power station that have two 90° bends.

We have 2x6mm^2 = 12 mm^2 total cables diameter, from the table in Appendix A.a.iv.2, we need conduit Trade Size 16mm and from column “2 Cables=31% Fill”. Maximum Occupancy Recommended is 60mm^2. But the existing conduit Trade Size is 35mm the Maximum Occupancy is 302mm^2, which is too large than needed. Therefore, this is an extra initial cost and there is no need to replace it now.

D. The DC underground cable shall be buried 50 cm underground at least. 10Cm sand layer and warning tab shall be covered above the DC underground conduits.

E. Closing conduit entries and ends, should be closed by isolating material like Polyurethane foam. In this station, all entries and ends of DC conduits are closed.

F. Multiple Systems. We can install both DC and AC cables in the same ways, outlets and junction boxes, but must be kept independently entries and identified all termination, connection, and splice points according to [17]. In our case, the DC and AC cables inserted in the same manhole (Manhole number “M9”) as shown in Figure (5.27) but there are no identification or labels.

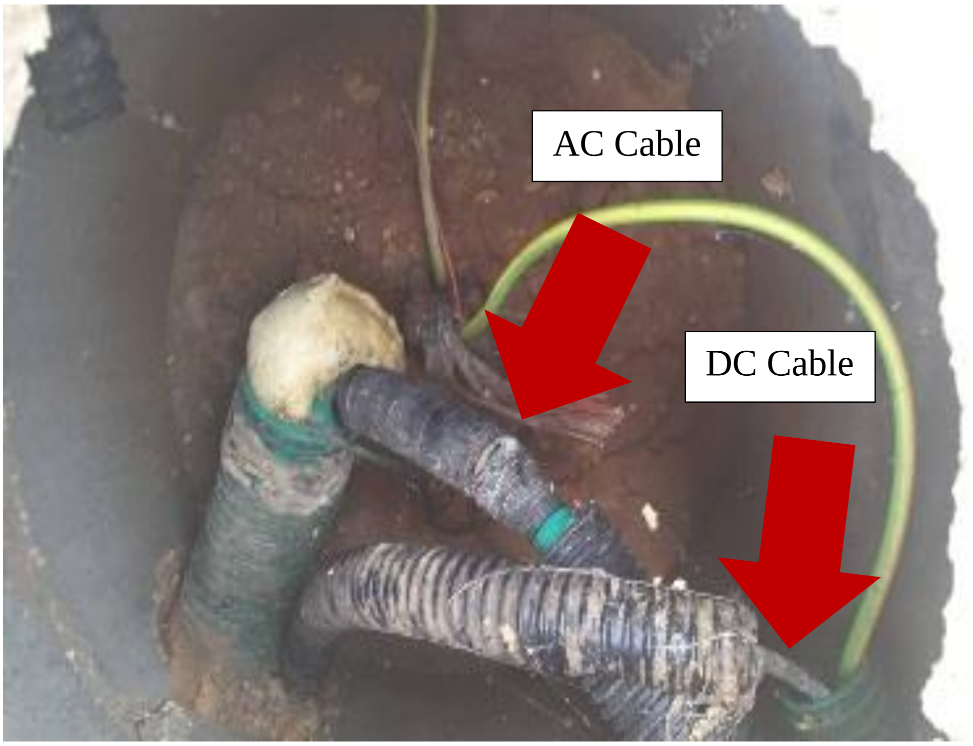


Figure (5.27): Multiple Circuit in the Same Manhole

Finally, Appendix F.11 shows general checklist table summaries all points that should be considered in the DC cable evaluation:

Briefly, the existing DC cable voltage rating, current carrying capacity, voltage drop and power losses are within acceptable ranges even if the string cables extended by $4mm^2$.The wiring measures need some modifications like checking the cable ties, rewiring the cables take in the account reducing induced voltage surges and identifying DC and AC cables where lies in manhole “M9”. Finally, this PV power station has expensive initial DC wiring system costs especially in the oversized string cable and underground conduits size.

5.11.2. AC Cables

The AC cables used in this station XLPE insulated, multi-core cables with copper conductor used for transmitting the AC electrical power from inverters to the MDB then to the MV transformer. There are 490m, 300m of 4x16 mm^2 and 4x25 mm^2 AC cables respectively that lies from inverters to MDB, hereafter termed “inverter cable”, and 34 meters of 4x240 mm^2 AC cables where lies from MDB to the MV transformer, this cable, hereafter termed “Main cable”.
All inverter cables are lays 100 cm underground levels inside 78cm (3inch) flexible conduit. Nevertheless, the main cable has been directly buried between MDB and Transformer without manhole and proper conduit. Table (5.8) shows AC cables specifications for more details see (Appendix B.3)

Table (5.8): AC Cables Specifications

General:
• Brand: SEVAL KABLO
• Origin: Turkey
• Conductor: Solid or stranded copper
• Insulation: Cross linkable polyethylene (XLPE)
• Lead free
• UV resistant
General Technical data:
• Ambient temperature: -25 °C up to + 90 °C
• Rated voltage AC: 0.6/1kV
• Outstanding UV- resistance
Technical data for 4x16mm^2 "inverter cable":
• Conductor DC resistance at 20°C max : 1.15 ohm/km
• Current carrying capacity according to installation method "Ground": 112A
• Current carrying capacity according to installation method "Air": 98A
Technical data for 4x25mm^2 "inverter cable":
• Conductor DC resistance at 20°C max : 0.727 ohm/Km
• Current carrying capacity according to installation method "Ground": 145A
• Current carrying capacity according to installation method "Air": 133A
Technical data for 4x240mm^2 "main cable":
• Conductor DC resistance at 20°C max : 0.0754 ohm/Km
• Current carrying capacity according to installation method "Ground": 517A
• Current carrying capacity according to installation method "Air": 564A
Standard:
• IEC/EN 603332-1-2 "flame redundant"

The general AC layout shown in the Figure (4.2) was notified by red dash, blue and black lines, each inverter cables go throw concrete manholes each 6 meter that facilitate cable wiring.

To maximize the output of the solar PV system; the losses should be minimized. Nevertheless, the AC voltage drop on the cables also needs to be considered.

When specifying cabling the following design considerations should be taken into account:

1. Cable Voltage Rating

Cable must be rated for the maximum expected voltage. The AC operating voltage in this PV power station is 400V for 3phase system and 230V for singe phase system. Commonly LV AC cable rating is 0.6/1KV, which is compatible with the existing AC cable of this PV station.

2. Cable Current Carrying Capacity

The cables should be able to pass the operating current and short circuit current safely. The maximum current of these cables could be carried as mentioned Table (5.8). The basic sizing principle is according to Equation 5.31 and Equation 5.32,

$$1.25 * \mathrm{I}_{\mathrm{load.}} \leq \mathrm{I}_{\mathrm{Protection\ divice}} \quad (5.31)$$

And

$$1.25 * \mathrm{I}_{\mathrm{Protection\ divice}} \leq \mathrm{I}_{\mathrm{Cable}} \quad (5.32)$$

Where,

I_{load}: The maximum current could pass in the cable.

$I_{protection\ divice}$: The ampacity if protection device needed.

I_{cable}: Minimum needed ampacity of cable.

Therefore;

Table (5.9) shows the all inverter cables within accepted current range but the main cable is undersized.

Table (5.9): AC Cable Current Capacity Size

Cable Route	Cable Cross Section Area (mm^2)	Rated Current of Cable according to Ground Installation (A)	Full load current (A)	Protection Device Size (A)	Minimum Needed Ampacity of Cable (A)	Pass/ Failed
Inv.(1)	4 x 16	112	33	41	52	Pass
Inv.(2)	4 x 16	112	45	56	70	Pass
Inv. (3)	4 x 16	112	45	56	70	Pass
Inv. (4)	4 x 16	112	45	56	70	Pass
Inv. (5)	4 x 16	112	45	56	70	Pass
Inv. (6)	4 x 25	145	45	56	70	Pass
Inv. (7)	4 x 25	145	45	56	70	Pass
Inv. (8)	4 x 25	145	45	56	70	Pass
Inv. (9)	4 x 16	112	45	56	70	Pass
Inv. (10)	4 x 16	112	45	56	70	Pass
Inv. (11)	4 x 16	112	45	56	70	Pass
Inv. (12)	4 x 16	112	45	56	70	Pass
Main Cable from MDB to Transformer	4 x240	517	528	660	825	Failed

3. Voltage Drop

Conductors should be sized to avoid voltage drop outside statutory limits and equipment performance. Cables should be sized to minimize voltage drop to ensure that the voltage at inverter terminals is close to that at mains connection point (inverter voltage will always be higher than the connection point due to voltage drop along the circuit). If the voltage difference is too large, the inverter may be prone to nuisance tripping at times where the grid voltage is high (while the grid voltage may within statutory limit, the voltage seen at the inverter terminals may be above the trip point) [6].

The maximum voltage drop recommended in AC side is 3% [3] which is calculated according to Equation 5.33.

$$\mathrm{VD}\,\% = \frac{\mathrm{VD}}{\mathrm{V_{rated}}} * 100\% \tag{5.33}$$

Where,

VD %: Voltage drop in percent

VD: Voltage drop in Volt calculated according to Equation 5.34

V_{rated}: Rated voltage

$$\mathrm{VD} = \left(\rho * \frac{L}{A} \cos\phi + \lambda * L * \sin\phi\right) * I \tag{5.34}$$

Because we have unity power factor; so sin Φ = 0.

Appendix A.b table shows that the calculated voltage drop in each inverter cable and main cable on the accepted range (less than 3%), where the maximum voltage drop in inverter 9 is about 7.48V (1.87%).

4. Power Losses and Efficiency

Conductors should be sized appropriately to ensure that losses produced by the cable are within acceptable limits, which is less than 3% and that the economic balance is maintained between capital cost and operational cost (losses).

Appendix A.b table shows that the calculated power losses in W and percent for each inverter cable and main cable according to Equation 5.35 and Equation 5. 36 that finds that the power losses for each inverter 4,9 and 10 are 908W/3.03%, 1010W/3.37% and 903W/3.01% respectively which exceeds the acceptable limit; therefore, these inverter cables should be replaced by 4x25mm^2 cables.

$$P_{Loss,AC} = 3 * I^2 * \left(\rho * \frac{L}{A}\cos\phi + \lambda * L * \sin\phi\right) \tag{5.35}$$

Because we have unity power factor; so sin Φ= 0.

$$\%P_{loss,AC} = \frac{P_{loss,AC}}{P_{rated}} * 100\% \tag{5.36}$$

The total theoretical AC power losses in this PV station are 9136W.

The efficiency can be calculated by the following equation:

$$\eta_{AC,cable} = \left(\frac{P_{Rated} - P_{AC\ cable,total\ loss}}{P_{Rated}}\right) * 100\% \tag{5.37}$$

Where,

$\eta_{AC,cable}$: Overall AC cable efficiency

P_{rated}: Total power of PV station (W)

$P_{AC\ cable,\ total\ loss}$: Total power losses in AC cables (W)

$\eta_{AC,cable} = \left(\frac{350000W\text{-}9136\ W}{350000W}\right) * 100\%$

$\eta_{DC,cable} = 97.39\%$

5. Cable Cost

Reducing cable cost is one of the main issues. It is cost effective to increase cable size so that the losses and voltage drop remain small. Nevertheless, on larger systems, cable size may need to be influenced by financial return calculations, increasing the costs. All AC cables in the PV power station have optimum size with its costs except 3 AC inverters cables for inverter (4), inverter (9), inverter (10), and main AC cables. Table (5.10) shows that 10490 NIS is the total cost of replacing these inverter cables by 4x25 mm^2 cables with capital and installation cost of 45NIS/m, which complies with all technical issues.

Table (5.10): Inverter's AC Cable Replacement Cost

Cable Route	Cable Cross Section Area	New Cable with Cross Section Area	Max Cable Length (m)	New Voltage Drop (%)	New Power Losses (%)	Pass / Failed	Total Price (NIS)
Inverter (4)	4 x 16 mm^2	4 x 25 mm^2	75	1.06%	1.91%	Pass	3375
Inverter (9)	4 x 16 mm^2	4 x 25 mm^2	83.5	1.18%	2.13%	Pass	3758
Inverter (10)	4 x 16 mm^2	4 x 25 mm^2	74.6	1.06%	1.90%	Pass	3357

It is necessary to replace the main AC cable since when short circuit occurs it can be burnt. However, this cable was directly buried; so the replacement is too difficult. We suggest to leave this cable until the fault occurs, then it will approximately cost, if we replace it by double 4x240m^2 new cable with its installation, 21760NIS.

6. Wiring Measures

Practically, the following points should be considered in AC cable wiring:

A. Inserting AC cables in suitable conduit if existing. This is expressed by conduit fill as mentioned in previous section. Each three-inverter cables occupied 78cm (3inch) flexible conduit. The worst case was in the conduit that extended from manhole number 9 to the MDB, which occupied by 3 cables of $4x25mm^2$ with total area of $1253mm^2$ and have two bends. From Table 2 in Appendix A.c shows a maximum of is 40% (1918 mm^2) which is optimum size.

B. The DC underground cable should be buried 100 cm underground at least. 10cm sand layer and warning tab should cover the DC underground conduits.

C. All conduits ends should be closed by isolating material like Polyurethane foam as shown in the Figure (5.28) illustrating the closed and non-closed conduits in this PV station

Non-end closed conduits

Closed end conduits

Figure (5.28): Closed and non-Closed Conduits

D. Multiple Systems, we can install both DC and AC cables in the same way, outlet and junction boxes, but must be kept independently entries and identified all termination, connection, and splice points according to [17]. In our case, the DC and AC cables are inserted in the same manhole (Manhole number "M9") as shown in Figure (5.27) but there are no identification or labels.

Finally, Appendix F.12 shows general checklist table summaries all points that should be considered in the AC cable evaluation:

Briefly, the existing AC cable voltage rating, current carrying capacity for all inverter cables and the distance between manholes are within acceptable ranges even the followings are the summery of the problems and the corresponding recommendations:

- The main AC cable is undersized and direct buried, which make difficult and costly maintenance. We recommend to leave this cable until a fault occur, then it will approximately cost if we replace it by double 4x240m^2 new cable with its installation 21760NIS.
- The percentage power losses for the inverters 4, 9 and 10 are 3.03%, 3.37% and 3.01% respectively, which exceeds the acceptable limit, cable replacement is recommended by 4x25 mm^2 that costs 10490 NIS.
- AC inverter's 7-cable joint inside manhole number 9 should be jointed by suitable heated joint.
- Closing the opened end conduits by Polyurethane foam

- Identifying the AC cables by color coding, marking tape or tagging at points of termination, connections, and splices.

5.12. Metering System

Electric meters in PV systems installed to measure electrical energy generated by this system. Commonly TDECO use bidirectional meter for these systems that measure both electrical energy generated and consumed; so this meter offers anti-tamper security features.

This section discusses all components for metering system (meter and current transformer (CT)) and evaluate the installation.

The meter has been installed in the DB where two meters near MDB are fixed; its brand is Schneider PM3255 with the following specifications:

Table (5.11): Meter Specifications.

General:
• Type No.: SCHNIDER PM3255
• Power meter with Modbus communications, DI/DO
• Power consumption is 5VA
• Accuracy Class :0.5
Type of measurement:
• Energy Import and export
• Active and reactive power
• Present, min and max for total current harmonic distortion THD (I)

• Present, min and max for total voltage harmonic distortion THD (U)
• Voltage
• Current
• Frequency
• Power factor
• Apparent power
• Demand, present and peak power and current
Standards:
IEC 61557-12, IEC 62053-21/22, IEC 62053-23, IEC 62052-11, EN 61557-12, EN 61010-1, IEC 61557-12, EN 50470-3, EN 50470-1 and UL 61010-1
Voltage inputs:
• Wye: 60 – 277 V L-N, 100 – 480 V L-L ,± 20%
• Delta: 100 – 480 V L-L ± 20%
• Frequency: 50 / 60 Hz ±10%
• Impedance: 3 MΩ
• Measurement category III
Current inputs:
• 1 A or 5 A nominal; requires x/5A or x/1A
• Measured current: 20 mA – 6 A
• Withstand: 10 A continuous, 20 A at 10 sec/hr
• Impedance: < 1 mΩ
Installation:
• Operating temperature: -25 °C (-13 °F) to +55 °C (131 °F)

• Storage temperature: -40 °C (-40 °F) to +85 °C (185 °F)
• 5% – 95% RH non-condensing
• IP40 front panel, IP20 meter body
• < 3000 m (9842 ft) above sea level

The CT's have been installed on the Main AC cable in MDB, in our case installing CT's is very important because the maximum measured current in this meter should not exceed 6A as mentioned in meter specification Table (5.11)

The following table shows the main CT specifications:

Table (5.12): Current Transformer Specifications

Type No.: CP 74/50
CT ratio :500/5
Rated Burden: 10VA
Accuracy Class :0.5
Standard: IEC44-1, BS3938, DIN42600, GB1208-2006.
Cases are made of ABS, meet UL-94V.
Short -time thermal current: Ith=60x1h.
Security factor: FS less than 5.

The description of metering system installation.

Figure (5.29) shows how meters are connected. Three CTs are installed around each R, S, and T phases (Main AC cable outing MDB. Each CT has two secondary winding ports S1 (IN-port) and S2 (OUT-port) connected by

4 meter length, 2.5mm^2 copper wires. Each S1 wire connected by meter current port and S2 wires connected by each other and neutral in MDB then connected to the S2 meter ports. The bidirectional meter was located in 4m away from MDB, the power supply meter and voltage ports are connected by 2.5 mm^2 wires to inverter 12 were located 2m away.

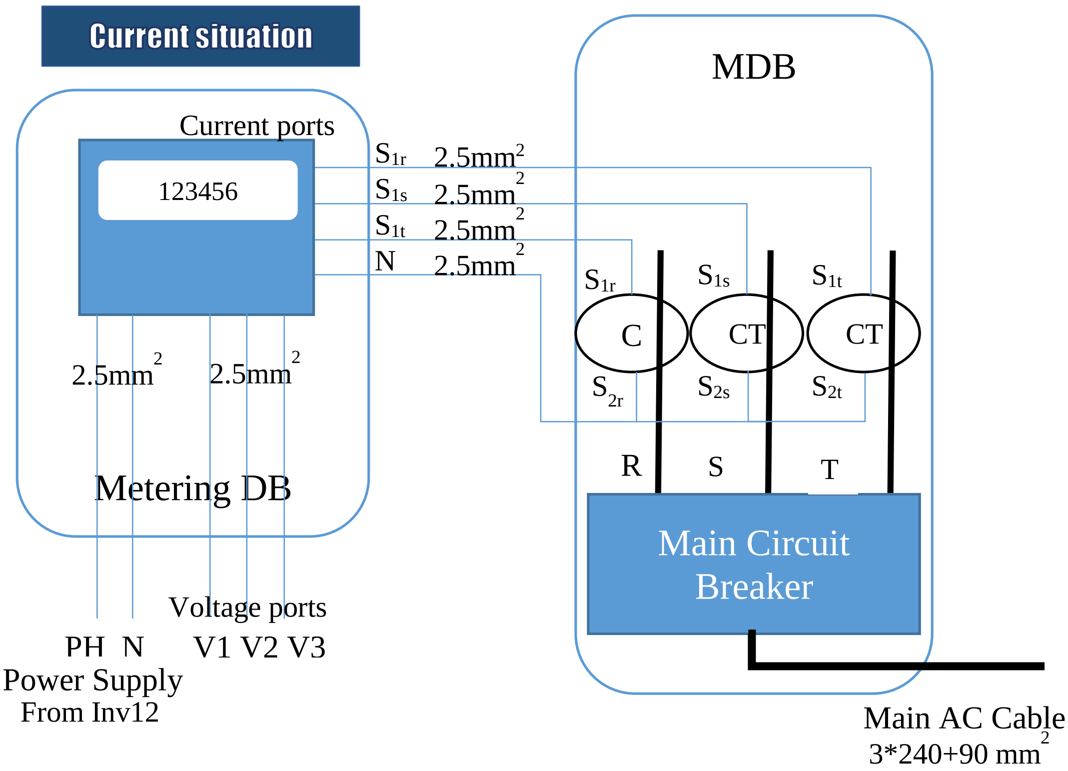


Figure (5.29): Metering Installation – Current Situation

Figure (5.30) shows the right installation for metering system, the red circles indicate where modification should be done.

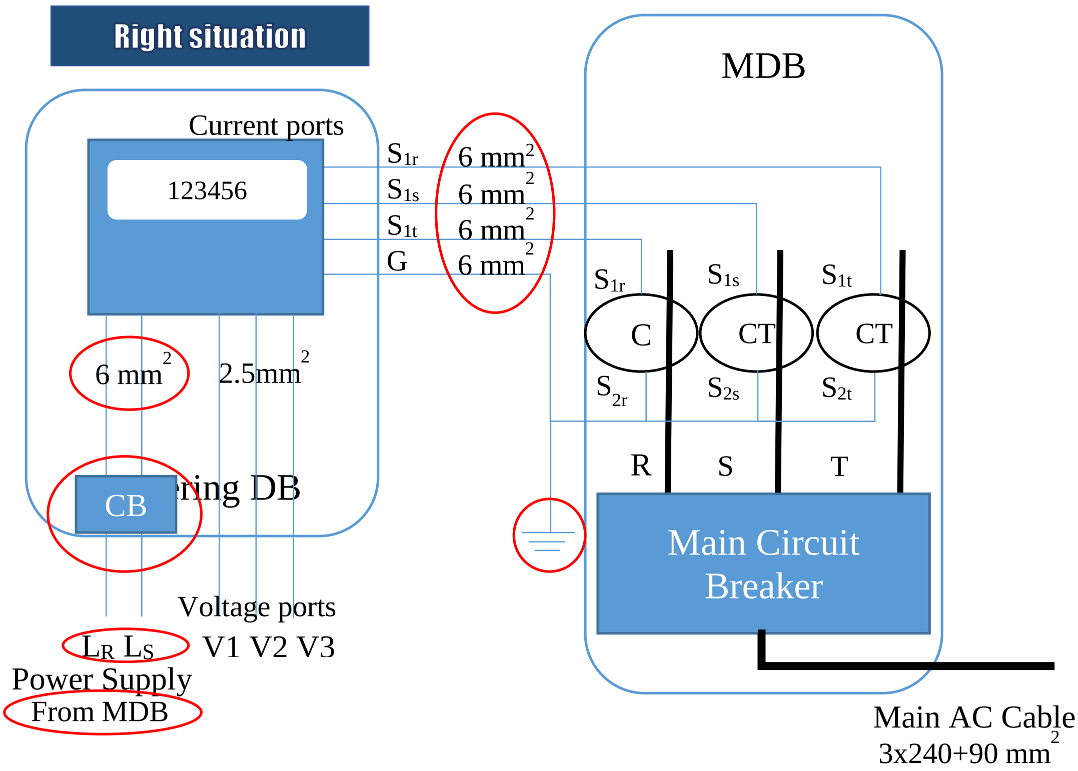


Figure (5.30): Metering Installation – Right Situation

Appendix F.13 shows the main items that should be considered in evaluating metering system and illustrates the suggested modifications

The following main modifications should be done in metering system:

1. Installing environmental resistance information signs and fixed it in the meter's electrical panel written "**Meter Panel** "with following information:

    a. CT ratio and installing date

    b. Installing another sheet contains empty table for future rehabilitation that can include date of meter replacement, meter serial number and CT ratio.

2. Installing lock for metering DB
3. Convert meter power supply and CTs cable by $6mm^2$
4. Install 250 mA fuses or circuit breaker on L_R and L_S ports
5. Connect the meter power supply to the main busbar.
6. Connect the secondary terminals of current transformers to the grounding system.

5.13. Transformer

This is the electrical device that transfers electrical energy from low voltage level produced from PV power station to Medium voltage of utility grid.

Figure (5.31) shows the electrical MV grid map for the site, which shows three transformers; 250kVA for transformer maintenance center, 160 kVA for first stage of Czech PV power station and 400kVA for this PV power station.

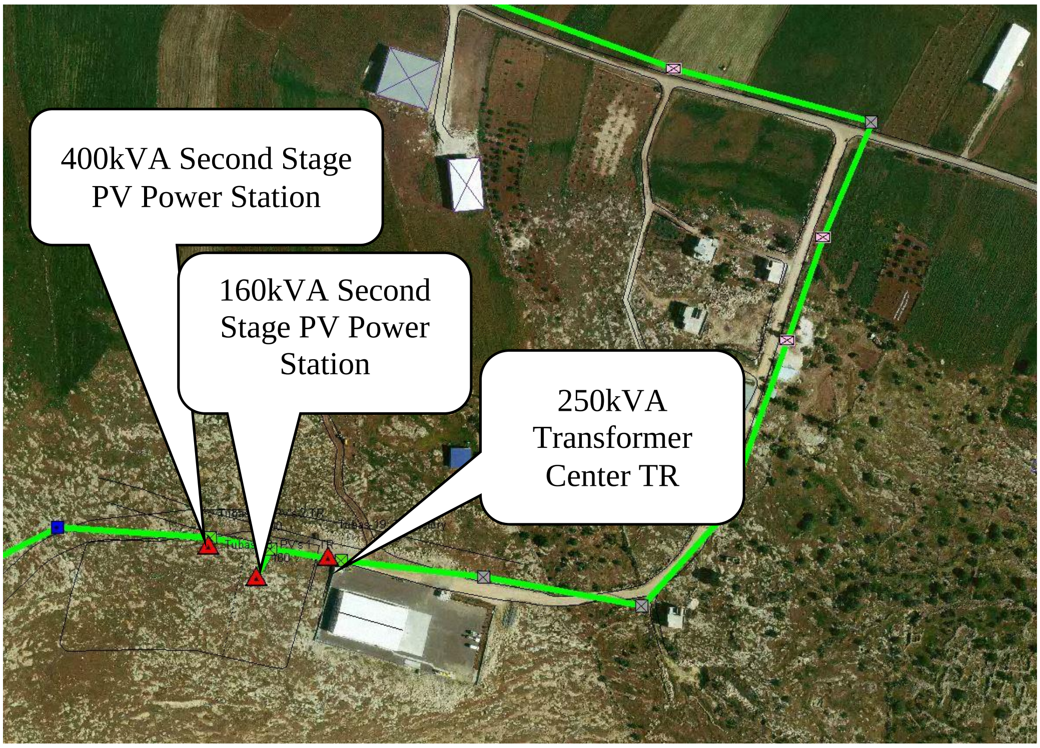


Figure (5.31): MV Grid for PV power Stations and Czech Transformer Center

Appendix F.14 shows the main item that should be considered in evaluating MV transformers

The transformer complies with all requirements but the losses and the feasibility study of replacing these transformers will be discussed on section 7.2.

5.14. Safety, Labeling and Identification

We should draw attention to the safety requirements that recognizes hazards in order to achieve an acceptable level of risk. The label is a piece of paper, plastic film or metal used to clearly identify assets for maintenance and operational purposes that indicate clearly electrical installation has multiple supplies and which circuits are affected by these supplies. Appendix F.15 that shows some items to achieve good safety in PV stations and other labeling issues and it shows either these items are available in this PV station or not.

Note: some of these items are adopted from Australian Standards according [18], American standards according to [17] and others from our practice and local code.

The following main modifications should be done:

1. Dual supply warning labels should be fitted at point of interconnection
2. The fence and doors should be connected to grounding manholes
3. Installing warning signs with yellow triangular stating "**Electrical Danger**" should be fixed on fence every 5-10meter
4. Labels on DC cable stating 'PV array cable- live during daylight' should be fixed every 5-10 m
5. Installing the number of strings and inverter on DC cable at the beginning, the end, each cable joint and every 5-10 meter
6. Installing the number of inverters and distribution on AC cable at the beginning, the end, each cable joint and every 5-10 meter
7. Installing two caution signs on ABB enclosure stating on the first is "**Warning Dual Supply**, isolate both normal supply from MDB and solar supplies from DC isolator switch at the bottom of ABB enclosure and all string fuses before working on this electrical board", and the second is “active parts inside the boxes are fed from a PV array and may still be live after isolation from the PV inverter and public supply “
8. Labels for Inverter protection settings shall be installed

9. Installing ground fault protection label stating "**Warning Electric Shock Hazard**, if a ground fault is indicated normally grounded conductors maybe ungrounded and energized "
10. Providing Fire extinguishers on the site and fixing it in clear locations.

5.15. Power Factor Correction

In general, PV power station decreases the power factor at connection point because the real power is supplied from this station, counter to the reactive power that still supplied from the grid. To mitigate this problem TDECO require any PV power station should be operated at power factor control mode to maintain power factor within accepted range to IECo, which force PF penalties for less than 0.9 power factor. This mitigation can be done by two ways:

1. Decreasing power factor from inverter setting, that could be decreased the real power generated from PV station; so decreasing the income.
2. Installing external capacitor bank on the PV station connection point.

This section discusses the second way of power factor correction, which comply with TDECO and PETEL power factor instructions. The penalties forced for any PV power station that have 0.9 power factor or more. Nevertheless, according to [19] the method of control and deployment of the reactive capability shall be determined by the system impact studies that shall be done according to the Palestinian grid code, which is not established yet. The reactive support must be dynamic in nature unless otherwise specified in the system impact study results and project connection agreement.

This PV power station operates at unity power factor now, Figure (5.32) and Equation 5. 16 determine the capacitor bank capacity that should be installed at the connection point to maintain the power factor within accepted range.

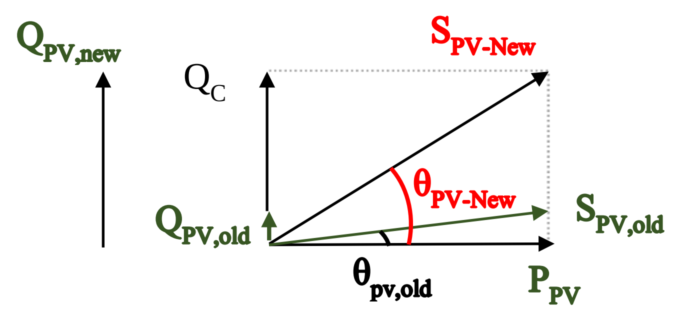


Figure (5.32): Phasor Diagram for Correcting Power Factor

Where,

P_{pv}: Active power generated from PV system

$Q_{pv,old}$: Reactive power produced from the PV system before installing capacitor bank; assume it has small magnitude.

Q_{pvnew}: Reactive power produced from the PV system after installing capacitor bank.

Q_c: Reactive power produced from the installed capacitor bank.

S_{old} : Apparent power before installing capacitor bank.

S_{new} : Apparent power after installing capacitor bank.

$\theta_{pv,old}$: The angle between the real and reactive power before installing capacitor bank.

$\theta_{pv,new}$: The angle between the real and reactive power after installing capacitor bank.

We find from the above phasor diagram that reactive power should be added to the PV system in order to correct the total power factor.

$$\tan\theta_{PV,old} = \frac{Q_{PV,old}}{P_{PV}} \tag{5.38}$$

Likewise,

$$\tan\theta_{PV,new} = \frac{Q_{PV,new}}{P_{PV}}$$

But,

$$Q_{PV,new} = Q_{PV,old} + Q_c$$

Therefore,

$$P_{PV} * \tan\theta_{PV,new} = Q_{PV,old} + Q_c$$

$$P_{PV} * \tan\theta_{PV,new} = \left(P_{PV} * \tan\theta_{PV,old}\right) + Q_c$$

So,

$$Q_C = P_{PV}\left(\tan\theta_{new} - \tan\theta_{old}\right) \tag{5.39}$$

There are three choices to install this capacitor bank:

1. Installing fixed capacitor during the complete day and variable with months.
2. Installing fixed capacitor during the day time and variable with months
3. Installing a variable capacitor, which proportion the PV energy production.

The best choice is the third one, because the reactive power production fits to the grid needed, but it will not discussed now; because it needs very complicated technology, which is not available in the local market.

The chosen one of the remaining choices needs good understanding of the TDECO power factor grid profile shown in Figure (5.33).

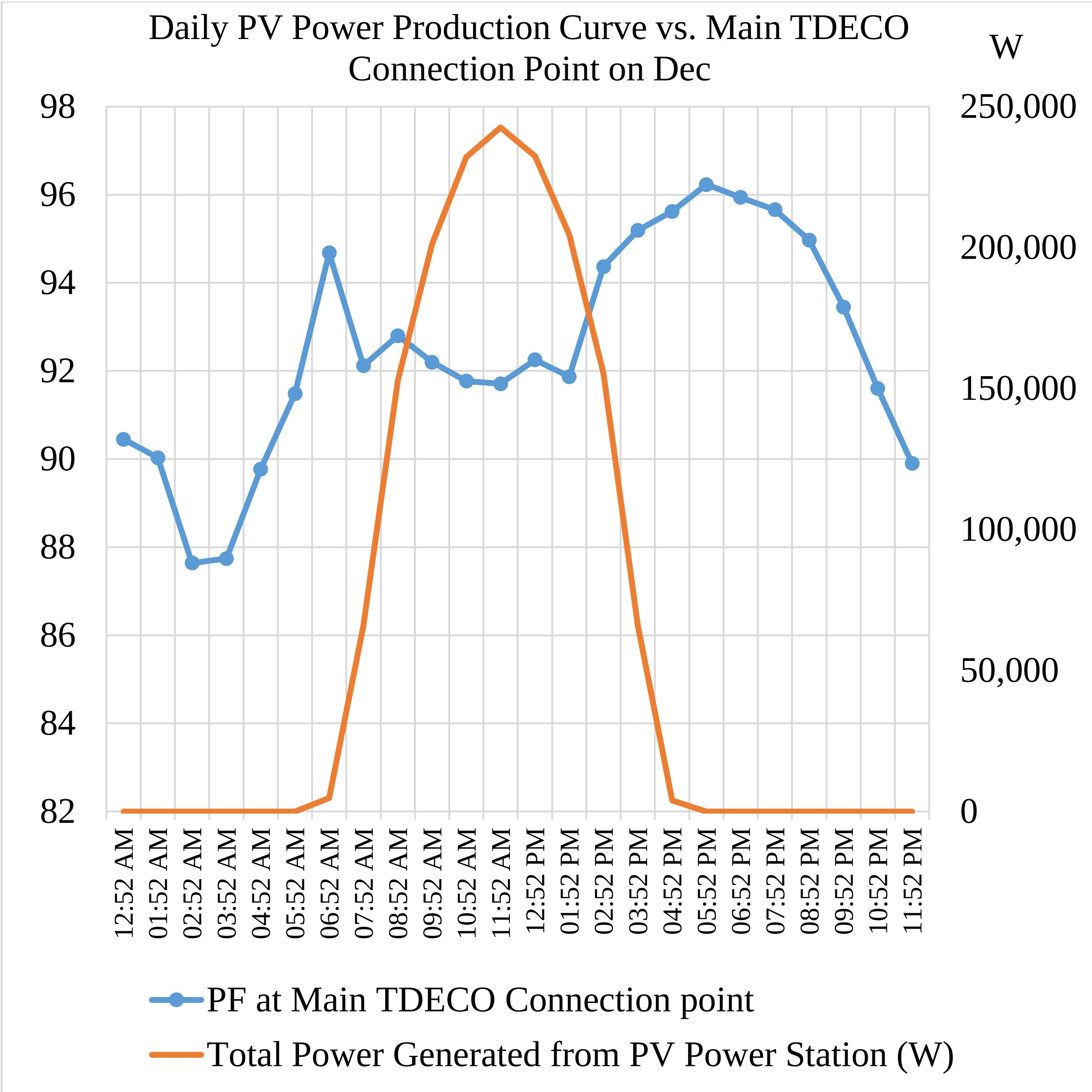


Figure (5.33): Daily PV Power Production Curve vs. Main TDECO Connection Point on Dec.

Figure (5.33) shows the power factor at TDECO/ IECo connection point during the day Dec, 10th.2017and the total power generated from PV power station during the same day. It is clear, the power factor decreased during the daytime and increases at night.

1. Installing Fixed Capacitor During the Complete Day and Variable with Months.

This choice finds the capacitor bank capacity needed to remain the power factor during less than 0.9 during the months that will be operated 24h.

Table (5.13) and Figure (5.34) show the monthly-expected PV power station energy production, number of days per month, the monthly reactive power needed to achieve 0.9 power factor that calculated according to Equation 5.38. The installed capacity of capacitor bank that calculated according to Equation 5.39, the capacity of capacitor bank available on local market and the expected new power factor after installing the capacitor bank.

Table (5.13): Fixed Capacitor Bank Calculations on 24h

Months	Days per Month	Monthly Expected PV Station Energy Production (kWh)	Monthly Reactive power needed (kVArh)	Capacity of the Capacitor Bank (kVAr)	Capacitor needed from Market	Monthly Reactive power Generated from Installed Capacitors (kVArh)	Power Factor After Adding Capacitor Bank
Jan	31	34,878	16,892	23	25kVAr	18600	0.88
Feb	29	46,120	22,337	32	25kVAr+ 10kVAr	24360	0.88
Mar	31	50,640	24,526	33	25kVAr+ 10kVAr	26040	0.89
Apr	30	60,852	29,472	41	20kVAr+ 25kVAr	32400	0.88
May	31	62,917	30,472	41	20kVAr+ 25kVAr	33480	0.88
Jun	30	63,482	30,746	43	20kVAr+ 25kVAr	32400	0.89
Jul	31	61,689	29,877	40	20kVAr+ 25kVAr	33480	0.88
Aug	31	52,589	25,470	34	25kVAr+ 10kVAr	26040	0.90
Sep	30	51,718	25,048	35	25kVAr+ 10kVAr	25200	0.90
Oct	31	51,830	25,102	34	25kVAr+ 10kVAr	26040	0.89
Nov	30	41,575	20,136	28	25kVAr+ 10kVAr	25200	0.86
Dec	31	30,739	14,888	20	20kVAr	14880	0.90
Total in 2016	366	609,029	294,966				

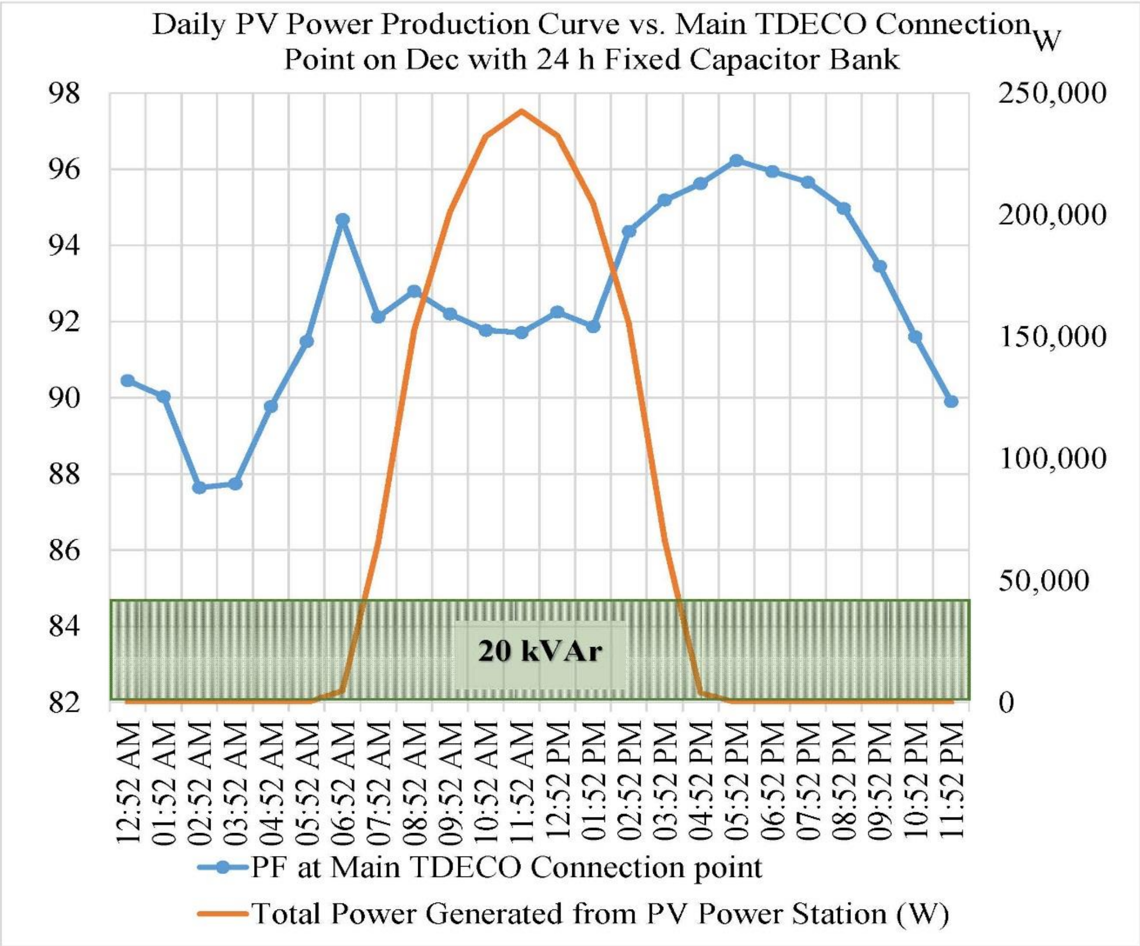


Figure (5.34): Daily PV Power Production Curve vs. Main TDECO Connection Point on Dec with 24 h Fixed Capacitor Bank

This solution costs 4943NIS that needs three types of capacitor bank with rated capacity 10kVAr, 20 kVAr and 25 kVAr, which cost 150NIS, 205NIS and 298NIS respectively, controller costs 900 NIS and contactor costs 3390NIS.

This choice is not fit in our case because operating the capacitor bank during the night could increase the power factor too much.

2. Installing Fixed Capacitor During the Day Time and Variable with Months

This choice finds the capacitor bank capacity needed to remain the power factor during less than 0.9 during the months that will be energized during the daytime only.

Table (5.14) and Figure (5.35) show the monthly expected PV power station energy production, number of days per month, number of daytime hours during the day, the monthly reactive power needed to achieve 0.9 power factor calculated according to Equation 5.38, the installed capacity of capacitor bank calculated according to Equation 5.39. The capacity of capacitor bank available on the local market and the expected new power factor after installing the capacitor bank.

Table (5.14): Daily PV Power Production Curve vs. Main TDECO Connection Point in Dec with Daytime Fixed Capacitor Bank

Months	Days per Month	Day Time (td)	Monthly Expected PV Station Energy Production (kWh)	Monthly Reactive power needed (kVArh)	Capacity of the Capacitor Bank (kVAr)	Capacitor needed from Market	Monthly Reactive power Generated from Installed Capacitors (kVArh)	Power Factor After Adding Capacitor Bank
Jan	31	10:30	34,878	16,892	52	50kVAr	16275	0.91
Feb	29	11:00	46,120	22,337	70	50kVAr+20kVAr	22330	0.90
Mar	31	12:00	50,640	24,526	66	50kVAr+20kVAr	26040	0.89
Apr	30	12:45	60,852	29,472	77	50kVAr+20kVAr+ 10kVAr	30600	0.89
May	31	14:00	62,917	30,472	70	50kVAr+20kVAr	30380	0.90
Jun	30	14:30	63,482	30,746	71	50kVAr+20kVAr	30450	0.90
Jul	31	14:30	61,689	29,877	66	50kVAr+20kVAr	31465	0.89
Aug	31	14:15	52,589	25,470	58	50kVAr+10kVAr	26505	0.89
Sep	30	13:00	51,718	25,048	64	50kVAr+20kVAr	27300	0.88
Oct	31	12:15	51,830	25,102	66	50kVAr+20kVAr	26582 .5	0.89
Nov	30	11:00	41,575	20,136	61	50kVAr+10kVAr	19800	0.90
Dec	31	10:15	30,739	14,888	47	50kVAr	15887 .5	0.89
Total in 2016	36 6		609,02 9	294,96 6				

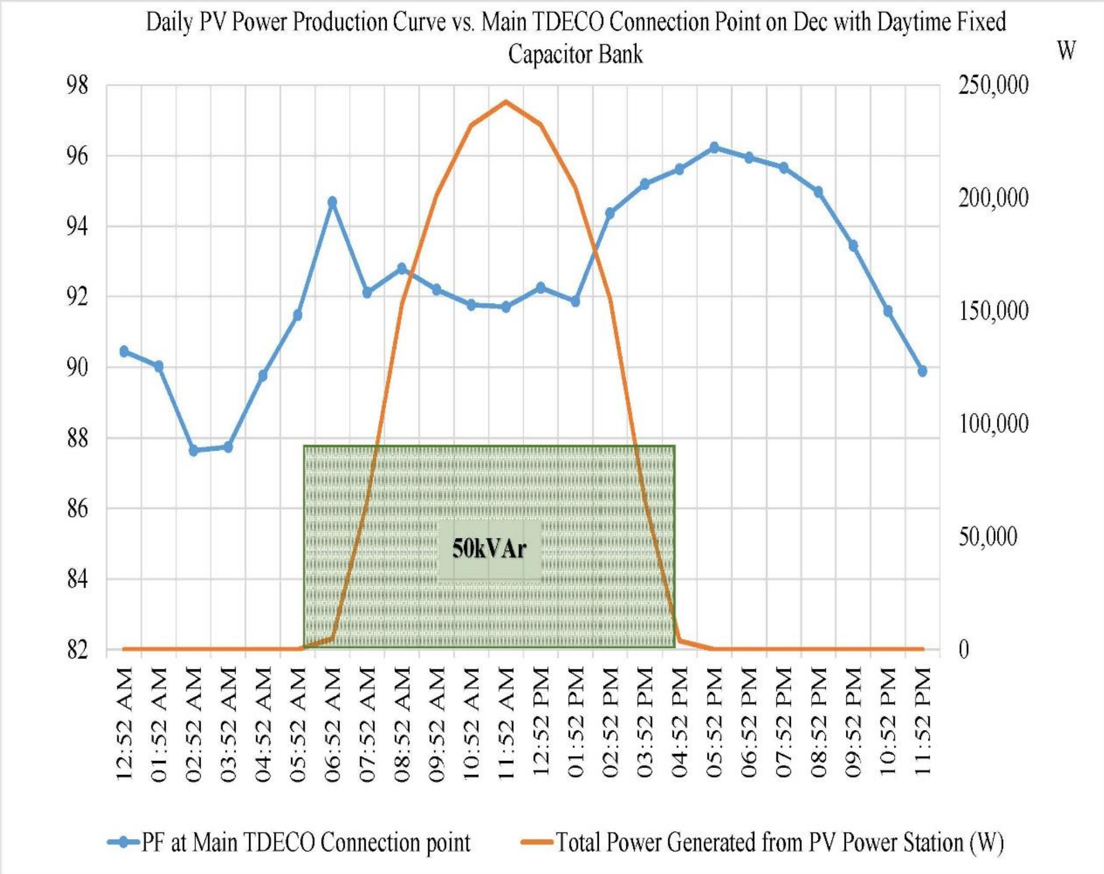


Figure (5.35): Daily PV Power Production Curve vs. Main TDECO Connection Point on Dec with Daytime Fixed Capacitor Bank

This solution costs 5985 NIS that needs three types of capacitor bank with rated capacity 20 kVAr, 25 kVAr and 50 kVAr, which cost 205NIS, 289NISand 1192NIS respectively, controller costs 900 NIS and contactor costs 3390NIS.

This choice is more suitable in our case because the capacitor bank will not be operated during the night; so no increasing of the power factor at night.

The feasibility of installing capacitor bank according to this case will be discussed in section 7.4.

5.16. On Site Tests

There are many tests that should be done for PV station some of them checked before first operation(like visual inspection, grounding test, cable insulation test, open circuit test and polarity testing), and others after operation(like functional test, operational circuit test, short circuit test, thermo imaging test, continuity test and performance test). All of these tests summarizes common types of testing conducted on PV systems that are discussed in this section

5.16.1. Before Operation Tests

There are several types of tests; one of them is visual and the others are electrical tests conducted on PV systems that are used to verify system installation quality and performance.

Many of these electrical tests can be conducted with common electrical test equipment like digital multi-meter, while some measurements require special meters and instruments like (insulation tester (Mega-ohmmeter) and earthing tester).

1) Visual Inspection

Visual inspections of PV systems should be performed as part of commissioning and routinely over the system lifetime to verify and ensure that the system remains in a safe and properly functioning condition. Table (5.15) shows the checklist that shall be achieved in this test.

Table (5.15): Visual Inspection

	Inspection Point	Available or Not	Note
A	Visual inspections :		
A.1	Are PV module checklist completed as seen in Appendix F.2?	Yes	
A.2	Are inverter checklist completed as seen in Appendix F.3?	Yes	
A.3	Are electrical protection system checklist completed as seen in Appendix F.5?	No	
A.4	Are grounding system checklist completed as seen in Appendix F.6?	No	
A.5	Are lightning protection system checklist completed as seen in Appendix F.7?	No	
A.6	Are mounting structure checklist completed as seen in Appendix F.8?	No	
A.7	Are monitoring system checklist completed as seen in Appendix F.9?	Yes	
A.8	Are cables checklist completed as seen in Appendix F.11 and F.12?	No	
A.9	Are weather station checklist completed as seen in Appendix F.10?	Yes	
A.10	Are metering system checklist completed as seen in Appendix F.13?	No	
A.11	Are transformer checklist completed as seen in Appendix F.14?	Yes	
A.12	Are safety, labeling and identification checklist completed as seen in Appendix F.15?	No	

2) Grounding and Continuity Tests

Proper grounding of PV systems reduces the risk of electrical shock to personnel and the effects of lightning and surges on equipment.

This test is essential to ensure safe operating standards, verifies the integrity of grounding and bonding systems, conductors, connections and other terminations. There is not one standard ground resistance threshold that is recognized by all agencies; ideally, a ground should be of zero ohms resistance. However, the (National Fire Protection Association) NFPA and (Institute of Electrical and Electronics Engineers) IEEE have recommended a ground resistance value of 5.0 ohms or less, while TDECO have recommended ground of PV power station 3 ohms or less and the ground of lightening arrestors 7 ohms or less. Table (5.16) shows the ground site test that is inspected by using earthing tester. The grounding resistance of the all system is less than the two manholes grounding resistance that refers to the connection between the support structure and the steel bars inside the concrete bases are supported the total grounding resistance.

Table (5.16): Grounding on Site Tests

	Value (Ohms)	Accepted Range	Notes
PV Station Grounding System			
Grounding of all system	2.9	Less than 3 ohms	Pass
Manhole 1:			
Grounding of electrodes only	21	Less than 5 ohms	Failed
Manhole 2:			
Grounding of electrodes only	18.5	Less than 5 ohms	Failed
Manhole 3:			
Grounding of electrodes only	17	Less than 5 ohms	Failed
Lightening System Grounding			
Grounding of electrodes only	11.3	Less than 7 ohms	Failed
Grounding of all system	11.3	Less than 7 ohms	Failed

Continuity testing is commonly used to verify grounding and bonding connections in electrical systems. These tests also verify the proper operation of disconnecting means and the function of overcurrent protection devices like fuses and circuit breakers. Table (5.17) shows the continuity on site test that is inspected by using digital multi-meter.

Table (5.17): Continuity on Site Test

Inspection Point	Result	Accepted Range	Notes
Are there electrical connection between PV station grounding system and lightning grounding system?	No	No electrical connection	Pass
Are there electrical connection between PV station grounding system and TDECO grid grounding system?	No	No electrical connection	Pass
Are there electrical connection between PV station grounding system and TDECO grid neutral?	No	No electrical connection	Pass
Are there electrical connection between lightning grounding system and TDECO grid grounding system?	No	No electrical connection	Pass
Are there electrical connection between lightning grounding system and TDECO grid neutral?	No	No electrical connection	Pass

3) Cable Insulation Resistance Test

This is mandatory test; wiring and equipment integrity should verify that to detect faults and degradation or damage in insulation of wiring within PV arrays and other system circuits.

Compared to conductors that have very low resistance in the order of a few ohms or less, insulators have very high resistance measured in Mega-ohms (MΩ). The higher its resistance value, the better the conductor insulating quality.

Insulation resistance tests are recommended on a 3-year maintenance interval, or more frequently as circumstances dictate.

Insulation resistance is measured between the conductors under test and ground, or between other conductors. Insulation resistance and leakage current testing are used to verify the integrity of the following PV system circuits and components:

- Verifying integrity of PV modules and array source and output circuit conductors.
- Measuring the leakage current through overcurrent and disconnect devices, including fuses, switches and circuit breakers.
- Measuring the insulation resistance for any equipment with windings, such as motors, generators, transformers and inductors.
- Testing the grounding electrode resistance.

Insulation resistance testing is commonly measured with a Mega-ohmmeter A Mega-ohmmeter is a special type of ohmmeter that measures very high values of resistance by applying high-test voltages between conductors and measuring the leakage current.

Insulation tests may be performed using either of the following two methods:

1. Between the positive DC conductor and ground, and between the negative DC conductor and ground.
2. Between the shorted positive and negative DC conductors and ground..

The IEC 62446 standard recommends 0.5 MΩ as an acceptable minimum insulation resistance value for PV arrays operating at less than 120 V.

For system voltages higher than 120 V, 1 MΩ or higher is considered acceptable [20]. Table (5.18) shows the onsite test of DC cables insulation test for this PV power station and Table (5.19) shows the AC cables insulation test.

Table (5.18): DC Cables Insulation Test

Inverter No.	Testing Value (MΩ) String 1 +ve	Testing Value (MΩ) String 2+ve	Testing Value (MΩ) String 3+ve	Testing Value (MΩ) String 4+ve	Testing Value (MΩ) String 5+ve	Testing Value (MΩ) String 6+ve	Accepted Range (MΩ)	Notes and Recommendation
1	1.94	1.97	1.92	1.94			1	Pass
2	1.93	1.9	1.92	1.93	1.93	1.9	1	Pass
3	1.91	1.88	1.9	1.92	1.91	1.88	1	Pass
4	1.93	1.88	1.91	1.92	1.93	1.88	1	Pass
5	1.93	1.92	1.93	1.94	1.93	1.92	1	Pass
6	1.93	1.85	1.9	1.92	1.93	1.85	1	Pass
7	1.93	1.88	1.92	1.94	1.93	1.88	1	Pass
8	1.93	1.86	1.91	1.92	1.93	1.86	1	Pass
9	1.91	1.83	1.94	1.86	1.91	1.83	1	Pass
10	1.93	1.91	1.92	1.93	1.93	1.91	1	Pass
11	1.93	1.85	1.91	1.93	1.93	1.85	1	Pass
12	1.93	1.94	1.91	1.93	1.93	1.94	1	Pass

Table (5.19): AC Cables Insulation Test

Inerter No.	Testing Value (MΩ) R	Testing Value (MΩ) S	Testing Value (MΩ) T	Accepted Range (MΩ)	Notes and Recommendation
AC Cables from inverters to MDB					
1	1.83	1.93	1.94	1	Pass
2	1.85	1.93	1.93	1	Pass
3	1.87	1.9	1.91	1	Pass
4	1.87	1.92	1.93	1	Pass
5	1.91	1.92	1.93	1	Pass
6	1.82	1.91	1.93	1	Pass
7	0.86	0.71	0.74	1	Pass
8	1.85	1.91	1.93	1	Pass
9	1.85	1.92	1.91	1	Pass
10	1.81	1.91	1.93	1	Pass
11	1.89	1.92	1.93	1	Pass
12	1.84	1.92	1.93	1	Pass
Main AC Cable from MDB to Transformer					
	1.85	1.91	1.93	1	Pass

All DC and AC cables have very good insulation values except the AC cable from inverter 7 to MDB that has low insulation; the existing joint could be the reason of this result.

4) Open Circuit Voltage Test

Verifies that PV array and system operating parameters are within specifications.

Measured to ensure correct installation and operation of each PV string. Measured values should be compared with expected values. For systems with multiple identical strings, values should be within 5% of other PV strings in array [20].

In March22[th],2016 at 3:15pm the cell temperature was 33.43°C, the strings open circuit voltages are measured by digital multi-meter as shown in Table (5.20) the accepted rage calculated according to Equation5.6.as the following

$V_{OCT,module}$ = 37.7 V*(1+ -0.31%*(33.43°C-25°C))

$V_{OCT,module}$ = 36.71V

$V_{OCT,string}$ = $V_{OCT,module}$ * N_{mod}

$V_{OCT,string}$ =36.71V * 20 modules

$V_{OCT,string}$ = 734.3V

Note: the MPPT1 and MPPT2 inputs hereafter input1 and input2.

From our practice, we finds the accepted open circuit string voltage range is more than -26% of theoretical one, which is 543.38V.

Table (5.20): Open Circuit Voltage on Site Test

Inverter No.	Open Circuit Voltage Input1	Open Circuit Voltage Input2	Accepted Range (MΩ)	Notes and Recommendation
1	703.27	702.2	More than 543.38V	Pass
2	699.58	700.55	More than 543.38V	Pass
3	701.73	703.42	More than 543.38V	Pass
4	705.61	704.22	More than 543.38V	Pass
5	705.11	700.18	More than 543.38V	Pass
6	705.84	703.44	More than 543.38V	Pass
7	702.2	708.38	More than 543.38V	Pass
8	700.55	705.14	More than 543.38V	Pass
9	703.42	705.04	More than 543.38V	Pass
10	704.22	705.21	More than 543.38V	Pass
11	700.18	705.66	More than 543.38V	Pass
12	703.44	702.63	More than 543.38V	Pass

All open circuit voltages are in the accepted range. The variation between the max and min open circuit voltages is about 1.26%, which is acceptable (less than 5%).

5) Polarity Testing

This test is to ensure that all strings and arrays are correctly marked and connected.

Polarity is verified by measuring the voltage on energized circuits, prior to closing disconnects and operating the system for the first time. Most digital multi-meters can be used for this purpose, as well as specialized PV array testing equipment capable of measuring DC voltage over the appropriate range. Electronic meters typically indicate the polarity of DC voltage measurements with a plus (+) or minus (-) symbol on the display, according to the connections of the positive and negative test leads. Analog voltmeters are not used for polarity testing, as the meter movements on these instruments can be damaged by connecting them in reverse polarity.

Polarity should be verified on the following DC components and circuits PV system:

- Photovoltaic modules
- Photovoltaic source circuits
- Photovoltaic output circuits
- Disconnecting means
- Inverter input terminations

Table (5.21) shows the polarity on site test for this PV power station that is inspected by using digital multi-meter.

Table (5.21): Polarity Test

Inverter No.	String 1	String 2	String 3	String 4	String 5	String 6
1	Pass	Pass	Pass	Pass		
2	Pass	Pass	Pass	Pass	Pass	Pass
3	Pass	Pass	Pass	Pass	Pass	Pass
4	Pass	Pass	Pass	Pass	Pass	Pass
5	Pass	Pass	Pass	Pass	Pass	Pass
6	Pass	Pass	Pass	Pass	Pass	Pass
7	Pass	Pass	Pass	Pass	Pass	Pass
8	Pass	Pass	Pass	Pass	Pass	Pass
9	Pass	Pass	Pass	Pass	Pass	Pass
10	Pass	Pass	Pass	Pass	Pass	Pass
11	Pass	Pass	Pass	Pass	Pass	Pass
12	Pass	Pass	Pass	Pass	Pass	Pass

This PV power station passed the polarity test.

5.16.2. After Operation Tests

There are several types of tests; functional test, operational test, short circuit test, thermal imaging and performance test.

Many of these electrical tests can be conducted with common electrical test equipment like digital multi-meter, while some measurements require special meters and instruments like (thermo-graph camera and external shorting device). In these cases, system performance information voltage and current tests are measured, recorded and displayed by monitoring system, and can be used to verify system functions and proper operation.

1) Functional Test

System functional test ensure that the system starts and operates properly, and can be safely disconnected. Among the types of functional tests conducted on PV systems include:

- Verifying the proper operation of disconnecting means and component connection and disconnection sequences.
- Verify that interactive inverters and AC modules de-energize their output to utility grid upon loss of grid voltage. This is a safety requirement to prevent interactive inverters from operating as an islanded electrical system without voltage or frequency control, and preventing them back feeding de-energized electrical systems. These functions are performed internally by all utility-interactive inverters listed according to the IEEE 1547 and UL1741 standards.
- Verify that interactive inverters automatically reconnect to their output to the grid once the voltage has been restored for at least 5 minutes

Table (5.22) shows the results of functional test in this PV power station.

Table (5.22): Functional Test

Inverter No.	Functional Test Results
1	Pass
2	Pass
3	Pass
4	Pass
5	Pass
6	Pass
7	Pass
8	Pass
9	Pass
10	Pass
11	Pass
12	Pass

2) Voltage and Current Tests

Basic voltage and current tests are conducted on both DC and AC circuits in PV systems to verify these parameters are within acceptable limits prior to closing disconnects and beginning system operations.

In March 22th 2016 at 10:15am the cell temperature was 42.27 °C, the strings operating voltages were measured by digital multi-meter as shown in Table (5.23), the accepted range calculated according to Equation 5.6 as the following and Table (5.24) shows the strings DC current

$V_{MPPT,module}$ = 30.4 V*(1+ -0.31%*(42.27 °C-25°C))

$V_{MPPT,module}$ = 28.77V

$V_{MPPT,string}$ = $V_{OCT,module}$ * N_{mod}

$V_{MPPT,string}$ =28.77V * 20 modules

$V_{MPPT,string}$ = 575.45V

From our practice, we find the accepted open circuit string voltage range is more than -10% of theoretical one, which is 517.9V.

Table (5.23): Operating Voltage

Inverter No.	V_{MPPT} at st.1 (V)	V_{MPPT} at st.2 (V)	V_{MPPT} at st.3 (V)	V_{MPPT} at st.4 (V)	V_{MPPT} at st.5 (V)	V_{MPPT} at st.6 (V)	Accepted Range	Note and Recommendations
1	554.01	554.95	547.05	562.9			More than 517.9V	Pass
2	537.76	556.45	550.21	539.3	539.87	539.87	More than 517.9V	Pass
3	539.87	554.01	562.9	537.86	541.99	541.99	More than 517.9V	Pass
4	541.99	537.76	539.3	541.2	547.05	541.76	More than 517.9V	Pass
5	541.76	539.87	537.86	539.87	550.21	547.28	More than 517.9V	Pass
6	547.28	541.99	541.2	541.99	562.9	547.05	More than 517.9V	Pass
7	547.05	541.76	544.64	541.76	539.3	550.21	More than 517.9V	Pass
8	550.21	547.28	545.78	547.28	537.86	562.9	More than 517.9V	Pass
9	562.9	547.05	546.62	541.2	541.2	539.3	More than 517.9V	Pass
10	539.3	550.21	556.03	544.64	544.64	562.9	More than 517.9V	Pass
11	537.86	562.9	554.95	545.78	545.78	539.3	More than 517.9V	Pass
12	541.2	539.3	556.45	546.62	546.62	537.86	More than 517.9V	Pass

Table (5.24): Operational DC Strings Current

Inverter No.	I_{MPPT} at st.1(A)	I_{MPPT} at st.2(A)	I_{MPPT} at st.3(A)	I_{MPPT} at st.4(A)	I_{MPPT} at st.5(A)	I_{MPPT} at st.6(A)
1	3.96	4.01	3.95	4.06		
2	4.00	4.00	4.00	4.10	3.98	3.91
3	3.91	3.91	4.06	3.95	4.03	3.95
4	3.95	3.98	4.07	3.45	4.09	4.00
5	4.00	4.03	4.11	2.98	4.06	4.06
6	4.06	4.09	4.01	3.95	4.10	4.07
7	4.07	4.06	4.00	3.45	4.01	3.45
8	4.11	4.10	3.91	2.98	4.00	2.98
9	4.14	3.95	3.98	3.12	3.91	3.12
10	2.98	3.45	4.03	3.95	3.98	3.95
11	2.99	2.98	4.09	4.00	4.03	4.00
12	3.25	3.12	4.06	4.06	3.91	4.06

3) Short Circuit Test

Short-circuit current tests are conducted at PV string circuits to verify proper readings and that the circuits are clear from major faults.

Similar to the open-circuit voltage tests, these tests are only intended to verify proper system operation, not performance. Suitable test equipment, capable of safely short-circuiting high-voltage DC circuits is required. Most digital multi-meters can measure DC current up to 10 A, but require a suitable shorting device to safely measure the current. Clamp-on ammeters are also available for DC current measurements, and require and external shorting device as well.

Short-circuit current is directly proportional to the solar irradiance incident on the array. Consequently, these tests must be done quickly, under steady clear sky conditions at the same irradiance level. Make sure the array is not shaded or particularly soiled prior to testing. Short-circuit current readings taken under steady conditions should typically be within 5% of each other for acceptance. Unfortunately, we do not have an external shorting device to do this test.

4) Thermal Image Test (Panels, Electrical Panels, Connections)

Infra-Red (IR) thermography is becoming a very popular tool for the evaluation of electrical systems and particularly PV arrays. Thermal imaging can identify hot spots or overheating equipment, thermal gradients within PV arrays, and can help in locating internal problems of PV modules before failure that by using thermal camera. Common problems that can be identified with thermal imaging including bad module connectors, shorted or failing bypass diodes, or module busbar failures. Thermal imaging can also identify bad or loose circuit breakers, fuses, switchgear, connections or other equipment. After testing all PV modules, connections, combiner boxes and MDB in this PV power station, one PV module has hot spot as shown in Figure (5.36).

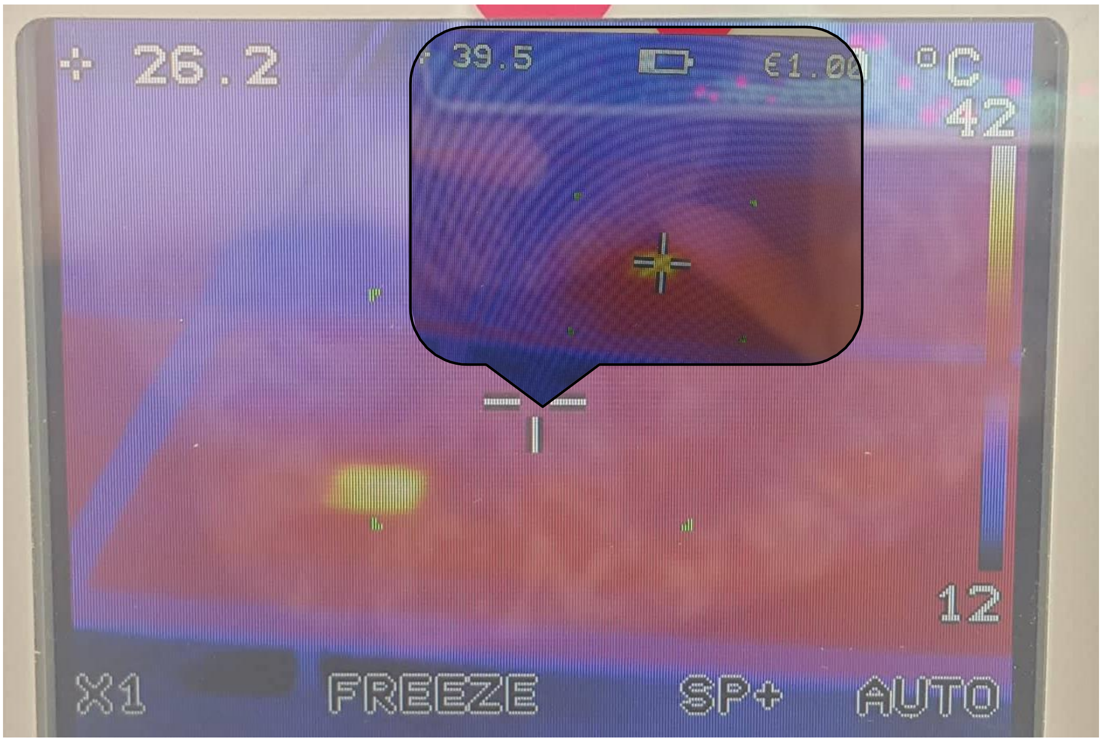


Figure (5.36): Thermal Image for Hot Spot in PV Module in this PV Power Station

5) Performance Test

It verifies the system power and energy output if they are consistent with expectations. These tests also require measurements of array temperature and solar irradiance.

PV systems are designed to produce a specified electrical output under certain operating conditions. Performance testing verifies the system power output and energy production are as expected, based on component and system ratings and the given operating conditions.

Performance data can also help to identify problems requiring service or maintenance, and may also be used for determining system financial revenues and warranty provisions. This is done in section 6.2.

Chapter Six

System Performance

6. System Performance

The system performance is the most important issue in PV power station evaluation. Usually, our main goal is reaching the maximum performance; this is achieved when we understand all factors that could affect by PV system production. This chapter discusses system efficiency and losses, system operational parameters, the energy production actual and expected, irradiance, temperature, dust, number of maximum power point impacts on PV power station.[1]

6.1. System Efficiency and Losses

This PV power station, which is rated at 350kWp produced 574040kWh in 2016 as shown in Table (6.1).

---

[1] All Data were collected on 2016

Table (6.1): Energy Production of the 350kWp PV Power Station in 2016

Time stamp	Generated Energy (kWh)
Jan	27,775
Feb	46,085
Mar	50,631
Apr	60,767
May	62,775
Jun	63,065
Jul	61,205
Aug	49,898
Sep	41,785
Oct	44,182
Nov	37,893
Dec	27,977
Total in 2016	574,040

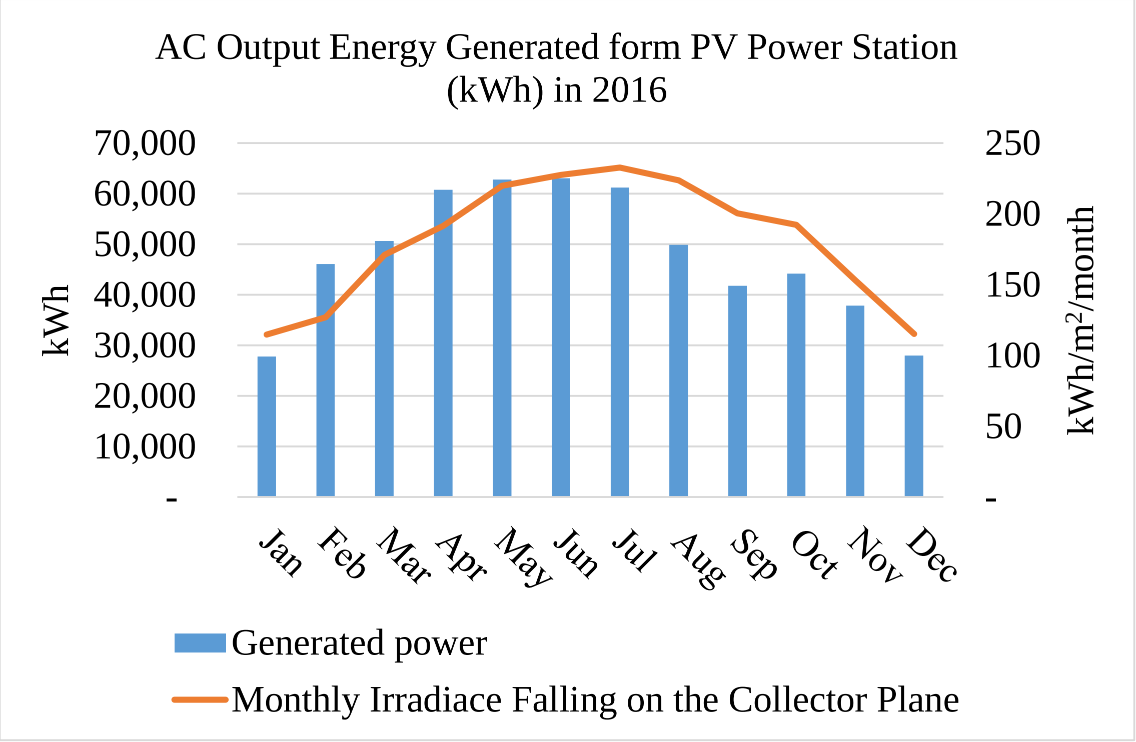


Figure (6.1): AC Output Energy Generated form PV Power Station (kWh) in 2016

Figure (6.1) shows both the solid bars indicates the actual monthly-generated power from this PV power station in 2016 and the line indicates the monthly irradiance falling on the collector plane. We notice two focal points: the energy produced in June is more than in July and in October is more than September; nevertheless, the irradiance falling on the collector plane is vice versa; this happens due to TDECO grid shortage in July and September.

This PV power station has lost the power by two main ways; uncontrollable losses and the PV station equipment losses.

6.1.1. Uncontrollable Losses

These losses don't relate to PV station installation this will be varied from year to another which was two types in this PV power station at 2016.

1. Inverters Faults Losses.

For deferent reasons many inverters in 2016 were disabled as shown in Table (6.2) Inverter 2 was disabled from Oct 10 to Nov 10, 2016. Each of inverter 1,3,4,6 and 8 were not disabled in 2016.

Table (6.2): The Inverter Faults and the Cleaning Period Schedule

	2016											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
inv.1												
inv.2										10	10	
inv.3												
inv.4												
inv.5	8-26								13	8		
inv.6												
inv.7										29		
inv.8												
inv.9	8-26											
inv.10	8-26											13
inv.11	8-26								13	8		
inv.12								17				
Schedule PV station Cleaning											4-8	

The total inverters faults losses in 2016 is 6% according to Equation 6.1.

$$\%\text{Inverter fault loss} = \left(\frac{E_{exp,inv.fault} - E_{PV,AC}}{E_{exp,inv.fault}}\right) * 100\% \qquad (6.1)$$

$E_{PV,AC}$: the annual, monthly or daily actual AC output energy generated form the PV power station (kWh).

$E_{exp,\ inv.\ fault}$: Expected output energy, if there is no inverters faults that calculated by the following:

- All inverters in this PV power station have the same conditions (as inverters specifications, modules specifications, number of modules in series, number of strings, number of MPPT, azimuth and tilt angle) except inverter 1.

- Taking the monthly average production for non-faulted inverters.
- Taking the summation of the monthly average production times seven inverters and the monthly energy production for all non-faulted inverters.

Table (6.3) shows the expected output energy and the inverters faults losses.

Table (6.3): The Inverters Faults Losses in 2016

Time Stamp	Generated Energy (kWh)	Expected Output Energy (kWh)	Losses
Jan	27,775	34,878	20.36%
Feb	46,085	46,120	0.08%
Mar	50,631	50,640	0.02%
Apr	60,767	60,852	0.14%
May	62,775	62,917	0.23%
Jun	63,065	63,482	0.66%
Jul	61,205	61,689	0.79%
Aug	49,898	52,589	5.12%
Sep	41,785	51,718	19.21%
Oct	44,182	51,830	14.76%
Nov	37,893	41,575	8.86%
Dec	27,977	30,739	8.98%
Total in 2016	574,040	609,030	5.75%

2. TDECO Grid Shortage.

In 2016, the TDECOs' load demand was more than the installed capacity of connection point and no extra power was available from IECo especially in July, August and September. Therefore, TDECO was obliged to cutoff electricity with scheduled program as load management, which affected the PV power station production. The down time in this PV power station reached 123 hours and 45 minute, which corresponds to about 8497kWh (3052NIS)lost and to 1.4% energy lost in that year.

Table (6.4): Uncontrollable Losses Summery

Time Stamp	Total Losses in Percent	Total Losses in kWh	Total Losses in NIS [1]
Inverter Faults Losses in 2016	5.75%	34,990	12,568
TDECO grid shortage	1.40%	8,497	3,052
Total losses	7.14%	43,487	15,621

Table (6.4) shows the total uncontrollable energy losses in 2016. It was 43487kWh, which is about 15621 NIS.

6.1.2. PV Station Equipment Efficiency and Losses

This type of losses depends on PV power station equipment. It will be approximately fixed[2] along project lifetime.

Figure (6.2) point out all-important symbols and energy shortcuts in this PV power station, which shows the energy flow from input solar irradiance energy ($E_{solar,T}$) up to the output energy from the PV power station (E_{meter}).

[1] IECo tariff in 2016 was 0.3592NIS/kWh
[2] There are degradation in equipment for example PV modules power production reach 80% after 25years

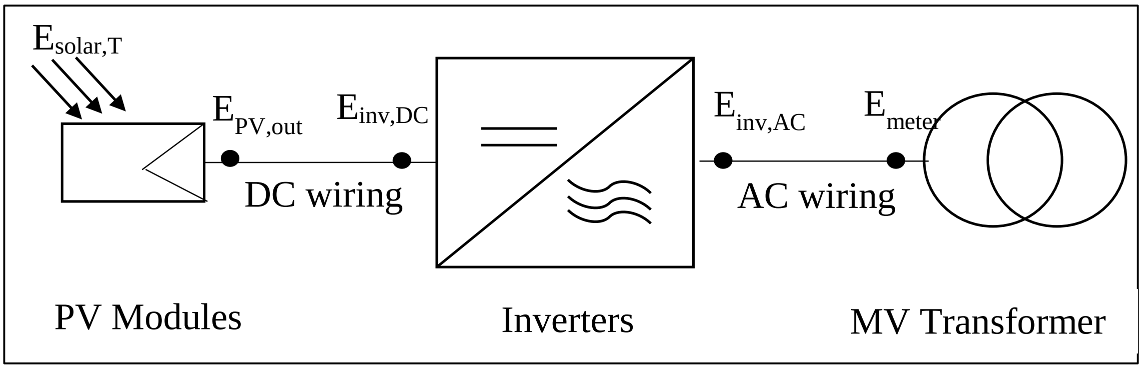


Figure (6.2): Illustration Figure Locates and Defines Energy Shortcuts

Where,

$E_{solar,T}$: Total energy on tilted plane of array (POA)(kWh).

$E_{pv,out}$: Total energy produced by the PV generator (kWh).

E_{meter}: Total Energy measured from PV power station by metering (kWh).

Following items' efficiency and losses will be determined of this PV power station:

1. Inverter.

A. <u>Efficiency</u>

The actual annual inverter efficiency in 2016 was 96.23%, as calculated in section 5.3.4. Nevertheless, the monthly inverter efficiency is included in total PV station equipment efficiency.

B. <u>Losses</u>

The actual annual inverter losses in 2016 is obtained according to Equation 6.2.

$$E_{inv,losses} = E_{inv,DC} - E_{inv,AC} \quad (6.2)$$

Where,

$E_{inv,losses}$: The energy lost from inverters (kWh)

$E_{inv,losses}$ = 596508kWh- 574040 kWh

$E_{inv,losses}$ =22468kWh

2. DC Wiring.

A. Efficiency

DC wiring losses includes the DC cable losses and the MC4 connections losses, the DC cable losses is 1.203kW, and the overall theoretical efficiency is 99.66%, which is calculated previously in section 5.11.1

B. Losses

For finding the actual energy lost in DC cables and referring to Figure (6.2)

$$E_{DC\ cable,losses} = E_{PV,out} - E_{inv,DC} \quad (6.3)$$

Where,

$E_{DCcable,\ losses}$: The energy lost in DC cables (kWh).

$$E_{PV,out} = \frac{E_{inv,DC}}{\eta_{DC,cable}} \quad (6.4)$$

Then,

$$E_{DCcable,losses} = \frac{E_{inv,DC}}{\eta_{DC,cable}} - E_{inv,DC}$$

Therefore,

$$E_{DC\ cable,losses} = E_{inv,DC} * \left(\frac{1-\eta_{DC,cable}}{\eta_{DC,cable}}\right) \quad (6.5)$$

$E_{DC\ cable,\ losses}$ =596508 *((1-0.9966)/0.9966)

$E_{DC\ cable,\ losses}$ = 2035kWh in 2016

3. PV module.

A. Losses

The PV module losses is varied according to the temperature and solar irradiance, that cannot be determined exactly from available data but it is included with the shading losses, it is calculated by Equation 6.6.

$$E_{PV,losses} = E_{solar,T} - E_{PV,out} \quad (6.6)$$

Where,

$E_{PV,losses}$: the shading and PV module losses (kWh).

Then, from Equation 6.4.

$E_{PV,out}$ = 596508kWh/0.9966

$E_{PV,out}$ =598543 kWh

Therefore;

$E_{PV,losses}$ = 4435087kWh - 598543kWh

$E_{PV,losses}$ = 3836544kWh

B. Efficiency

The PV module efficacy at STC is 15.5%, but the actual PV module efficiency will be calculated by Equation 6.7 that includes the shading losses

$$\eta_{PV,actual} = \frac{E_{PV,out}}{E_{solar,T}} * 100\% \quad (6.7)$$

Where,

$\eta_{PV.\ actual}$: The actual efficiency of PV modules including shading effect.

$\eta_{PV.\ actual}$= (598543 kWh /4435087 kWh)*100%

$\eta_{PV.\ actual}$= 13.5%

4. AC wiring

AC wiring losses includes the AC cable losses, bonding, connections and joints losses, the theoretical AC cable losses is 9.136kW, and the theoretical overall efficiency at rated is 97.39%, as is calculated previously in section 5.11.25.11.2. The actual overall AC wiring losses and efficiency in the station are disused hereafter.

A. Losses

Equation 6.8 finds the overall AC wiring losses in 2016, which includes the metering measuring accuracy.

$$E_{AC\ cable\ ,losses} = E_{inv,AC} - E_{meter} \tag{6.8}$$

Where,

$E_{AC\ cable,\ losses}$: The energy lost from all AC wiring system (kWh).

$E_{AC\ cable,\ losses}$=574040kWh - 529565kWh

$E_{AC\ cable,\ losses}$= 44475 kWh.

B. Efficiency

Equation 6.9 calculates the overall AC wiring efficiency in 2016

$$\eta_{AC\ cable,actual} = \frac{E_{meter}}{E_{inv,AC}} * 100\% \tag{6.9}$$

Where,

$\eta_{AC\ cable,\ actual}$: The actual overall AC wiring efficiency.

$\eta_{AC\ cable,\ actual}$= (529565kWh/ 574040kWh) *100%

$\eta_{AC\ cable,\ actual}$= 92.25%.

Note: The overall DC and AC losses vary according to the temperature and currents flow in theses cables which proportionally vary with solar irradiance; therefore, the DC and AC wiring monthly efficiency cannot be determined exactly from the available data but it is included in total PV station equipment monthly efficiency.

5. Shading Losses.

The actual shading efficiency and losses cannot be determined exactly from available data but it is included in PV modules efficiency and losses.

6. Transformer Efficiency.

The MV transformer efficiency cannot be determined from the available data and it is not included in total monthly, annually PV station equipment efficiency and losses.

6.1.3. Monthly and Annual Efficiency and Losses of PV System Equipment Summery

1. Annual Losses and Efficiency Summery

Some of input energy will be lost as calculated previously. Table (6.5)[1] and Figure (6.3) show the summery of energy lost, energy injected, and losses in percent and efficiency in percent for each stage.

[1] This table includes inverter faults losses

Table (6.5): Equipment Summery Losses and Efficiency

Equipment	Energy Losses (kWh)	Energy Losses (NIS)	Energy Losses (%)	Actual Efficiency [1] (%)	Energy Injected (kWh)
PV losses with shading	3,836,544	1,378,087	86.50%	13.50%	4,435,087
DC cable	2035	731	0.34%	99.66%	598,543
Inverter	22,468	8,071	3.77%	96.23%	596,508
AC cable	44,475	15,975	7.75%	92.25%	574,040
Meter	NA	NA	NA	NA	529,565

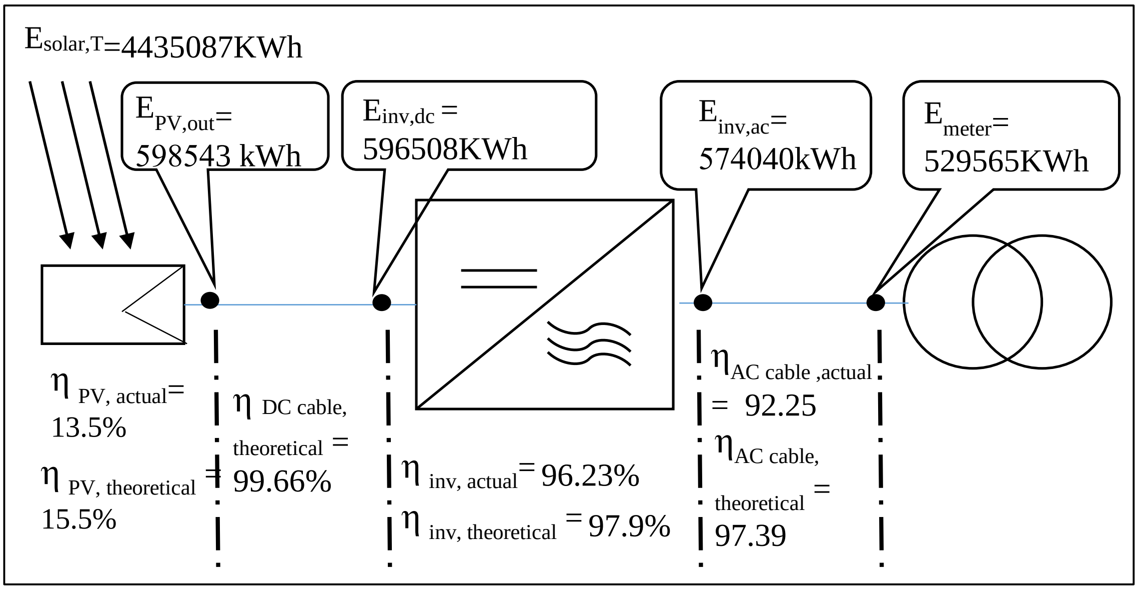


Figure (6.3): Total PV Station Equipment Efficiency and Energy Flow Summery Figure

The input energy from solar irradiance is 4435087kWh and the total output power from this PV power station is 529565kWh, the maximum losses were on PV modules then in AC wiring.

The actual total losses of PV power station in 2016 including all uncontrollable losses and all PV equipment losses except transformer losses determined with Equation 6.10

[1] This efficiency includes uncontrollable efficiency.

$$\eta_{overall} = \frac{E_{meter}}{E_{solar,T}} * 100\% \quad (6.10)$$

Where,

$\eta_{overall}$:The actual PV power station overall efficiency except transformer.

$\eta_{overall}$= 11.94%.

In ideal case, if the PV station equipment efficiency were 100%, the total money would be saved 1402864NIS per year.

2. Monthly losses and efficiency summery

From the available data, the monthly efficiency can be determined using Equation 6.11 and its results are shown in Table (6.6) that includes all equipment losses except transformer and AC cables.

$$\eta_{sys} = \frac{E_{Solar,T}}{E_{inv,AC}} * 100\% \quad (6.11)$$

Where,

η_{sys}: The overall efficiency of this PV station equipment except transformer and AC cables.

Table (6.6): Total PV Station Equipment Efficiency with and without Inverters Faults

Time Stamp	Total PV Station Equipment Efficiency with Inverters Fault	Total PV Station Equipment Efficiency without Inverters Fault
Jan	11.83%	12.86%
Feb	14.75%	14.76%
Mar	14.49%	14.49%
Apr	14.52%	14.54%
May	13.96%	13.99%
Jun	13.56%	13.65%
Jul	12.86%	12.96%
Aug	10.91%	11.49%
Sep	10.20%	12.63%
Oct	11.24%	13.18%
Nov	12.09%	13.27%
Dec	11.87%	13.04%
Total efficiency in 2016 without transformer and AC cables	12.94%	13.73%

Therefore, the overall efficiency of this PV station equipment except transformer and AC cables without inverters fault is 13.73% while its efficiency with inverters fault is 12.94%.

3. Daily Efficiency Summery

The daily measurements of actual power production of this PV station, for a typical clear day of each month performed on hourly basis, are shown Appendix E.6.

Table (6.7) shows that the maximum power produced from PV power station at noon of the selected days for each months over the peak power of this PV power station. This shows that the maximum was 87% in April and the minimum was 65% in September.

Table (6.7): PV Power Station Efficiency at the Daily Maximum Power Production

Month	Day Time	Actual Total AC power of Inverters at Solar Noon (W)	Max. Power Produced Over the Peak Power of PV Station
Jan	06/01/2016 11:00	254,097	73%
Feb	04/02/2016 11:00	294,382	84%
Mar	01/03/2016 11:00	301,885	86%
Apr	01/04/2016 12:00	305,871	87%
May	11/05/2016 12:00	287,566	82%
Jun	01/06/2016 12:00	270,562	77%
Jul	01/07/2016 12:00	273,902	78%
Aug	03/08/2016 12:00	253,304	72%
Sep	01/09/2016 12:00	229,196	65%
Oct	09/10/2016 11:00	237,444	68%
Nov	03/11/2016 11:00	236,032	67%
Dec	09/12/2016 11:00	242,547	69%

6.2. System Operational Performance

The operational performance of a PV plant may be quantified according to the followings:

6.2.1. Performance Ratio

The Performance Ratio (PR) is a parameter to quantify the PV power station performance in (%). The PR provides a benchmark to compare plants over a given time independent of plant capacity or solar resource [7]. The closer to 100%, the PV power station is better performing.

The PR quantifies the overall effect of system losses on the rated capacity, including losses caused by modules, temperature, low light efficiency reduction, inverters, cabling, shading and soiling.

The PR is defined as the ratio between the actual AC energy yield and the theoretical yield that would be generated by the plant if the modules would convert the irradiation received into energy according to their rated peak capacity, that calculated by Equation 6.12 according to [21].

$$PR = \frac{Y_F}{Y_R} \tag{6.12}$$

Where,

PR: Performance ratio (%).

Y_F: Final yield according to Equation 6.13.

Y_R: Reference yield according to Equation 6.14.

$$Y_F = \frac{E_{PV,AC}}{P_{PV@STC} * PSH} \tag{6.13}$$

Where,

$E_{PV,\,AC}$: The annual, monthly or daily AC output energy generated form PV power station (kWh)

$P_{PV@STC}$: Installed capacity of PV power station at STC (kWp)

PSH: Peak sun hours (h)

$$Y_R = \frac{G_T}{G_0 * PSH} \tag{6.14}$$

Where,

G_T= Total irradiance on tilted plane (kWh/m^2).

G_o= Global irradiance at STC (W/m^2).

Therefore, the actual annul PR in 2016 with inverter shutdown is

$PR_{annual, actual}$= (574040kWh*1kW/m^2)/ (350kW*2169.57 kWh/m2)

$PR_{annual, actual}$= 75.6%.

Nevertheless, the proposed annul PR in 2016 without inverter shutdown is

$PR_{annual, expected}$= 80.2%.

Both actual and expected PR are less than the common annual average PR of 82 % according to [7]. This is because the TDECO grid shortage and dirt of PV modules, that is clearly seen from monthly PR Table (6.8).

Table (6.8): Performance Ratio

Timestamp	Performance Ratio with Inverter Faults	Performance Ratio without Inverter Faults	Notes
Jan.2016	69%	87%	Inverter Faults
Feb.2016	96%	96%	
Mar.2016	85%	85%	
Apr.2016	91%	91%	
May.2016	82%	82%	
Jun.2016	79%	80%	
Jul.2016	75%	76%	TDECO grid shortage
Aug.2016	64%	67%	PV station needs cleaning, TDECO grid shortage, Inverter Faults
Sep.2016	60%	74%	TDECO grid shortage, Inverter Faults
Oct.2016	66%	77%	Inverter Faults
Nov.2016	71%	77%	Inverter Faults
Dec.2016	69%	76%	Inverter Faults
Annual PR	76%	80%	

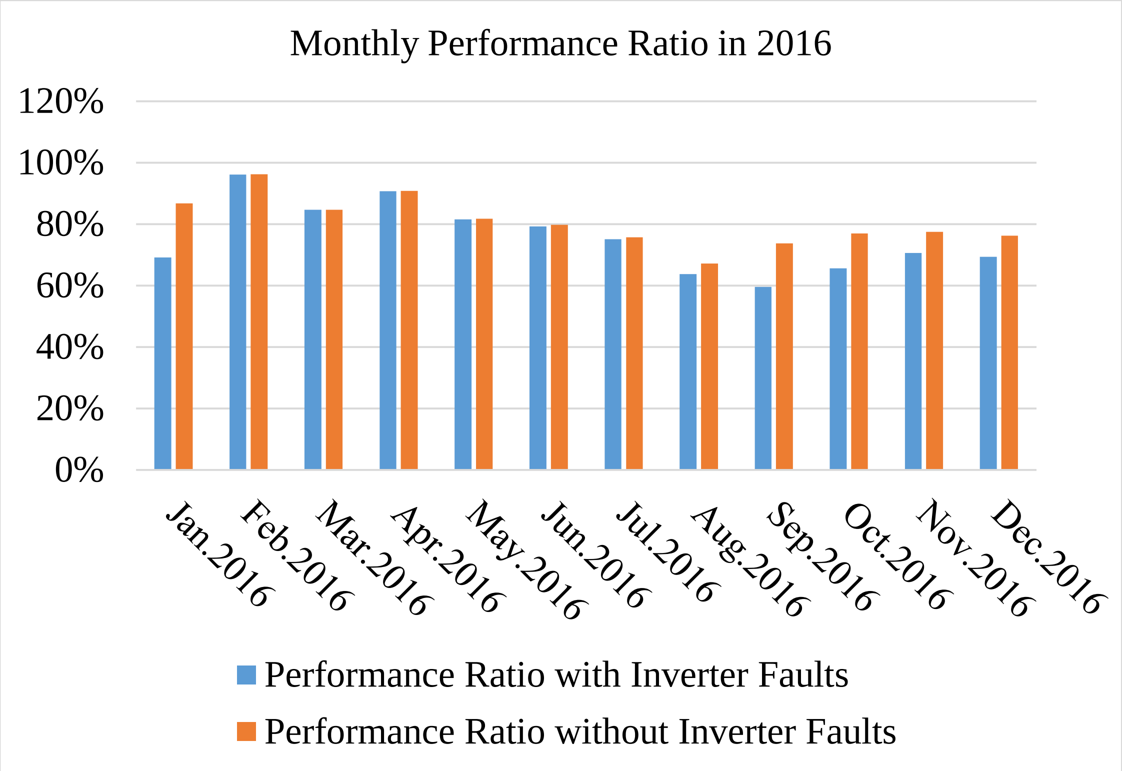


Figure (6.4): Monthly Performance Ratio in 2016 with and without Inverters Faults

Figure (6.4) shows good PR above 96% in winter and spring season, the bad PR in summer mainly in August were 67%. According to [7] a PR varies from approximately 77 % in summer to 96 % in winter

6.2.2. Specific Annual Yield (Y_S)

The specific yield is the total annual energy generated per kWp installed [7] that depends on:

- The total annual irradiation falling on the collector plane.
- The performance of the module, including sensitivity to high temperatures and low light levels.
- System losses including inverter downtime.

$$Y_s = \frac{E_{PV,AC}}{P_{PV@STC}} \tag{6.15}$$

Therefore, the actual specific annual yield Y_s is 1640 kWh/kWp, while the expected specific annual yield $Y_{s,proposed}$ is 1740 kWh/kWp

6.2.3. Capacity Factor (CF)

The capacity factor of a PV power station stated as a percentage, which is the ratio of the actual output AC energy over a period of a year and its output if it had operated at nominal power the entire year, as described by the Equation 6.16

$$CF = \frac{E_{PV,AC}}{\text{Hours per year} * P_{PV@STC}} \tag{6.16}$$

CF= 574040kWh/ (8784h*350kWp)

Therefore, the actual CF is 18.7% while the proposed capacity factor $CF_{proposed}$ is 19.81%

According to [7] the capacity factor of a fixed tilt PV plant can vary from 12% to 24% depending on the solar irradiance and the performance ratio of the PV power plant; therefore, this PV power station has CF on the accepted range.

6.3. Actual and Proposed Energy Production

We calculate proposed energy according to the following equation

$$E_{prop} = G_T * A_{PV,station} * \eta_{sys} \tag{6.17}$$

Where,

E_{prop} =Yearly proposed energy in kWh.

η_{sys}: Overall System efficiency without inverters fault.

E_{prop}= 2169.57kWh/m^2/year*2044.224 m^2 * 0.13732

E_{prop}=609029.83kWh/year

The Actual yearly energy produced in 2016 is 574039.59 kWh

Figure (6.5) shows the actual monthly power production is denoted by continuous line, the expected monthly power production using fixed efficiency during the year, which is 13.732%, and the expected monthly power production using variable efficiency without inverter faults during the year as shown in Table (6.6). It is clearly in this figure, the expected production with variable efficiency is closer than the fixed one because the temperature effect as mentioned later in section 6.6.1. In August, September and October there are gap between actual and expected production because the uncontrollable losses as mentioned in section 6.1.1.

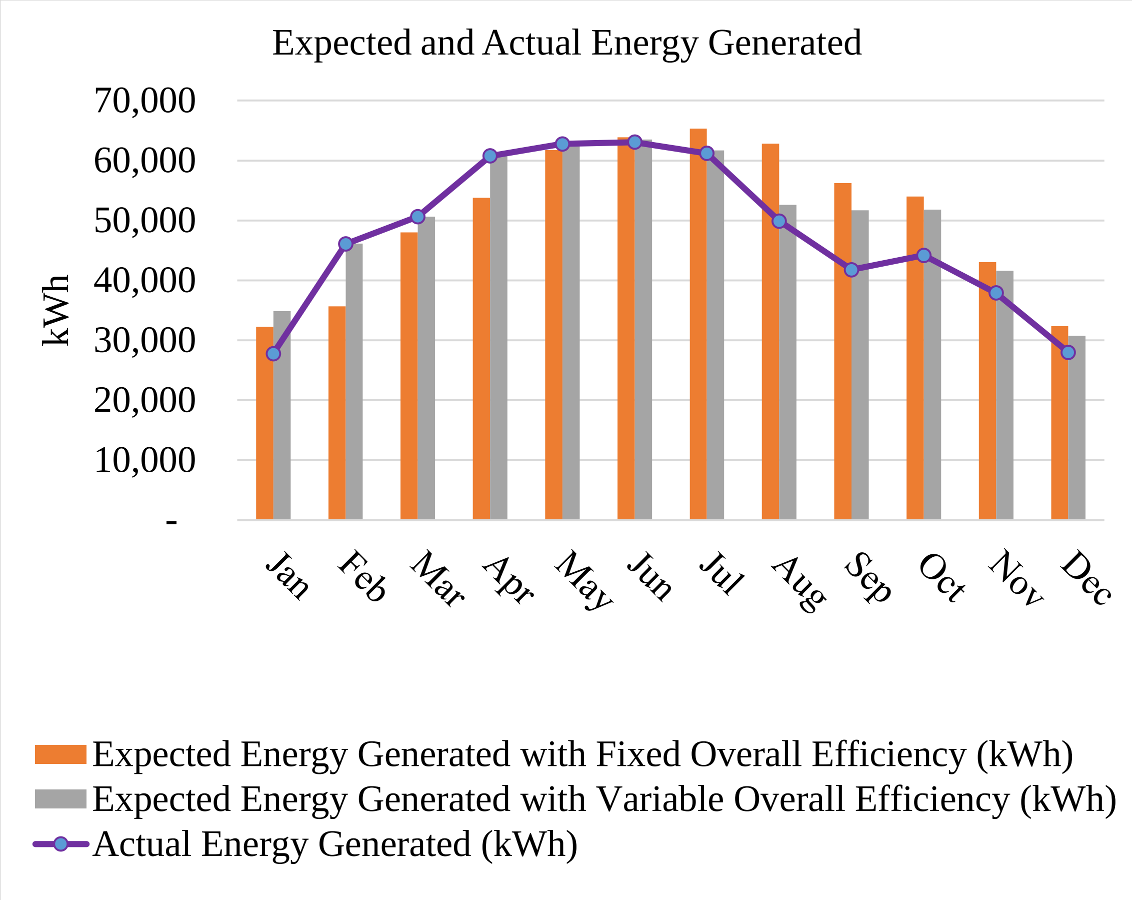


Figure (6.5): Expected and Actual Energy Generated

Table (6.9) shows the maximum monthly actual and expected energy with variable efficiency that were in June 63,065kWh and 63,482kWh respectively, while from Figure (6.5) the maximum expected with fixed efficiency was in July 65339 kWh.

Table (6.9): Actual and Proposed Energy Generated

Month	Days per Month	Actual Energy Generated (kWh)	Expected Energy Generated with Variable Overall Efficiency (kWh)	Daily Actual Energy Generated (kWh/kWp /day)	Daily Expected Energy Generated with Variable Overall Efficiency (kWh/kWp/day)
Jan	31	27,775	34,878	2.56	3.21
Feb	29	46,085	46,120	4.54	4.54
Mar	31	50,631	50,640	4.67	4.67
Apr	30	60,767	60,852	5.79	5.80
May	31	62,775	62,917	5.79	5.80
Jun	30	63,065	63,482	6.01	6.05
Jul	31	61,205	61,689	5.64	5.69
Aug	31	49,898	52,589	4.60	4.85
Sep	30	41,785	51,718	3.98	4.93
Oct	31	44,182	51,830	4.07	4.78
Nov	30	37,893	41,575	3.61	3.96
Dec	31	27,977	30,739	2.58	2.83
Total at 2016	366	574,040	609,030	4.48	4.75

6.4. Irradiance Impact on Inverter Efficiency

This section discusses the solar irradiance impact on the efficiency of inverters with different capacities. Table (6.10) shows the efficiency of inverter1 (20kW installed capacity and 96.4% loading factor) and inverter10 (27.6kW installed capacity and 104.9% loading factor) on July.1st.2016.

Table (6.10): Irradiance Impact on Inverter Efficiency

Time Stamp	Irradiance on Tilted POA (W/m2)	Efficiency of Inverter 1 (20kW)	Efficiency of Inverter 10 (27.6kW)
12:00 AM	0	0	0
1:00 AM	0	0	0
2:00 AM	0	0	0
3:00 AM	0	0	0
4:00 AM	0	0	0
5:00 AM	0	0	0
6:00 AM	3.58	81.4%	95.9%
7:00 AM	73.67	96.0%	96.3%
8:00 AM	252.67	96.8%	97.1%
9:00 AM	469.42	97.0%	97.7%
10:00 AM	668.75	97.3%	97.9%
11:00 AM	834.08	97.4%	97.8%
12:00 PM	952.33	97.4%	97.9%
1:00 PM	997.67	97.4%	97.9%
2:00 PM	970.83	97.4%	97.8%
3:00 PM	885.75	97.4%	97.7%
4:00 PM	736.25	97.3%	98.1%
5:00 PM	544.08	97.1%	97.9%
6:00 PM	336.42	96.9%	97.8%
7:00 PM	141.5	97.0%	97.3%
8:00 PM	22.42	93.4%	99.4%
9:00 PM	0	0	0
10:00 PM	0	0	0
11:00 PM	0	0	0

Figure (6.6) shows that TRIO20kW inverter is less efficient than TRIO27.6kW inverter in the very low irradiance, which is less than 500 W/m^2 at the early morning (7:00am to 9:00am) and in the afternoon (5:00pm to 8:00pm), and both inverters have approximately constant efficiency at higher irradiance.

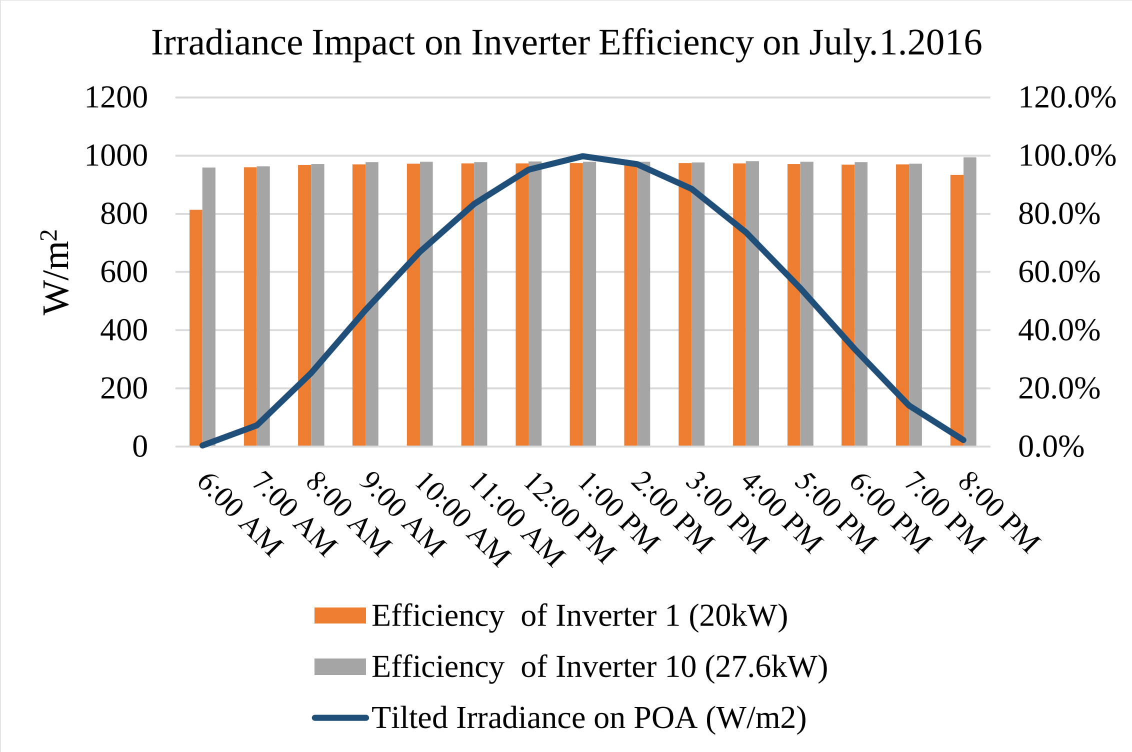


Figure (6.6): Irradiance Impact on Inverter Efficiency on Juy.1.2016

6.5. Inverter Loading Impact on Inverter Efficiency

This section discusses the impact of undersized installed capacity of inverter on its efficiency.

Inverter 1 with 20kW (LF_{inv} = 96.4%) installed capacity have been replaced by other inverter with a capacity of 27.7kW (LF_{inv} = 70%) since 9/11/2017. Table (6.11) shows the input DC power of inverter, output AC power of inverter, energy produced per kWp, and inverter efficiency. These data were taken for each inverter on Feb.2nd.2018.

Table (6.11): Impact of Inverter Sizing on Inverter Efficiency

	Input DC Power (kWh)	output AC Power (kWh)	Inverter Efficiency	Energy Produced (kWh/kWp)
Inverter 1	109.10	107	97.76%	5.33
Inverter 2	159.74	157	97.99%	5.22
Inverter 3	160.91	157	97.57%	5.23
Inverter 4	160.66	157	97.80%	5.24
Inverter 5	162.02	158	97.31%	5.26
Inverter 6	164.19	160	97.24%	5.32
Inverter 7	166.68	162	97.20%	5.40
Inverter 8	164.37	160	97.39%	5.34
Inverter 9	161.52	157	97.22%	5.23
Inverter 10	160.83	157	97.66%	5.24
Inverter 11	160.16	157	97.79%	5.22
Inverter 12	163.68	159	97.14%	5.30
Total	1,893.86	1,846	97.50%	5.28

Figure (6.7) shows that there is no clear relation between the efficiency or power production of oversized inverter (inv1) and rest inverters.

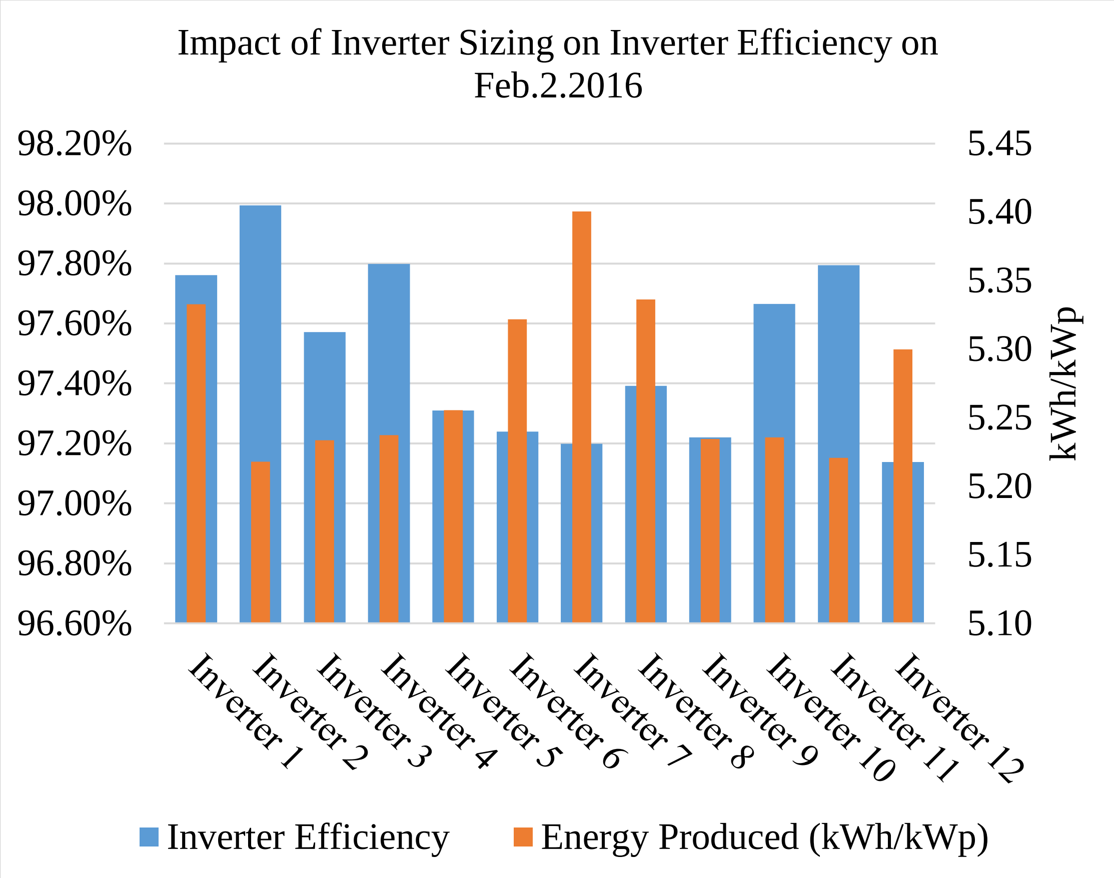


Figure (6.7): Impact of Inverter Sizing on Inverter Efficiency on Feb.2.2016

6.6. Temperature Effect

This section discusses the effect of ambient temperature on this PV power station efficiency, power production and input voltage.

6.6.1. Temperature Effect on PV Power Station Efficiency

Table (6.12) shows the average monthly ambient temperature in 2016 and the total PV station equipment efficiency without inverters faults to terminate unneeded parameter effects, which could make false impacts.

Table (6.12): Temperature Impact

Month	Monthly Average Ambient Temp.(Celsius)	Total PV Station Equipment Efficiency without Inverters Fault
Jan	10.4	12.9%
Feb	14.7	14.8%
Mar	16.1	14.5%
Apr	21.9	14.5%
May	22.4	14.0%
Jun	27.8	13.6%
Jul	27.3	13.0%
Aug	27.0	11.5%
Sep	25.3	12.6%
Oct	23.6	13.2%
Nov	18.0	13.3%
Dec	10.9	13.0%

Figure (6.8) shows that there is an inverse proportion between PV station efficiency and ambient temperature, the maximum efficiency (14.8%) was in the cold weather on February and the lowest efficiency (11.5%) was in the hot weather in August.

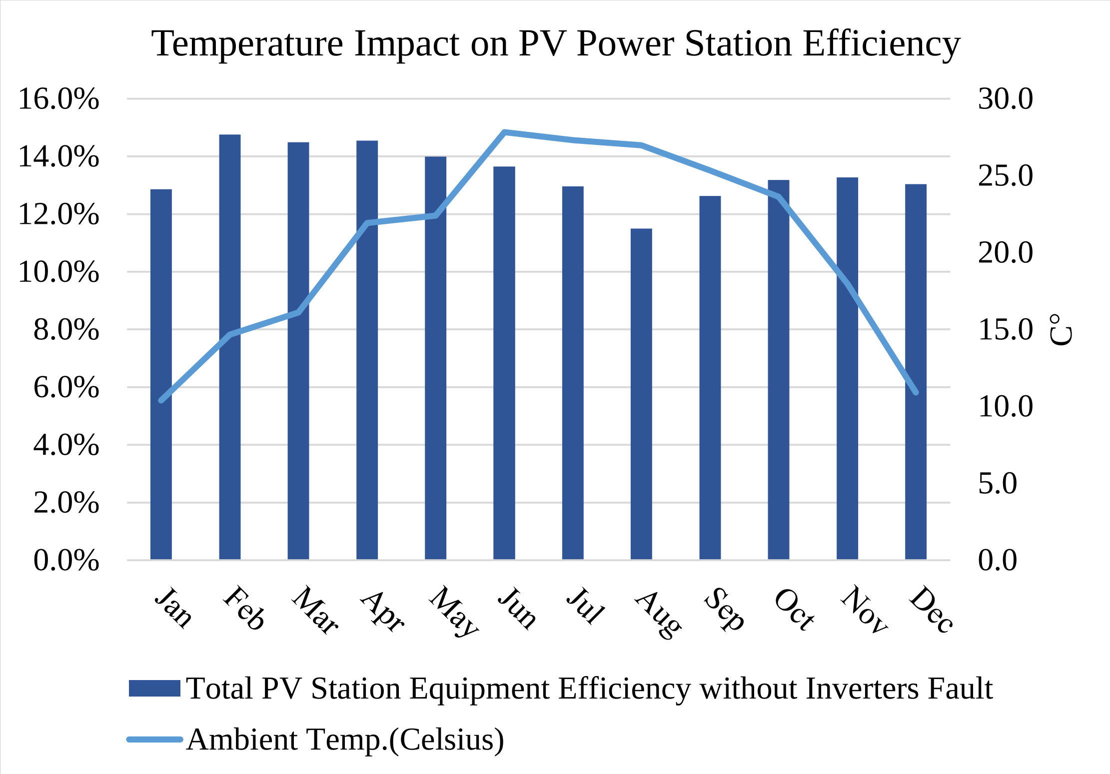


Figure (6.8): Temperature Impact on the Efficiency

6.6.2. Temperature Effect on Power Production of PV Power Station

The clear weather days have been selected in each month to show the daily production in Figure (6.9) [1]. Inverter4 will demonstrate the temperature effect on daily energy production. This shows that the maximum power production at peak time was during lower ambient temperature days, for example on February as shown in Figure (6.10) the maximum power was 25238.87 W at 11:00am and tilted irradiance on POA of 896.08 W/m^2. On the other hand, the minimum power production at peak time was during higher ambient temperature days for example in August as shown in Figure

[1] See Appendix D for high resolution figure

(6.11) where the maximum power was 22009.86 W at 12:00am and tilted irradiance on POA of 927.17 W/m^2

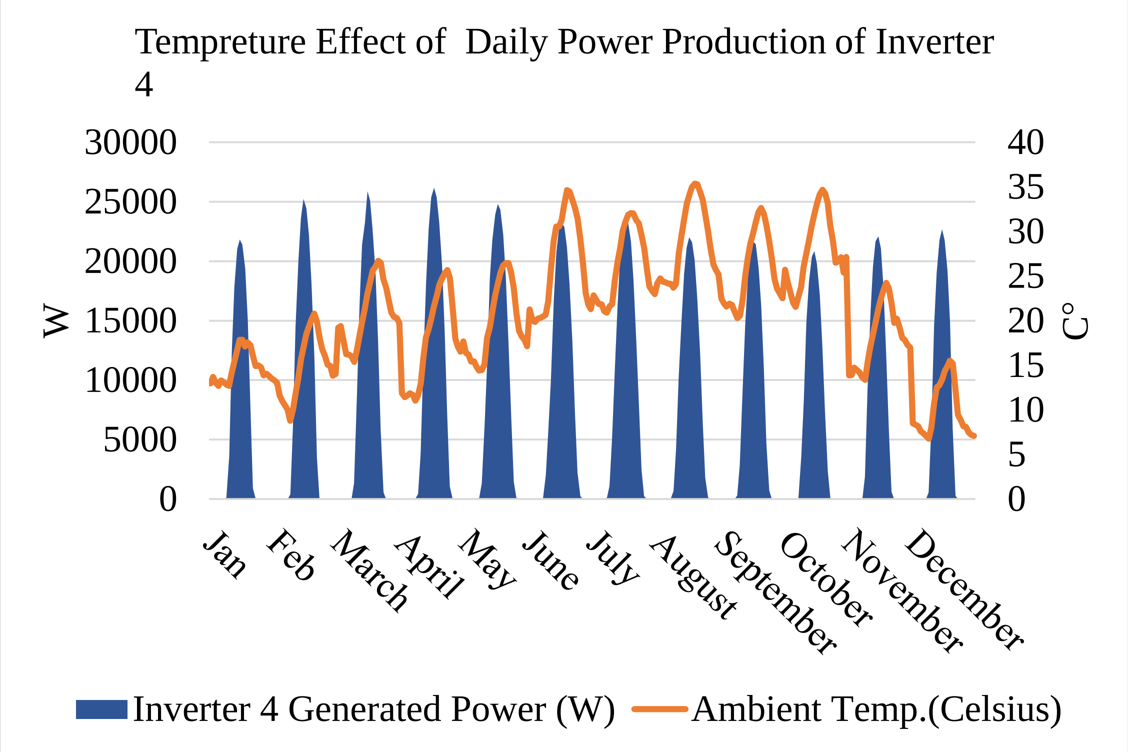


Figure (6.9): Temperature Effect on Daily Power Production of Inverter 4

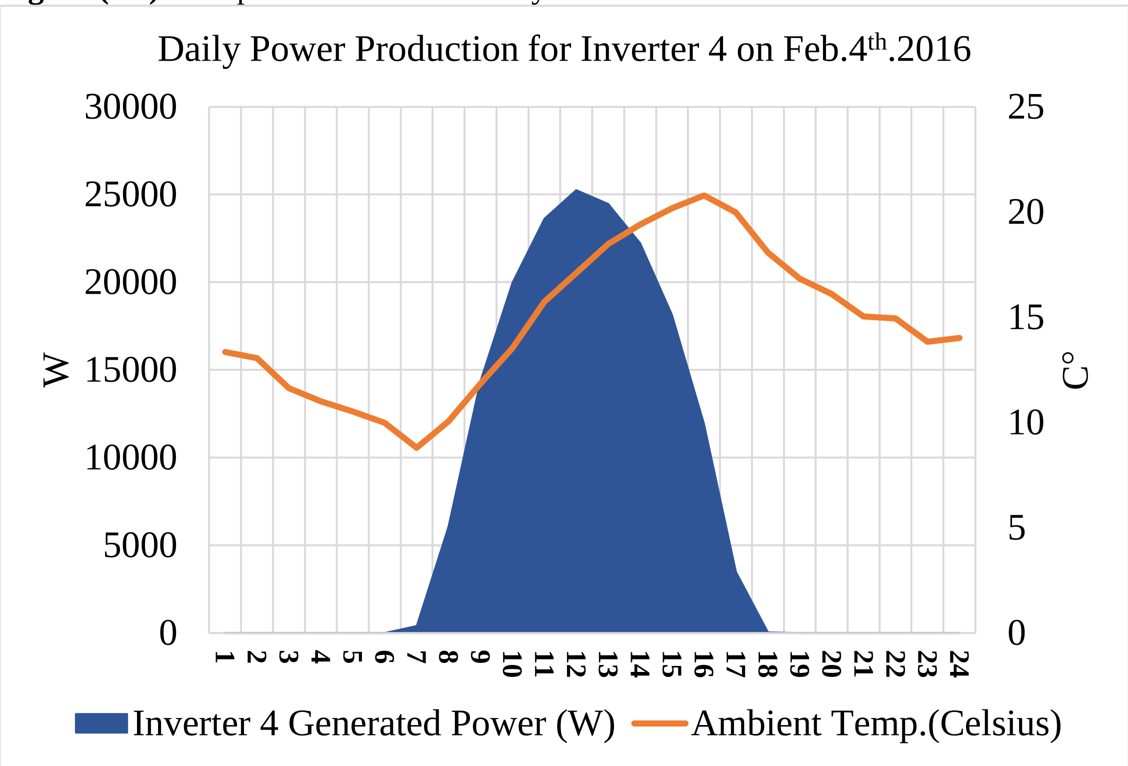


Figure (6.10): Daily Power Production for Inverter4 on Feb.4th.2016

Table (6.13): Daily Power Production for Inverter4 on Feb.4th.2016

Feb.4th.2016			
Time Stamp	Inverter 4 Generated Power (W)	Ambient Temp.(Celsius)	Tilted Irradiance on POA (W/m^2).
12:00 AM	--	13.34	0
1:00 AM	--	13.06	0
2:00 AM	--	11.62	0
3:00 AM	--	11	0
4:00 AM	--	10.51	0
5:00 AM	--	9.99	0
6:00 AM	397.99	8.79	5.33
7:00 AM	6053.4	10.06	234.42
8:00 AM	14369.54	11.86	488.25
9:00 AM	19966.54	13.53	686.75
10:00 AM	23617.68	15.73	827.25
11:00 AM	25238.87	17.11	896.08
12:00 PM	24454.12	18.47	873.78
1:00 PM	22216.96	19.4	788.67
2:00 PM	18136.67	20.18	632.33
3:00 PM	11937.61	20.78	425.92
4:00 PM	3472.08	19.98	180
5:00 PM	30.29	18.08	4.75
6:00 PM	--	16.83	0
7:00 PM	--	16.1	0
8:00 PM	--	15.04	0
9:00 PM	--	14.94	0
10:00 PM	--	13.84	0
11:00 PM	--	14.01	

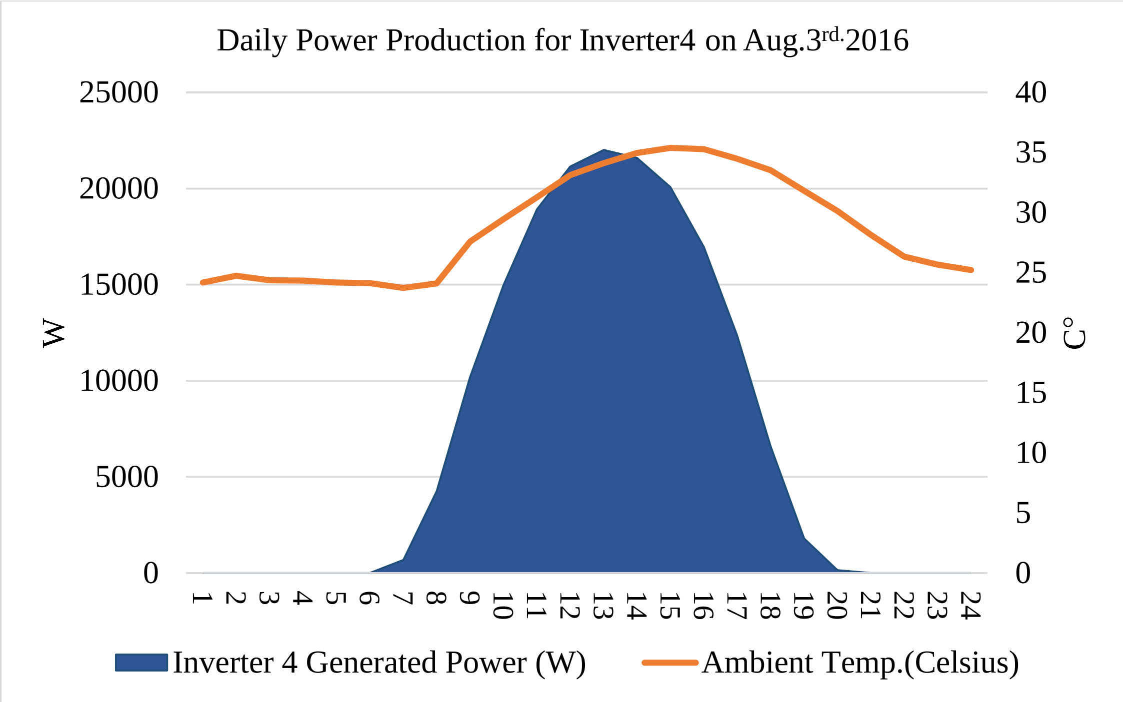


Figure (6.11): Daily Power Production for Inverter4 on Aug.3rd.2016

Table (6.14): Daily Power Production for Inverter4 on Aug.3rd.2016

August.3rd.2016			
Time Stamp	Inverter 4 Generated Power (W)	Ambient Temp.(Celsius)	Tilted Irradiance on POA (W/m^2).
12:00 AM	0	24.19	0
1:00 AM	0	24.73	0
2:00 AM	0	24.37	0
3:00 AM	0	24.33	0
4:00 AM	0	24.17	0
5:00 AM	0	24.12	0
6:00 AM	681.24	23.72	0.42
7:00 AM	4253.6	24.11	46.58
8:00 AM	10176.58	27.58	224.5
9:00 AM	14993.19	29.44	461
10:00 AM	18917.06	31.25	645.67
11:00 AM	21143.01	33.13	812.75
12:00 PM	22009.86	34.11	927.17
1:00 PM	21589.51	34.96	976.58
2:00 PM	20069.81	35.38	953.25
3:00 PM	16947.6	35.29	859.33
4:00 PM	12336.12	34.49	697.56
5:00 PM	6612.48	33.53	511
6:00 PM	1802.62	31.83	305.25
7:00 PM	147.12	30.13	123.75
8:00 PM	0	28.15	14.17
9:00 PM	0	26.33	0
10:00 PM	0	25.66	0
11:00 PM	0	25.21	0

6.6.3. Temperature Effect on DC Voltage Input of PV Power Station

The input DC voltage will be affected by temperature according to Equation6.18 and Equation 5.6

$$V_{MPPT@T} = A * \text{number of modules in serise} * V_{OCT,module} \quad (6.18)$$

Where,

$V_{MPPT@T}$: Theoretical maximum power point voltage at specific temperature

A: Conversion factor, which is 0.8 according to [13]

$V_{OCT,module}$ according to Equation 5.6

Table (6.15) shows the measured ambient temperature, tilted irradiance, cell temperature and two DC input voltages of inverter4 at Aug.3rd.2016, the theoretical DC input voltages were calculated by Equation 6.18.

Table (6.15): Temperature Effect on DC Input Voltage in Aug.3rd.2016.

Time Stamp	Ambient Temp. (C°)	Tilted Irradiance on POA (W/m^2).	Cell Temp. (C°)	Measured V_{MPPT1} (V)	Measured V_{MPPT2} (V)	Theoretical V_{MPPT} (V)
12:00 AM	24	0	23	0	0	0
1:00 AM	25	0	22	0	0	0
2:00 AM	24	0	22	0	0	0
3:00 AM	24	0	23	0	0	0
4:00 AM	24	0	23	0	0	0
5:00 AM	24	0	22	0	0	0
6:00 AM	24	0	22	407	425	609
7:00 AM	24	47	21	513	523	610
8:00 AM	28	225	29	569	572	597
9:00 AM	29	461	35	568	572	584
10:00 AM	31	646	44	548	553	568
11:00 AM	33	813	51	528	530	555
12:00 PM	34	927	54	518	519	549
1:00 PM	35	977	59	509	510	540
2:00 PM	35	953	58	513	514	542
3:00 PM	35	859	53	527	532	551
4:00 PM	34	698	48	541	546	560
5:00 PM	34	511	43	555	561	570
6:00 PM	32	305	37	559	564	581
7:00 PM	30	124	31	539	540	591
8:00 PM	28	14	26	405	428	601
9:00 PM	26	0	24	0	0	0
10:00 PM	26	0	24	0	0	0
11:00 PM	25	0	23	0	0	0

Figure (6.12) shows the voltages where higher values coincides with lower ambient temperature before 9:00am and the lower values of input voltages are at higher ambient temperature between 10:00am and 4:00pm .

Figure (6.12) shows also that the theoretical and measured voltages were approximately closed except in the low irradiance range (less than 300W/m^2); therefore, the A-factor (which is 0.8) should be reduced to 0.65 in that range to fit as far as possible to the measured value.

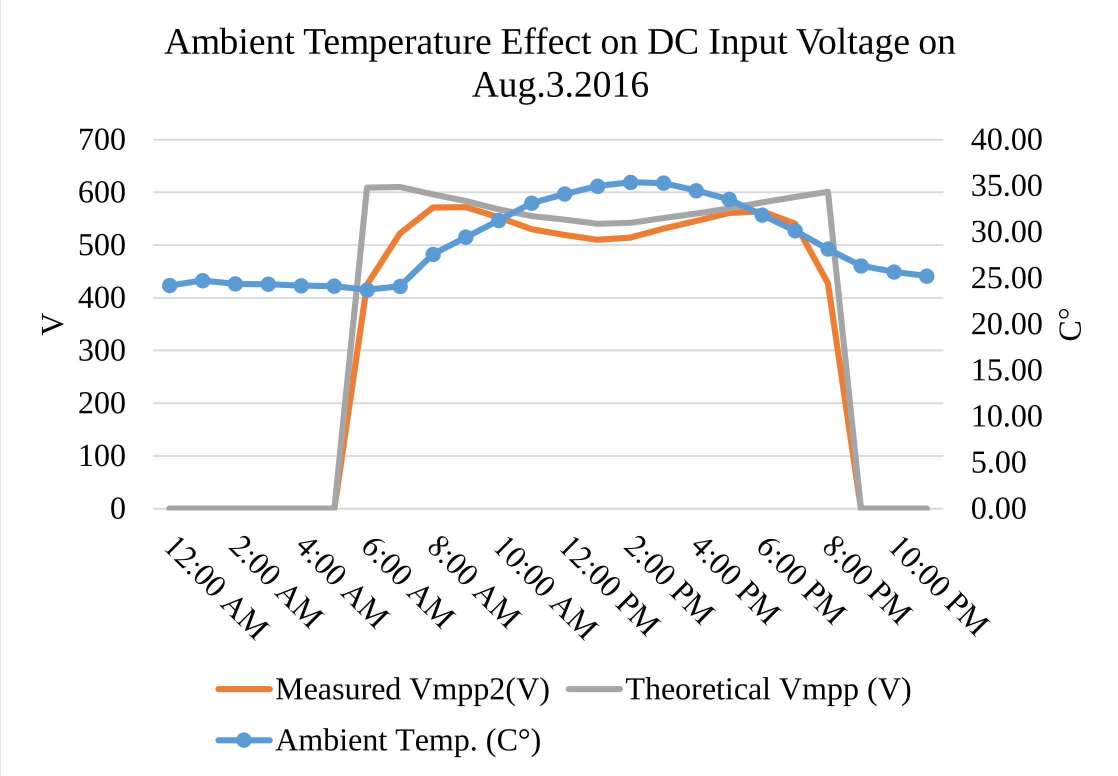


Figure (6.12): Ambient Temperature Effect on DC Input Voltage on Aug.3.2016

6.7. Effect of Dirt on PV Power Station Performance.

Any dirt or soiling on any PV array will reduce the amount of sunlight reaching the PV cells; so reduce the system output. This section discuss high, medium and low dirt PV modules in this PV power station.

A. Low Dirt PV Modules in the PV Power Station

Low dirt PV module is illustrated as shown in Figure (6.13). Cleaning low dirt PV modules was from Nov.4th.2016 to Nov.8th.2016. Before and after cleaning date, the hourly PV station power production sample are selected to studying low dirt effect on its production. The power generated from the PV power station in Nov.3rd.2016 is before cleaning sample and Dec.9th.2016 is after cleaning sample. See Appendix D.1 and Appendix D.2 for daily power production before and after cleaning low dirt PV module respectivley.

Figure (6.13): Low Dirt PV Module

Table (6.16) shows that the efficiency is slightly increased from 15.43% to 15.66% before and after cleaning.

Therefore, there is no significant effect of low dirt case.

B. Medium dirt PV modules in this PV power station

Medium dirt PV module is illustrated as shown in Figure (6.14). Cleaning medium dirt PV modules was in Oct.4th.2017. Before and after cleaning date, the hourly PV station power production sample were selected to studying medium dirt effect on its production. The power generated from the PV power station in Oct.2nd.2017 was before cleaning sample and Oct.17th.2017 was after cleaning sample. Although symmetrical condition in all inverters of this PV power station the medium dirt made non-symmetrical power production for all inverters that disappeared after cleaning. See Appendix D.3 and Appendix D.14 for daily power production before and after cleaning low dirt PV module respectivley.

Figure (6.14): Medium Dirt PV Module

Table (6.16) shows the efficiency is increased from 13.15%to 15.34%before and after cleaning.

Therefore, cleaning medium dirt PV modules effects about 2.19%.of its efficiency.

C. High dirt PV modules in this PV power station

Cleaning high dirt PV modules was in July.19th.2017. Before and after cleaning date, the hourly PV station power production sample were selected to studying high dirt effect on its production. The power generated from the PV power station in July.14th.2017 was before cleaning sample and Aug.2nd.2017 was after cleaning sample. This high dirt was from the stone crusher that worked near the PV site. Figure (6.15) shows the PV modules in this case.

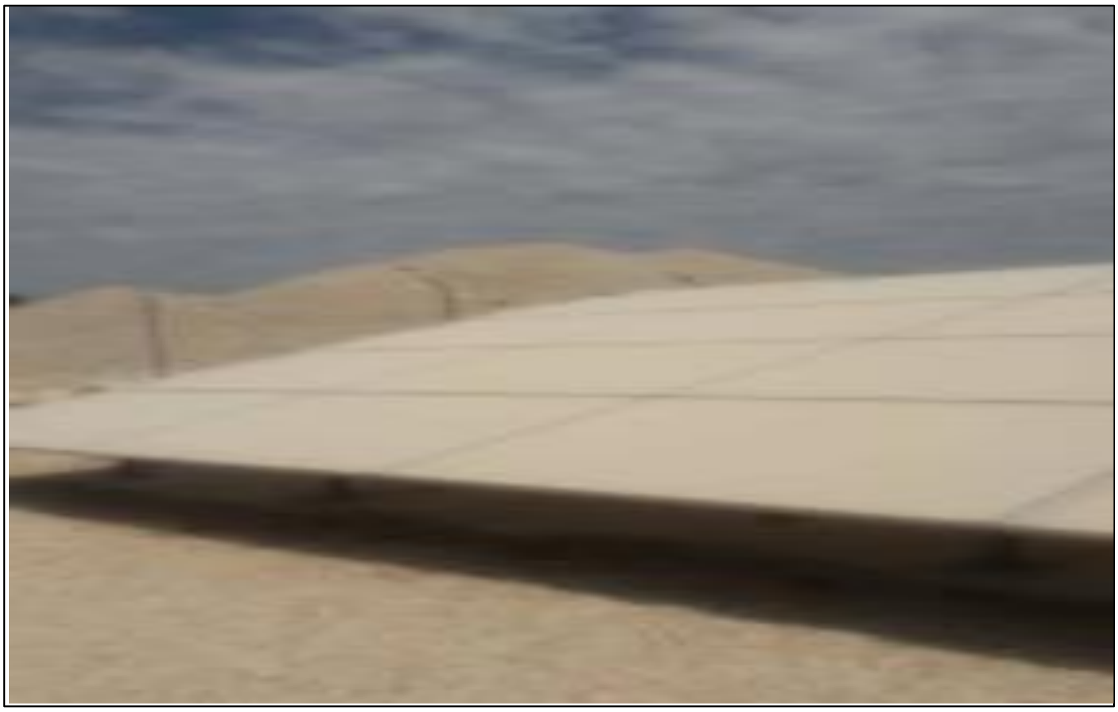


Figure (6.15): High Dirt PV Module

In spit of symmetrical conditions in all inverters the high dirt made non-symmetrical power production of all inverters that was approximately disappeared after cleaning, (see Appendix D.5 and Appendix D.6) for daily power production before and after cleaning high dirt PV module respectivley.

Table (6.16) shows the efficiency is increased from 8.32% to 13.85%before and after cleaning.

Therefore, cleaning high dirt PV modules increasing the efficiency by 5.53%.

Table (6.16): Effect of Dirt on PV Power Station Performance

	Low Dirt	Medium Dirt	High Dirt
Energy Production Before Cleaning Wh	1,570,728	1,373,748	1,045,302
Energy Irradiance POA Before Cleaning Wh/day	10,179,049	10,443,678	12,557,207
Efficiency Before Cleaning	15.43%	13.15%	8.32%
Energy Production After Cleaning Wh	1,561,827	1,553,686	1,729,295
Energy Irradiance POA After Cleaning Wh/day	9,972,056	10,128,108	12,486,138
Efficiency After Cleaning	15.66%	15.34%	13.85%
Efficiency Incremental	0.23%	2.19%	5.53%
Available Capacity kWp	320	300	300
Notes	Inverter 12 was disabled; so PV modules area is 1869 m^2	Inverter 1and 6 were disabled; so PV modules area is 1752 m^2	Inverter 1and 6 were disabled; so PV modules area is 1752 m^2

6.8. Number of inverter's Maximum Power Point Tracker Impact on Power Production

This section discuss the number of inverter's maximum power point tracker impacts on power production. Inverter 7 had been changed from 2MPPT to 1MPPT from March.22th.2017 to Nov.8th.2017 to studying the impact in this period.

All inverters have symmetrical condition like tilt and azimuth angle, solar irradiance and temperature until May.23th.2017 when the stone crusher was operated near the PV power station, the irradiance was changed by heavy dust was produced.

Figure (6.16) shows that the power produced from the PV power station in May2015.No difference between inverter 7 and the reset inverters was founded until May.23th.2017 because no heavy dust was covered the PV modules (all inverters have the symmetrical conditions), nevertheless, after stone crusher begun operating, inverter 7 production was the lowest one.. Therefore, there is no impact of changing the inverter from 1MPPT to 2 MPPT or vice versa in symmetrical condition, in contrast of non-symmetrical conditions.

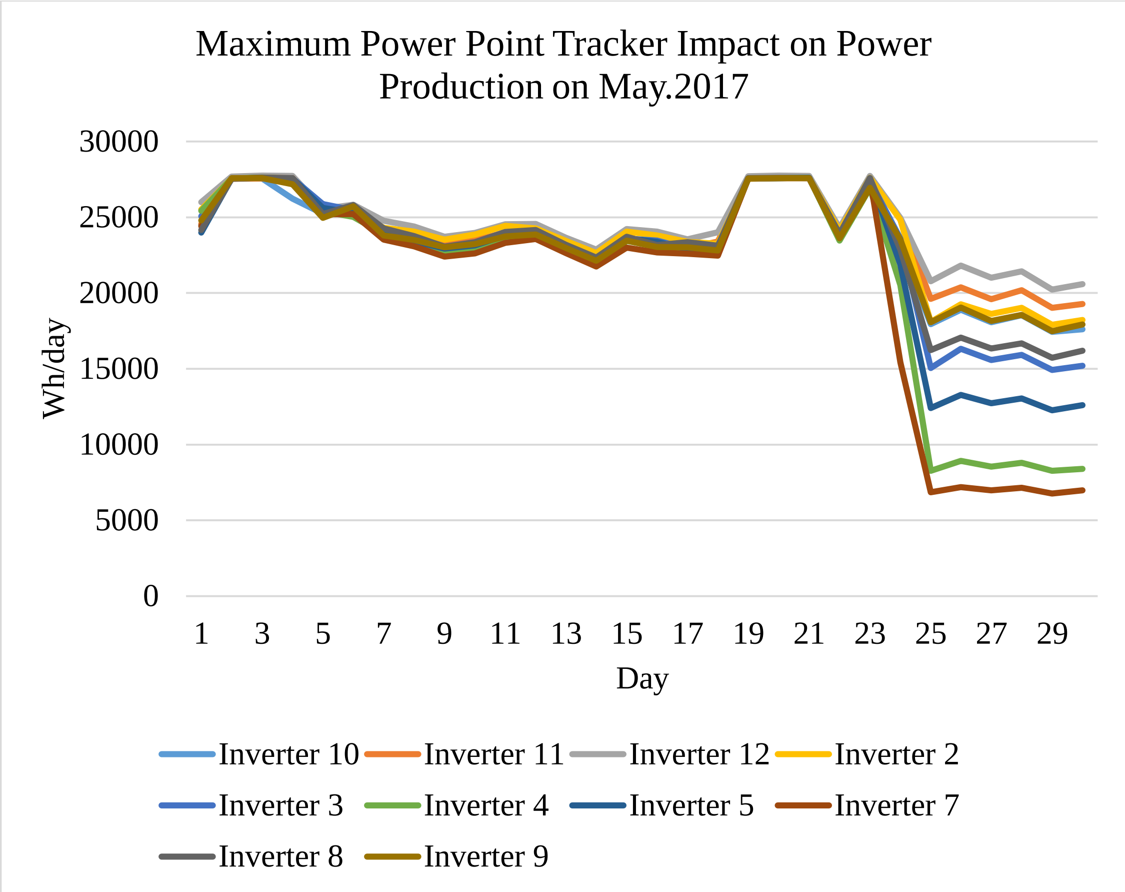


Figure (6.16): Maximum Power Point Tracker Impact on Power Production on May.2017

Table (6.17) shows the total generated power of each inverter in May 2016 and 2017.In 2016, inverter 11 production was the closest one to inverter7[1], which was 682W, production difference in that month was about 0.09%. Nevertheless, the difference of power production between two inverter in 2017 was 94175W, which is about 13.14%.

[1] All inverters were 2mppt

Table (6.17): Comparison of MPPT Number Impact of Production Between May. 2016 and May. 2017

	Total Energy Generated (Wh) for each inverter in May 2016	Total Energy Generated (Wh) for each inverter in May 2017	Notes
Inverter 1 (20kW)	538,814	-	Inverter 1 was disabled in 2017
Inverter 2	776,847	714,405	
Inverter 3	781,601	689,235	
Inverter 4	781,616	640,005	
Inverter 5	780,311	669,043	
Inverter 6	775,855	-	Inverter 6 was disabled in 2017
Inverter 7	777,609	622,623	The Inverter was 1MPPT in 2016 then 2MPPT in 2017.
Inverter 8	776,326	694,932	
Inverter 9	776,425	702,601	
Inverter 10	774,293	702,456	
Inverter 11	778,291	716,798	
Inverter 12	778,521	735,040	

Therefore; the inverter power production is not effected by one or two MPPT tracker in symmetrical condition, but the one MPPT inverter power production becomes lower in the unsymmetrical or dirt condition, it could reach about 13% less production.

Chapter Seven

Economic Analysis and Optimization

7. Economic Analysis and Optimization

The aim of this chapter is to predict the income of this PV power station during its lifetime, which is considered as 20 years. The feasibility study of replacing transformers to reduce the running cost of this PV power station, studying the cables selection to optimize the cost, studying the feasibility of installing new capacitor bank to this PV power station, commercial comparison between using class 0.5 and class 1 meters and finally studying the economic impact of cleaning this PV power station from the dust are considered in the study.

7.1. Project Cash Flow

An economic analysis is very important that will evaluate the feasibility of installing this PV power station. As mentioned previously this PV power station is donated form Czech Republic. Therefore, the cash flow it will be different from other PV stations. This section discusses some economical parameters like cash flow, Life Cycle Cost (LCC) , net cash flow, Simple Pay Back Period (SPBP) and Levelized Cost of Energy (LCOE) for each of two financial studies; the first one for ordinary case without any donations and the second case for the actual situation with donation.

7.1.1. Project Cash Flow without Any Donations

This is the economic study for this PV power station if we did not have any donations. Figure (7.1) shows the main cash flow parameters as the followings:

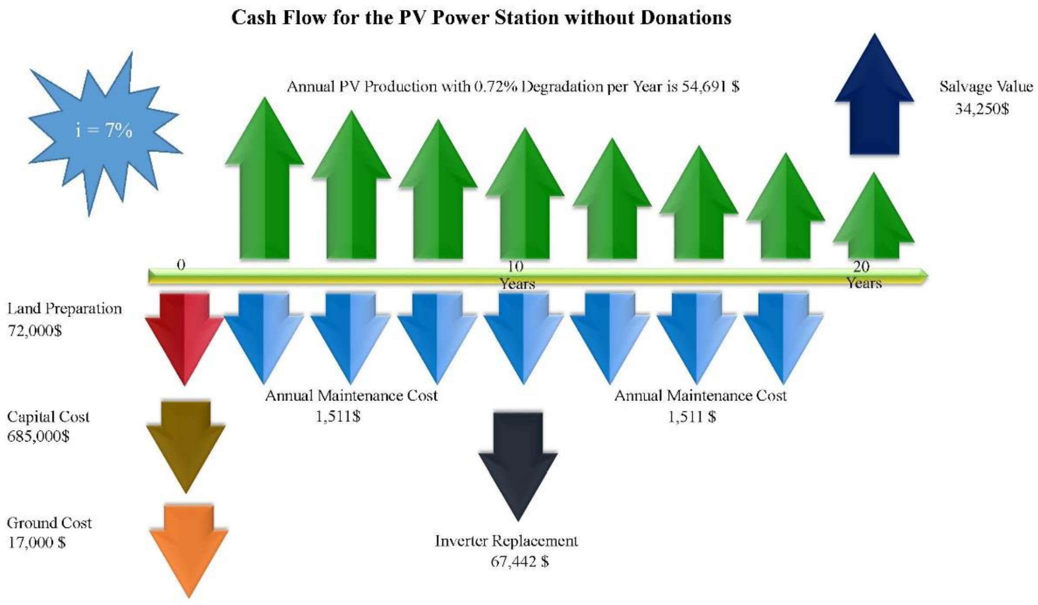


Figure (7.1): Cash Flow of the PV Power Station without Donations

- Installing 350kWp PV station that includes; photovoltaic modules, inverters, galvanized structure with foundation, cabling, MDB, fence, transformer with all accessories and all accessories needed to complete the job, it is cost is 685000$.
- Ground cost is 17000$.
- Land preparation cost is 72000$.
- The annual maintenance, operation and guard cost is 1511$ per year which is 2.5% of capital cost.

- Inverter replacement cost after 12 year is 67442$.Commonly inverters' lifetime is not more 12 years.
- Salvage value is the estimated value of the project when the components are sold at the end of system useful life. Commonly it is considered 5% of the project capital cost, which is 34250$.
- Project life cycle is 20 years.
- Dollar price is 4NIS/$ (average value).
- Interest is 7%.
- Total expected energy production from this PV station is 11382363kWh for project life.
- First year income from energy generated is 54691$.
- Grid tariff is 0.3592NIS/kWh in 2016.
- PV power production reduces to less than 82% of the labeled power output classification after 25 years, therefore the power production degradation 0.72% per year.
- The present value of expected income from energy produced from this PV power station during the lifetime is 549994$ as calculated in Table (7.1) according to Equation 7.2.

Table (7.1) shows that the total expected energy generated in 20 years is 11,382,363 kWh, which corresponds to 1,022,136 $; therefore, the average annual revenue is 51106$.

Table (7.1): Present Value of Expected Energy Generated ($)

Year no.	Expected Energy Generated (kWh)	Expected Income from Energy Generated ($)	Present Value of Expected Income from Energy Generated ($)
1	609,030	54,691	51,113
2	604,645	54,297	47,425
3	600,292	53,906	44,004
4	595,969	53,518	40,829
5	591,678	53,133	37,883
6	587,418	52,750	35,150
7	583,189	52,370	32,614
8	578,990	51,993	30,261
9	574,821	51,619	28,077
10	570,683	51,247	26,052
11	566,574	50,878	24,172
12	562,494	50,512	22,428
13	558,444	50,148	20,810
14	554,424	49,787	19,308
15	550,432	49,429	17,915
16	546,469	49,073	16,623
17	542,534	48,720	15,423
18	538,628	48,369	14,311
19	534,750	48,021	13,278
20	530,899	47,675	12,320
Total	11,382,363	1,022,136	549,994

The LCC is an economic technique used to find all costs related to this project, which includes the followings:

1. Total initial costs, which include all PV power station equipment, land cost and land preparation costs.
2. Maintenance, operation and guard costs.

3. Inverter replacement cost.
4. Salvage value of the PV power station.

To find LCC of this PV power station; the annuity of maintenance, operation cost and guard, inverter replacement and the salvage values shall be converted to the present worth according to the followings:

- Converting the annuity of maintenance, operation and guard cost to the present worth (P/A) according to Equation 7.1 [22]

$$P = A\left[\frac{(1+i)^n - 1}{i\,(1+i)^n}\right]\ ; i \neq 0 \qquad (7.1)$$

Where,

P: Present worth

A: Annuity worth

i: Interest rate

n: Number of years

Therefore, the present worth of maintenance, operation and guard cost is 17125$.

- Converting the future worth of salvage value and inverter replacement to the present worth (P/F) according to Equation 7.2 [22]

$$P = F\left[\frac{1}{(1+i)^n}\right] \qquad (7.2)$$

Where,

F: Future worth

Therefore, the present value of salvage value and inverter replacement cost are 8851 $ and 29945 $ respectively.

$$\begin{aligned} \text{LCC} \\ &= \Sigma \text{ initial costs} \\ &+ \text{Present value(Maintenance, operation and guard costs)} \\ &+ \text{Present value(Inverter replacement)} \\ &- \text{Present value(Salvage value)} \end{aligned} \tag{7.3}$$

Therefore,

LCC= (685,000$ +17,000$ +72,000$) +17125$+ 29945$ - 8851 $.

LCC= 812219$.

Net cash flow is yearly cash diagram, which shows the cash flow during the project lifetime. It shows how the LCC will be decreased by the incomes from this project. Figure (7.2) shows the net cash flow of this PV power station, which shows the zero point between outcomes and incomes after 17 years all outcomes will be recovered, while the SPBP that calculated according to Equation 7.4 is 15 years and 11 months.[1]

$$\text{SPBP} = \frac{\text{LCC}}{\text{Average Annual Saving}} \tag{7.4}$$

SPBP= 8122197$ /51107$ per year.

[1] The difference between net cash flow and the SPBP equation refers to the yearly degradation of power production of the PV

SPBP= 15 years and 11 months.

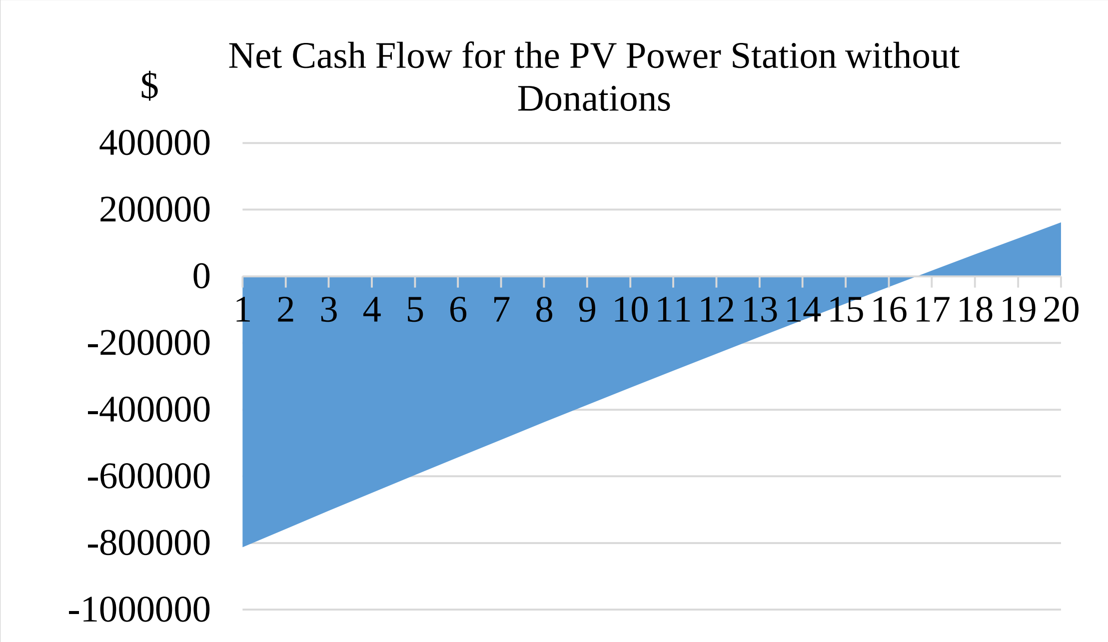


Figure (7.2): Net Cash Flow for the PV Power Station without Donations

Table (7.2) shows the total income after 20 years is 209917$ which corresponding to 10496$ per year.

Table (7.2): Net Cash Flow of PV power Station without Donations

Year no.	Expected Income from Energy Generated ($)	Net Cash Flow($)
1	54,691	-812219
2	54,297	-757528
3	53,906	-703231
4	53,518	-649325
5	53,133	-595807
6	52,750	-542674
7	52,370	-489924
8	51,993	-437554
9	51,619	-385560
10	51,247	-333941
11	50,878	-282694
12	50,512	-231816
13	50,148	-181304
14	49,787	-131156
15	49,429	-81368
16	49,073	-31940
17	48,720	17133
18	48,369	65853
19	48,021	114222
20	47,675	162242
Total	1,022,136	209917

LCOE is defined as a total LCC of the power generation project divided on the expected energy generated from this project, on other words energy tariff of this project

$$\text{LCOE} = \frac{\text{Production Cost}}{\text{Produced Energy}} \qquad (7.5)$$

Production cost is equivalent to LCC, which is 812219$.

The produced energy for 20 years as shown in Table (7.1) is 11382363kWh

Therefore,

LCOE is 0.071$/kWh or 0.2854NIS/kWh

7.1.2. Project Cash Flow with Donations

This is the economic study of the current situation of this PV power station. Figure (7.3) shows the main cash flow parameters as the followings:

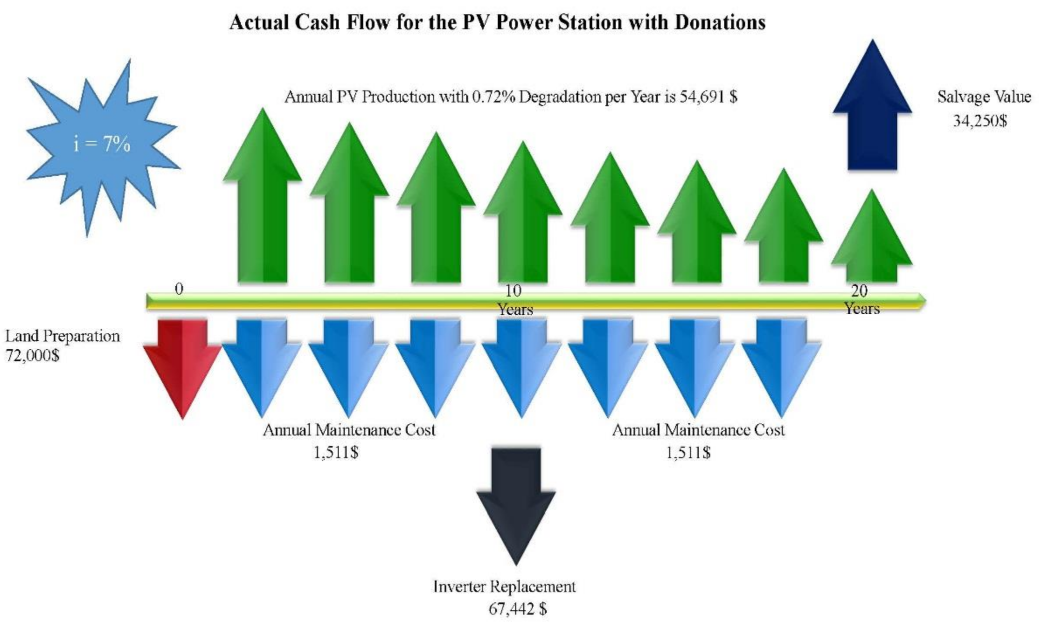


Figure (7.3): Actual Cash Flow of the PV Power Station with Donations

- Installing 350kWp PV station that includes: photovoltaic modules, inverters, galvanized structure with foundation, cabling, MDB, fence, transformer with all accessories and all accessories needed to complete the job is cost 685000$.(It is Donated from Czech Republic; thus it is cancelled).

- Ground cost is 17000$ (The land was allocated from governmental land; thus, it is cancelled).
- Land preparation cost is 72000$.
- The annual maintenance, operation and guard cost is 1511 $ per year.
- Inverter replacement after 12 year is 67442$.
- Salvage value is 34250 $.
- Project life cycle is 20 years.
- Dollar price is 4NIS/$ (average value)..
- Interest rate is 7%.
- First year income from energy generated is 54691$.
- Total expected energy production from this PV station is 11382363kWh for project life.
- Grid tariff is 0.3592NIS/kWh on 2016.
- PV power production reduces to less than 82% of the labeled power output classification after 25 years, therefore the power production degradation 0.72% per year.
- The present value of expected energy production form this PV power station during the lifetime is 549994$ as calculated in section 7.1.1

The LCC in this case includes the followings:

1. Initial cost, which is land preparation cost.
2. Maintenance, operation and guard costs.
3. Inverter replacement cost.
4. Salvage value of the PV power station.

The annuity of maintenance, operation and guard cost, inverter replacement and the salvage values shall be converted to the present worth as mentioned in section 7.1.1, which is 17125$, 29945 $ and 8851 $ respectively and Equation 7.3

Therefore;

LCC= 72000$+17125$+ 29945$ - 8851$

LCC=110219$

Figure (7.4) shows the net cash flow of this PV power station, which shows the zero point between outcomes and incomes in 4 years; this means after 4 years all outcomes will be recovered, while the SPBP that calculated according to Equation 7.4.

SPBP = 110219$/51106$ per year.

SPBP = 2 years and 2 months.[1]

[1] The difference between net cash flow and the SPBP equation refers to the yearly degradation of power production of the PV

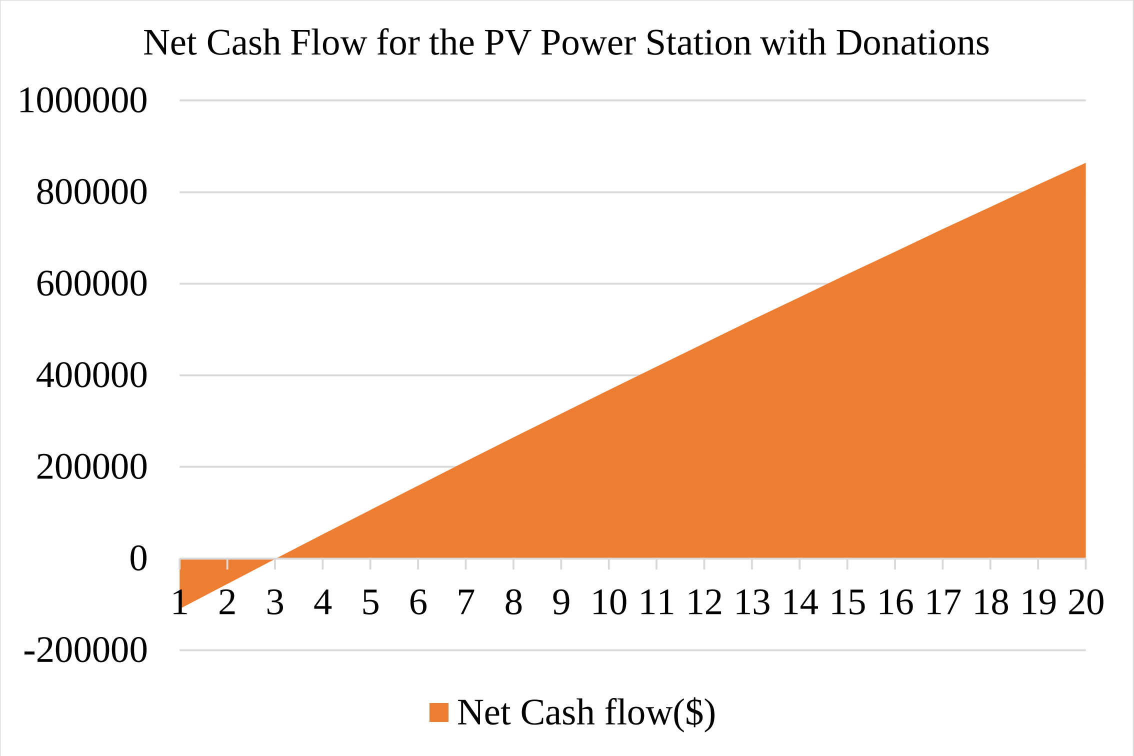


Figure (7.4): Net Cash Flow for the PV Power Station with Donations

Table (7.3) shows that the total income after 20years is 911917$ which means 45596$ per year.

Table (7.3): Net Cash Flow of PV power Station with Donations

Year no.	Expected Income from Energy Generated ($)	Net Cash flow($)
1	54691	-110219
2	54297	-55528
3	53906	-1231
4	53518	52675
5	53133	106193
6	52750	159326
7	52370	212076
8	51993	264446
9	51619	316440
10	51247	368059
11	50878	419306
12	50512	470184
13	50148	520696
14	49787	570844
15	49429	620632
16	49073	670060
17	48720	719133
18	48369	767853
19	48021	816222
20	47675	864242
Total	1022136	911917

To find LCOE according to Equation 7.5; the production cost is equivalent to LCC, which is 110219$ and the produced energy in 20 years as shown in Table (7.1) is 11382363kWh

Therefore,

LCOE is 0.0097$/kWh or 0.0387NIS/kWh.

7.2. Financial Analysis for Replacing Transformer

This PV power station has 400kVA transformer, furthermore there are another two distribution transformers near that, the first for transformer maintenance center with 250kVA capacity and another for 120 kWp PV station of phase I with 160kVA capacity as shown in Figure (7.5). Thus, there are extra technical losses and cost. This section discuss the feasibility of replacing these three transformers by new 630 kVA transformer.

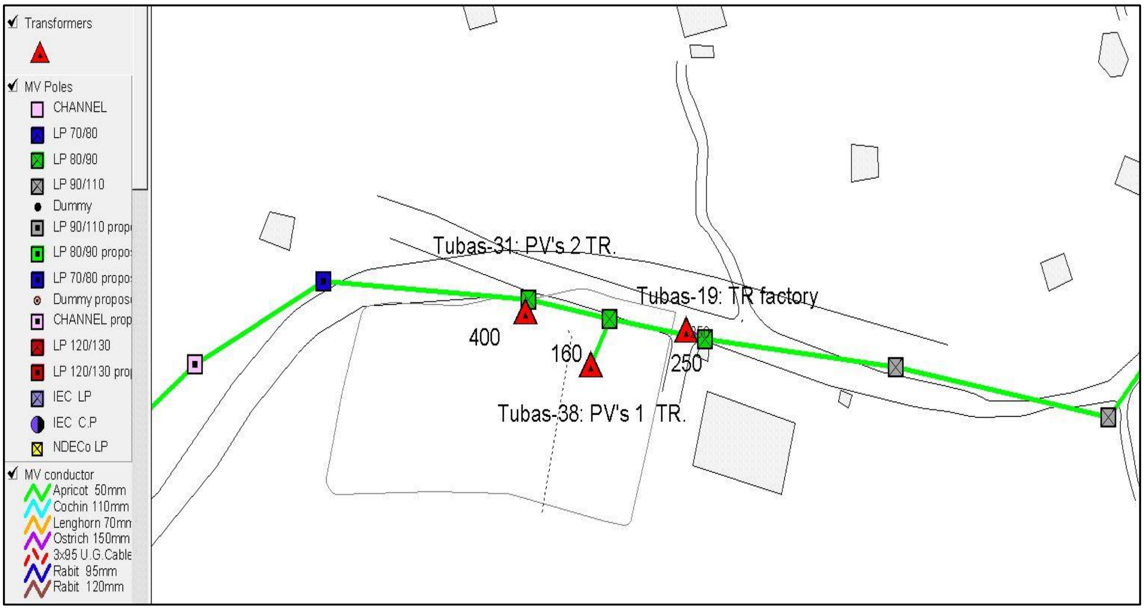


Figure (7.5): MV grid for the Site

Note: TDECO does not have exact information about these transformers brands; therefore, the Turkish transformers' data sheet is used for this study.

Each transformer life-cycle cost, called hereafter "Total Owning Cost (TOC)", in the current and proposed case is taken, which take into account the initial transformer cost and the running cost over its lifetime according to Equation 7.6

$$\begin{aligned} \text{TOC} = \text{Initial Cost} & \\ & + \text{Present Value of Annual Load Losses} \\ & + \text{Present Value of Annual Noload Losses} \end{aligned} \tag{7.6}$$

Table (7.4) shows the initial cost for each transformer. The actual cost of transformers is calculated according to Equation 7.7, annual and present value of no load losses is calculated by Equation 7.8 and Equation7.1 respectively. Annual and present value of load losses are calculated according to Equation7.9 and Equation 7.1 respectively, while the TOC is calculated according to Equation7.6.

$$\begin{aligned} \text{Intial cost of TR now} & \\ & = \text{TR Initial Cost} \\ & - [\text{TR age} * \text{ Depreciation factor} \\ & * \text{ TR Initial Cost}] \end{aligned} \tag{7.7}$$

$$\begin{aligned} \text{Annual no load losses} & \\ & = \text{No load losses} \\ & * \text{Number of hours per year} * \text{Tariff} \end{aligned} \tag{7.8}$$

$$\begin{aligned} \text{Annual load losses} & \\ & = \text{load losses} \\ & * \text{Number of operating hours per year} \\ & * \text{Tariff} \end{aligned} \tag{7.9}$$

Table (7.4): Financial Analysis for Replacing Transformer

	Actual Case			Proposed Case
Name	PV station Phase 1	Transformer Maintenance center	PV station Phase 2	New station
Rated capacity	160kVA	250kVA	400kVA	630kVA
Initial cost	15,000	32,000	42,200	49,500
Installed year	2013	2010	2015	2018
Transformer age now	5	8	3	0
Depreciation factor	5%	5%	5%	5%
Cost of transformer now	11,250	19,200	35,870	49,500
Operating hours	4,576	2,340	4,576	4,576
No-load losses (kW)	0.39	0.55	0.79	1.10
Annual no-load losses (kW)	3,416	4,818	6,920	9,636
Annual no-load losses (NIS)	1,227	1,731	2,486	3,461
Present value of annual no-load losses (NIS)	19,609	27,653	39,720	55,307
Load losses (kW)	2.15	3	4.145	5.5
Annual load losses (kW)	9,838	7,020	18,968	25,168
Annual load losses (NIS)	3,534	2,522	6,813	9,040
Present value of annual load losses (NIS)	56,469	40,292	108,866	144,455
TOC	91,077	99,946	190,787	249,262

Briefly, the followings summarize the above table:

- TOC of the three existing TR is more expensive than TOC of new station which costs 381809NIS while it is 249262NIS for new one.
- The total annual load losses for three TR is 18312 NIS per year while 12502 NIS for new one; so the annual losses saved is 5811NIS (the present value of saving is 90584NIS according to Equation 7.1.
- Total actual cost now of these TR is 66320NIS while it is 49500NIS for a new one; so we save 16820NIS.
- Total saving from the TR costs and running costs during 20 years are 107404NIS.

  Therefore, it is profitable to change these transformers because the saving is 16820NIS from the capital cost and 5811NIS per year.

7.3. Cables Optimization

This section evaluate the cable selection from financial point of view. As mentioned in section 5.1.1 the DC string cables were 6mm^2 DC cables are oversized, using 4mm^2 fair enough to comply technical requirements. Using 4mm^2 cable as string cable instead of 6mm^2 is the new case, which will be financially analyzed as shown in Table (7.5).

Table (7.5): Cable Optimization

	New Case	Old Case
$6mm^2$ cable length	0	1105
$4mm^2$ cable length	1105	0
$6mm^2$ cable cost	5NIS/m	5NIS/m
$4mm^2$ cable cost	3NIS/m	3NIS/m
Total capital cost	3535 NIS	5524 NIS
Power losses	1330 W	1202 W
Total running hours per year	4576	4576
Total power losses during the year	6084517 W	5502410 W
Tariff	.3592 NIS/kWh	.3592 NIS/kWh
Total running cost	2186 NIS	1976 NIS

Table (7.5) shows that the cost difference between $4mm^2$ and $6mm^2$ is 1988NIS and the annual power saving by using $6mm^2$ is 209NIS per year. Therefore, the SPBP according to Equation 7.4 is 9 years and 6 months, which is not feasible period[1], however using $6mm^2$-string cable is good choice from technical and financial point view.

7.4. Financial Analysis for Installing Capacitor Bank

Installing capacitor bank is very important to avoid the penalties as mentioned in section 5.15. TDECO forced power factor penalties for the PV power station that has more than 0.9 power factor. This section discusses the feasibility study of installing capacitor bank in this PV power station.

[1] Commonly, 10 year or less is feasible for investment.

The power factor penalties are calculated by adding 1% of total bill for each 0.01 more than 0.9 power factor according to Equation 7.10

$$\text{Penalty} = E_{prop} * (PF_{PV} - 0.9) * \text{Tariff} \qquad (7.10)$$

Table (7.6) shows the monthly and total annual penalties from unity power factor is 21,876 NIS/year.

Table (7.6): Monthly PV Power Station Penalties

	Monthly Expected PV Station Energy Production (kWh)	Penalties (NIS)
Jan	34,878	1,253
Feb	46,120	1,657
Mar	50,640	1,819
Apr	60,852	2,186
May	62,917	2,260
Jun	63,482	2,280
Jul	61,689	2,216
Aug	52,589	1,889
Sep	51,718	1,858
Oct	51,830	1,862
Nov	41,575	1,493
Dec	30,739	1,104
Total in 2016	609,029	21,876

If we install capacitor bank as mentioned in section 5.15. It will cost 5985 NIS, according to Equation 7.4

$SPBP_{capacitor}$ = 5985NIS /21876 NIS per year

The simple payback period of installing this capacitor bank is around 3 months, which is highly feasible.

7.5. Impact of Changing Meter Accuracy Class

This section discusses the meter accuracy class effect of the final energy readings, which is done by Schneider meter with 0.5 accuracy class. This was mentioned previously in section 5.12 and another meter have been installed in parallel with Schneider meter with accuracy class one, of brand Holley GPRS meter. Both meters were connected to the same CT's to ensure that we have the same CT's accuracy.

The percentage error of energy readings for both meters are calculated according to Equation 7.11 [23] and the results are shown in Table (7.7).

$$\varepsilon_E = \sqrt{{\varepsilon_c}^2 + {\varepsilon_{ct}}^2} \quad (7.11)$$

ε_E= Calculated percentage error of the energy measured.

ε_c= Percentage error of the energy meter.

ε_{ct}= Percentage error of the current transformer.

Table (7.7): Percentage Error for Both Metering System

	Schneider meter	Holley GPRS meter
ε_c	0.50%	1%
ε_{ct}	0.50%	0.50%
ε_E	0.71%	1.12%

The annual energy production measured with error in 2016 is calculated by Equation 7.12

$$E_R = E_{prop} * (1 + \varepsilon_E) \quad (7.12)$$

Where,

E_R : Annual energy production measured with error (kWh)

E_{prop}: Annual proposed energy production according to Equation 6.17 that was 609029kWh on 2016.

Therefore,

The annual energy production measured with error for Schneider meter and Holley GPRS meter are 613336kWh and 615839kWh respectively.

The tariff was 0.3592 NIS/kWh in 2016 so the total annual energy production for Schneider meter and Holley GPRS meter are 220310NIS and 221209 NIS respectively. The less error meter is Schneider that saves about 899NIS yearly and 22474NIS over 25 years.

7.6. Financial Impact of Cleaning PV Power Station

This section discusses the financial impact of cleaning the PV power station in each low, medium and high dirt case as classified in section 6.7. Table (7.8) shows how much the efficiency will increase, the expected output energy in non-rainy months(from May to Nov), the expected output energy in that period(taking in to account the actual efficiency without inverters fault in each months as mentioned in Table (6.6) the expected additional energy from cleaning, the income from and the feasibility of cleaning.

Table (7.8): Financial Impact of Cleaning PV Power Station

	Low Dirt	Medium Dirt	High Dirt
Efficiency Effect of cleaning	0.23%	2.19%	5.53%
Expected Output Energy from May to Nov (kWh)	385,801	385,801	385,801
Expected Additional Energy from cleaning (kWh)	891	8,435	21,317
Income of Cleaning (NIS)	320	3,030	7,657
Average Cleaning Cost (NIS)	700	1,000	1,200
Feasibility of Cleaning	Not Feasible	Feasible for maximum three times cleaning	Feasible for maximum seven times cleaning

Therefore; cleaning is not feasible in low dirt PV modules, but it is feasible for medium dirt case PV modules (income about 3030 NIS) that can be cleaned three times in non- rainy months. The most cleaning feasibility when the PV module has high dirt (income is about 7567 NIS); so we can clean it monthly in non- rainy months.

Chapter Eight

Environmental Impact and the Proposed Mitigation Measures

8. Environmental Impacts and the Proposed Mitigation Measures

EIA (Environmental Impact Assessment) is one of the proven tools of facilitation to achieve the goal of environmentally and socially sound and sustainable development. The incorporation of EIA in developmental projects in Palestinian National Authority (PNA) was initiated in the late nineties.

However, with enforcement of the Environmental Strategy Plan (ESP) and the rules of Environment Quality Authority (EQA) in Palestine become compulsory. The importance of conducting an EIA for any project is:

- To determine whether the proposed investment may result in environmental or social impacts.
- To identify these affects, the negative as well as the positive.
- To propose the suitable mitigation and monitoring measures to protect the environment and give details for administering and monitoring the potential environmental impacts and their mitigation measures.
- To propose applicable safeguard documentation to address potential impacts.

- To evaluate the existing institutional capacity of the company staff to manage the recommendations for implementing the proposed measures.
- To provide recommendations to build capacity and strengthen environmental management and awareness.
- To develop procedures to identify and address potential environmental and social safeguard issues of the company.

This study aims at achieving the followings:

- To identify the type, nature and goals of the project.
- To determine, based on knowledge, whether the proposed investment may result in environmental impacts.
- Propose mitigation and monitoring measures in the form of applicable safeguard documentation to address potential impacts.
- Provide recommendations to build capacity and strengthen environmental management and awareness.
- Develop procedures to identify and address potential environmental and social safeguard issues of the projects.

Table (8.1) shows the environmental and safety component and its impact signs.

Table (8.1): Environmental and Safety Component's Impact

	Environmental and Safety Component	Impact		
		Positive	No Impact	Negative
1	Air Quality		X	
2	Groundwater Quality		X	
3	Heat Flow		X	
4	Community Water Supply		X	
5	Public Health and Services		X	
6	Workers Health and Safety		X	
7	Dust and Noise Reduction		X	
8	Cultural and Heritage	X		
9	Socio-economic	X		
10	Water Courses and Wadis		X	
11	Forests and Biodiversity Areas		X	
12	Aesthetic	X		
13	Waste Reduction		X	
14	Work Accidents	X		
15	Recycling Applications		X	
16	Poverty Alleviation	X		
17	Used Machinery Oils	X		

While the flowing points shows the environmental impacts and the related mitigation measures to be carried out in order to minimize its negativity to the minimum. It is a matter of innovation to find a mechanism how to balance between implementing development projects with the least loss to any of the environmental elements.

8.1. Environmental Impacts

Significant emission reductions can be accomplished through this PV power station electricity production since PV do not generate noise or chemical pollutants during their normal operation. Besides, PV modules help the increase of soil humidity and improve flora formation in dry/arid areas.

8.2. Socio-Economic Impacts

- Reduction of the national dependency on imported electricity.
- Diversification and security of energy supply.
- Provision of significant job opportunities and working positions.
- Support of the energy market deregulation.
- Acceleration of the rural electrification in developing countries.

8.3. Land Use

The impact of this PV power station on land use is minor on natural ecosystems is depended on specific factors such as the topography, the area and the type of the land covered by the system, the distance from areas of natural beauty or sensitive ecosystems and the biodiversity. The impacts and the modification on the landscape are likely to come up during construction stage, by activities such as earth movements and by transport movements, which is already done, therefore no mitigation needed for this.

8.4. Visual Impact

Visual satisfaction of this PV power station is highly dependent on the frame design and the surroundings of the PVs is positive, since the project site was chosen area where there now natural reserves, historical places, or nearby residential areas.

8.5. Accidental Releases and Occupational Health

This PV power station emission into soil and groundwater may be caused by inadequate storage of materials. In large-scale plants a release of these hazardous materials is likely to occur as a result of abnormal plant operations, damaged modules or fire and therefore to pose a small risk to public and occupational health. The increased potential danger of electrocution from the direct current produced by systems, needs to be taken into account especially by untrained users.

Mitigation: Occupational accidents can be avoided by good working practices and by the use of protective sunglasses and clothing during construction, maintenance and decommission stage.

8.6. Air Pollution

The PV power station emissions associated with transport of the modules are minor in comparison to those associated with manufacture; while the project will reduce the pollutant like CO_2, NO_x, SO_x … etc. gases emission. Typically coal fired power plants used in generating electricity produce about 949g, 2.3g, 2.07g of CO_2, NO_x and SO_x per kWh respectively [24], these values will be considered in the estimation of emission reduction. The estimated emissions reduction that could be achieved by installing PV power station instead of the coal fires power plant will be calculated according to Equation 8.1

$$\mathrm{Mass}_{\mathrm{Polutant,PV}} = \mathrm{E}_{\mathrm{prop}} * \mathrm{M}_{\mathrm{Polutant,coal-fired}} \quad (8.1)$$

Where,

Mass, $_{\text{Pollutant, PV}}$: Mass of the pollutant will be reduced from PV power station (kg).

$M_{\text{Pollutant, coal -fired}}$: Mass of the pollutant will be produced from coal-fired power station for each kilo watt hour of electricity (kg/kWh).

$\mathrm{Mass}_{CO_2,PV}$= 609,030 kWh/year * 0. 949kg/kWh

$\mathrm{Mass}_{CO_2,PV}$= 577.97ton CO_2/year

$\mathrm{Mass}_{NOx,PV}$ = 609,030 kWh/year * 0.0023kg/kWh

$\mathrm{Mass}_{NO_x,PV}$ = 1.4 ton NO_x/year

$\mathrm{Mass}_{SOx,PV}$ = 609,030 kWh/year * 0.00207kg/kWh

$\mathrm{Mass}_{SO_x,PV}$ = 1.26 ton SO_x/year

The reduction of CO_2 can be defined as money saving according [25], the metric ton CO_2 costs 50$. According to [26] the total CO_2 reduction from NO_x and SO_x are equivalent to 298 and 22800 kg respectively; therefore the total CO2 reduction is obtained by Equation 8.2

$$\text{Total yearly recuction of } CO_2 = \text{total reduction of } CO_2 + \text{total equivalent reduction of } NO_x + \text{total equivalent reduction of } SO_x \quad (8.2)$$

Total yearly reduction of CO_2 = 577.97ton CO_2/year + 1.4 ton NO_x/year * 298 kg CO_2/kg NO_x + 1.26 ton SO_x/year * 22800 kg CO2/kg SO_x.

= 29,723 ton CO_2

The saving is 1,486,158.5 $/year

8.7. Waste Management

The main input to the project is the daily sun light, which is transformed by the PV module to direct current electricity transformed to alternative current electricity by the power inverters and fed to TDECO grid through the connection point.

The project has no solid, liquid, or gas raw materials, so there is no waste comes out of the project, except PV modules if it is destroyed.

Mitigation: Restore these PV modules to the factory because there are warranty for 20 years.

8.8. Human Health

No human health hazards exist during the operational phase, only during construction and maintenance phase occupational accidents may happen.

Mitigation: Occupational accidents can be averted by good working practices and by the use of protective sunglasses and clothing during construction, maintenance and decommission stage.

8.9. Fire Risk

Electric contacts, cables and instruments over heating cause fire hazards.

Mitigation: Sustainable maintenance for all instruments, installation of efficient fire alarm and firefight systems and awareness programs for the staff.

Therefore, the followings are the main positive and negative impacts of this PV power station

8.10. Positive Impacts

The PV power station has positive environmental implications such as:

- Reduction of the $CO_{2,}$ NO_x and SO_x emissions by 577.97ton, 1.4 ton and 1.26 ton respectively annually, which means $CO_{2,}$ NO_x and SO_x gas emissions reduction by an amount of 14449.25 tons, 35 tons and 31.5 tons respectively during the 25 years of the project lifetime.
- Improvement of the quality of water supplies.
- Reclamation of degraded land.
- Reduction of the number of the required power transmission lines.

- Decrease dependency on foreign energy sources.
- Decrease fund out flow, which has direct effect on Palestinian Balance of payments and Gross National Product (GNP).
- Construction of the project and other similar of large ones will expand investments opportunities in this sector and its downstream activities, which will create job opportunities for skilled and semi-skilled laborers. It will also help to transfer technology, industrial systems and management skills plus opportunity for training and educational alliances.

8.11. Negative Impacts

The PV power station has minor negative environmental impacts:

- The main negative environmental impact of the project come out through project site preparation, which needs limited land excavation, and the carbon emission of the traffic used during project installation. As this is already done; so no mitigation procedure for this point.
- Installation the PV power station might have a minor negative impact on the environment as the variety of fauna and flora could be decreased.

Chapter Nine

Conclusion and Recommendations

9. Conclusion and Recommendations

9.1. Conclusion

Based on 350kWp PV power station evaluation, the followings are found:

- The PV modules, inverters, lightning protection system, weather station and transformer compliance with local specifications.
- No significant inter row shading in this PV power station while the southern fence shade 68 modules, which is 17kWp and the western fence shade 32 modules, which is 8kWp.
- The existing DC cable voltage rating, current carrying capacity, voltage drop and power losses are within acceptable ranges even if the string cables exchanged by $4mm^2$.The wiring measures need some modifications like checking the cable ties, rewiring the cables take in the account reducing induced voltage surges and identifying DC and AC cables where lies in manhole "M9".
- This PV power station has expensive initial DC wiring system costs especially in the oversized string cable and underground conduits size.
- The existing AC cable voltage rating, current carrying capacity for all inverter cables and the distance between manholes are within acceptable ranges.

- One spear inverter should be available in the site in case of any faults; this will reduce inverters faults losses that reached 6% in 2016.
- TDECO should find quick solution to avoid the grid shortage that reached 123 hours and 45 minute in 2016, which corresponds to about 8497kWh lost and to 1.4% energy lost in that year.
- Total uncontrollable energy losses in 2016 was 43487kWh, which is about 15621 NIS.
- The input energy from solar irradiance is 4435087kWh and the total output power from this PV power station is 529565kWh, the maximum losses were on PV modules 13.5%, then in AC wiring92.25%.
- The overall 350kWp PV power station efficiency is 11.94%, while in ideal case, if the PV station equipment efficiency were 100%, the total money would be saved 1402864NIS per year.
- The overall efficiency of this PV station equipment except transformer and AC cables without inverters fault is 13.73% while its efficiency with inverters fault is 12.94%.
- The PV power station efficiency at solar noontime of the selected days for each months. While the maximum efficiency was 87% on April and the minimum was 5% on September.
- The maximum power produced from PV power station at solar noontime of the selected days for each months over the peak power of this PV power station was 87% on April and the minimum was 65% on September.

- Both actual and proposed annual PR in 2016 are 75.6% and 80.2% respectively, where is less than the common annual average PR of 82 % that refers to the TDECO grid shortage and dirt of PV modules.
- Good PR was 96% in the winter and spring season and the bad PR was in the summer mainly in August were 67%.
- The actual specific annual yield Y_s is 1640 kWh/kWp, while the proposed specific annual yield $Y_{s,proposed}$ is 1740 kWh/kWp.
- The actual CF is 18.7% while the proposed capacity factor $CF_{proposed}$ is 19.81%, which is in the acceptable range (12%-24%).
- TRIO20kW inverter is less efficient than TRIO27.6kW inverter in the very low irradiance, which is less than 500 W/m2 at the early morning (7:00am to 9:00am) and in the afternoon (5:00pm to 8:00pm), and both inverters have approximately constant efficiency at higher irradiance.
- The maximum monthly actual and expected energy with variable efficiency that were in June 63,065kWh and 63,482kWh respectively.
- The annual actual and expected energy production in 2016 is 574039.59 kWh and 609029.83kWh/year respectively.
- There is no clear relation between the efficiency or power production of oversized inverter (inv1) and rest inverters.
- The maximum efficiency (14.8%) was in the cold weather on February and the lowest efficiency (11.5%) was in the hot weather in August.
- Cleaning high dirt PV modules increasing the efficiency by 5.53% while cleaning medium dirt PV modules increasing that about 2.19% and there is no significant effect of cleaning low dirt case

- There is no impact of changing the inverter's strings from 1MPPT to 2 MPPT or vice versa in the symmetrical conditions. While using the production of 2MPPT inverter is higher in the unsymmetrical conditions. According to our case, using 2MPPT could increase the production about 13.14%.
- The SPBP for this PV power station without any donations is 15 years and 11 months, which is not feasible that refers to the high ground and land preparation costs. While the SPBP for this PV power station with donations is 2 years and 2 months, which is feasible.
- The LCOE of this PV power station without any donations is 0.071$/kWh or 0.2854NIS/kWh, while the LCOE of this PV power station with Czech donation is 0.0097$/kWh or 0.0387NIS/kWh.
- Using 6mm^2-string cable instead of 4mm^2 is extra capital cost and both are technically good choice. Replacing 6 mm^2 string cables to another 4mm^2 cables is not good idea.
- The power factor penalties for PV power stations are calculated by adding 1% of total bill for each 0.01 more than 0.9 power factor.
- The less error meter saves about 899NIS yearly and 22474NIS over 25 years.
- The most cleaning feasibility when the PV module has high dirt (income is about 7567 NIS); so we can clean it monthly in non- rainy months, and it is feasible for medium dirt case PV modules (income about 3030 NIS) that can be cleaned three times in non- rainy months, despite low dirt PV modules cleaning is not feasible.

- Reduction of the CO_2, NO_x and SO_x emissions by 577.97ton, 1.4 ton and 1.26 ton respectively annually, which means CO_2, NO_x and SO_x gas emissions reduction by an amount of 14449.25 tons, 35 tons and 31.5 tons respectively during the 25 years of the project lifetime.
- Improvement of the quality of water supplies.
- Reclamation of degraded land.
- Reduction of the number of the required power transmission lines.
- Decrease dependency on foreign energy sources.
- Decrease fund out flow, which has direct effect on Palestinian Balance of payments and Gross National Product (GNP).
- Construction of the project and other similar of large ones will expand investments opportunities in this sector and its downstream activities, which will create job opportunities for skilled and semi-skilled laborers. It will also help to transfer technology, industrial systems and management skills plus opportunity for training and educational alliances.
- Locally enclosures safer than ABB one in fire breakout case
- ABB enclosures have higher environmental protection rating than locally one.
- Locally enclosures would save 3480$, if it were used instead of ABB enclosures.

9.2. Recommendations and Future Works

Based on this study the following recommendations are presented:

- Inverter1 should be reinstalled to Trio20 inverter because the power ratio is 1.43 now.
- The following main modifications should be done in grounding system:

  a) Each manholes of PV and lightning grounding pits should be connected to grounding check point with appropriate copper bus bare

  b) Grounding check point should be installed for each table with suitable electrical panel and suitable grounding busbar

  c) The fence and the main door should be connected to the PV grounding system.

  d) MDB and monitoring DB should be connected to the PV grounding system.

  e) System grounding resistance and lightning arrestor grounding resistance should be modified.
- The mounting structure should be checked using galvanic tester, bolts fixing should be tested using torque wrench according to Table (5.6), and there are corrosion in many holes' edges and welding points shall be treated.
- The monitoring electrical panel needs 16A circuit breaker and 16A with 30mA sensitivity RCD.
- The following main modifications should be done in AC cables:

a) The main AC cable is undersized and direct buried, which make difficult and costly maintenance. We recommend to leave this cable until a fault occur, then it will approximately cost if we replace it by double $4x240m^2$ new cable with its installation 21760NIS.

b) The percentage power losses for the inverters 4, 9 and 10 are 3.03%, 3.37% and 3.01% respectively, which exceeds the acceptable limit, cable replacement is recommended by 4x25 mm^2 that costs 10490 NIS.

c) AC inverter's 7-cable joint inside manhole number 9 should be jointed by suitable heated joint.

d) Closing the opened end conduits by Polyurethane foam

e) Identifying the AC cables by color coding, marking tape or tagging at points of termination, connections, and splices.

- The following main modifications should be done in metering system:

a) Installing environmental resistance information signs and fixed it in the meter's electrical panel written "Meter Panel "with following information:
   - CT ratio and installing date
   - Installing another sheet contains empty table for future rehabilitation that can include date of meter replacement, meter serial number and CT ratio.

b) Installing lock for metering DB

c) Convert meter power supply and CTs cable by $6mm^2$

d) Install 250 mA fuses or circuit breaker on L_R and L_S ports

e) Connect the meter power supply to the main busbar.

f) Connect the secondary terminals of current transformers to the grounding system.

- The following main modifications should be done as safety, labeling and identifications measures:

a) Dual supply warning labels should be fitted at point of interconnection

b) The fence and doors should be connected to grounding manholes

c) Installing warning signs with yellow triangular stating "Electrical Danger" should be fixed on fence every 5-10meter

d) Labels on DC cable stating 'PV array cable- live during daylight' should be fixed every 5-10 m

e) Installing the number of strings and inverter on DC cable at the beginning, the end, each cable joint and every 5-10 meter

f) Installing the number of inverters and distribution on AC cable at the beginning, the end, each cable joint and every 5-10 meters.

g) Installing two caution signs on ABB enclosure stating on the first is "Warning Dual Supply, isolate both normal supply from MDB and solar supplies from DC isolator switch at the bottom of ABB enclosure and all string fuses before working on this electrical board", and the second is “active parts inside the boxes are fed from a PV array and may still be alive after isolation from the PV inverter and public supply “

h) Labels for Inverter protection settings shall be installed

i) Installing ground fault protection label stating "Warning Electric Shock Hazard, if a ground fault is indicated normally grounded conductors maybe ungrounded and energized "

j) Providing Fire extinguishers on the site and fixing it in clear locations.

- Change existing three transformers to new 630kVA transformer; because this will save 16820NIS from the capital cost and 5811NIS per year.
- SPBP of installing capacitor bank to correct power factor is around 3 months, which is highly feasible.
- Studding the impact of this PV power station on the grid according to EN50160 (voltage characteristics in public distribution systems).
- PERC should adopt new standard for protection system valid for large PV power station like IEC62548 instead of AS4777-1.
- The following main modifications should be done in electrical protection system:

a) It should be replaced the 300mA RCD type A by another type B.

b) G59 and 650A contactor should be connected in the main connection with LV TDECO grid.

c) All CB were installed for 27.6kW inverters should be replaced by 63A CB.

d) Regarding the electrical fan connection, the existing AC power supply is connected from inverter 6 RCD without suitable OCPD, while it should be connected to the main MDB busbar through 6 A CB or fuse.

References

[1] M. Mahmoud, ***"Solar Electrical Powered RO Water Desalination System for the Rural Village Al Maleh: Design and Simulation,"*** **Taylor& Francis**, 2003.

[2] Palestine Cabinet, Rule no. 14 Articl no 11 "***Renewable energy and energy conservation law***", Palestine, 2015.

[3] The German Energy Society, **Planning and Installing Photovoltaic Systems**, second edition ed., 2008.

[4] National Energy Regulator of South Africa (NERSA), **Grid Connection Code For Renewable Power Plants (Rpps) Connected To The Electricity Transmission System (Ts) Or The Distribution System (Ds) In South Africa**, July2016.

[5] The Regulation and Supervision Bureau for the water, wastewater and electricity sector in the Emirate of Abu Dhabi, **Installation of Solar PV Systems(Guidance Document)**, 2017.

[6] The Instituation of Engineering and Technology, **Code of Practice Grid Connected Solar Phothovoltaic Systems**, London- United Kingdom, 2015.

[7] International Finance Corporation, **Utility-Scale Solar Photovoltaic Power Plants A Project Developer's Guide**, Washington, D.C., 2015.

[8] CIRCUTOR, **Full range of Type B earth leakage protection and monitoring devices**, Spain.

[9] The Institution of Engineering and Technology, **Requirmens for Electrical Installations BS7671**, 2008.

[10] D. M. Siran, **Residual Current Devices (RCD) in Electrical Installations**, Kuala Lumpur Convention Centre (KLCC), Malaysia, 2011.

[11] S. GIS, "https://solargis.info/," 2013. [Online]. [Accessed may 2018].

[12] P. E. a. E. R. Center, "https://www.pec.com.ps," 2014. [Online]. [Accessed May 2018].

[13] M. Marwan, **Renewable Energy Technology I &II Lectures, An-Najah National University**, 2015.

[14] Palestinian Electricity Regulatory Council, **Photovoltaic Net Metering Instructions, Palestine**, 2013.

[15] ABB, **Solar Inverter Product Manual for TRIO-20.0/27.6-TL-OUTD**, Italy, 2013.

[16] ABB, **Solar monitoring Product manual VSN800 Weather Station**, 2014.

[17] The National Electrical Code, Article 690 "**Solar Photovoltaic Systems**", United Stat of America, 2011.

[18] Australian Standard, **Grid connection of energy systems via inverters Part 1: Installation requirements**, Sydney - Australia , 2005.

[19] National Electric Power Company of the Hashemite Kingdom of Jordan, "**Intermittent Renewable Resources (Wind and PV)**

Distribution Connection Code (DCC) At Medium Voltage (MV)," 2015.

[20] Seaward Group, **Photovoltaic System Commissioning and Testing A Guide for PV System Technicians and Engineer***s*, USA.

[21] K. S. B. Shiva Kumar, "***Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India***," **Elsevier**, 2015.

[22] G. M. Masters, **Renewable and Efficient Electric Power Systems, Stanford University: A JOHN WILEY & SONS, INC., PUBLICATION**, 2004.

[23] ABB, **CT Current transformers Ideal for measuring Designed to create efficiency.**

[24] M. L. Mittal, "***Estimates of Emissions from Coal Fired Thermal Power Plants in India,"*** **Archived Emission Inventory Conferences and Workshops**, 2012.

[25] R. C. a. K. Deyes, **"Estimating the Social Cost of HM Treasury"**,*London*, 2002.

[26] M. Brander, "***Greenhouse Gases, CO2, CO2e, and Carbon: What Do All These Terms Mean?***," **Ecometrica**, 2012.

[27] PVTECH, "https://www.pv-tech.org/," 15 1 2018. [Online]. [Accessed 3 2018].

Appendices

Appendix A: Cables and Conduits Calculations

a) DC Cable Calculations

I.DC Cables Voltage Drop Calculations (Actual Case)

Appendix A.a.i: DC Cables Voltage Drop Calculations (Actual Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	String #	Cable Size mm2	Type of Cable	Length (+ & -) m	Resistance	String Resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 1	S1	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	0.42%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S3	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S4	4	module cable	36.8	0.187312	0.217144	608	8.23	1.79	0.29%	Pass	
		6	String cable	8.8	0.029832							
Inverter 2	S1	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	0.44%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	54.4	0.276896	0.291812	608	8.23	2.40	0.40%	Pass	
		6	String cable	4.4	0.014916							
	S4	4	module cable	54.4	0.276896	0.3268646	608	8.23	2.69	0.44%	Pass	
		6	String cable	14.74	0.0499686							
	S5	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S6	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							

Appendix A.a.i: DC Cables Voltage Drop Calculations (Actual Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	String #	Cable Size mm2	Type of Cable	Length (+ & -) m	Resistance	String Resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 3	S1	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	0.48%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	54.4	0.276896	0.291812	608	8.23	2.40	0.40%	Pass	
		6	String cable	4.4	0.014916							
	S4	4	module cable	54.4	0.276896	0.355205	608	8.23	2.92	0.48%	Pass	
		6	String cable	23.1	0.078309							
	S5	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S6	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
Inverter 4	S1	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	0.49%
		6	String cable	11.8	0.040002							
	S2	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	54.4	0.276896	0.3596798	608	8.23	2.96	0.49%	Pass	
		6	String cable	24.42	0.0827838							
	S4	4	module cable	54.4	0.276896	0.291812	608	8.23	2.40	0.40%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.2700958	608	8.23	2.22	0.37%	Pass	
		6	String cable	24.42	0.0827838							
	S6	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							

Appendix A.a.i: DC Cables Voltage Drop Calculations (Actual Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	String #	Cable Size mm2	Type of Cable	Length (+ & -) m	Resistance	String Resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 5	S1	4	module cable	54.4	0.276896	0.291812	608	8.23	2.40	0.40%	Pass	0.46%
		6	String cable	4.4	0.014916							
	S2	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.2827744	608	8.23	2.33	0.38%	Pass	
		6	String cable	28.16	0.0954624							
	S5	4	module cable	36.8	0.187312	0.246976	608	8.23	2.03	0.33%	Pass	
		6	String cable	17.6	0.059664							
	S6	4	module cable	54.4	0.276896	0.33656	608	8.23	2.77	0.46%	Pass	
		6	String cable	17.6	0.059664							
Inverter 6	S1	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	0.42%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S3	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S4	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S5	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S6	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							

Appendix A.a.i: DC Cables Voltage Drop Calculations (Actual Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	String #	Cable Size mm2	Type of Cable	Length (+ & -) m	Resistance	String Resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 7	S1	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	0.42%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.3133522	608	8.23	2.58	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S3	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	54.4	0.276896	0.291812	608	8.23	2.40	0.40%	Pass	
		6	String cable	4.4	0.014916							
	S6	4	module cable	54.4	0.276896	0.3097112	608	8.23	2.55	0.42%	Pass	
		6	String cable	9.68	0.0328152							
Inverter 8	S1	4	module cable	36.8	0.187312	0.2633836	608	8.23	2.17	0.36%	Pass	0.38%
		6	String cable	22.44	0.0760716							
	S2	4	module cable	36.8	0.187312	0.2633836	608	8.23	2.17	0.36%	Pass	
		6	String cable	22.44	0.0760716							
	S3	4	module cable	36.8	0.187312	0.2786386	608	8.23	2.29	0.38%	Pass	
		6	String cable	26.94	0.0913266							
	S4	4	module cable	36.8	0.187312	0.2786386	608	8.23	2.29	0.38%	Pass	
		6	String cable	26.94	0.0913266							
	S5	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S6	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							

Appendix A.a.i: DC Cables Voltage Drop Calculations (Actual Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	String #	Cable Size mm2	Type of Cable	Length (+ & -) m	Resistance	String Resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 9	S1	4	module cable	36.8	0.187312	0.260536	608	8.23	2.14	0.35%	Pass	0.39%
		6	String cable	21.6	0.073224							
	S2	4	module cable	36.8	0.187312	0.287656	608	8.23	2.37	0.39%	Pass	
		6	String cable	29.6	0.100344							
	S3	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S6	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
Inverter 10	S1	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	0.33%
		6	String cable	11.8	0.040002							
	S2	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.23206	608	8.23	1.91	0.31%	Pass	
		6	String cable	13.2	0.044748							
	S6	4	module cable	36.8	0.187312	0.2454844	608	8.23	2.02	0.33%	Pass	
		6	String cable	17.16	0.0581724							

Appendix A.a.i: DC Cables Voltage Drop Calculations (Actual Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	String #	Cable Size mm2	Type of Cable	Length (+ & -) m	Resistance	String Resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 11	S1	4	module cable	36.8	0.187312	0.2902324	608	8.23	2.39	0.39%	Pass	0.39%
		6	String cable	30.36	0.1029204							
	S2	4	module cable	36.8	0.187312	0.2766724	608	8.23	2.28	0.37%	Pass	
		6	String cable	26.36	0.0893604							
	S3	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S6	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
Inverter 12	S1	4	module cable	36.8	0.187312	0.251722	608	8.23	2.07	0.34%	Pass	0.34%
		6	String cable	19	0.06441							
	S2	4	module cable	36.8	0.187312	0.224602	608	8.23	1.85	0.30%	Pass	
		6	String cable	11	0.03729							
	S3	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.227314	608	8.23	1.87	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S6	4	module cable	36.8	0.187312	0.202228	608	8.23	1.66	0.27%	Pass	
		6	String cable	4.4	0.014916							

II.DC Cables Voltage Drop Calculations (Proposed Case)

Appendix A.a.ii: DC Cables Voltage Drop Calculations (Proposed Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner										
	string #	Cable Size sqmm	Length (+ & -) m	Resistance	String resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 1	S1	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	0.51%
		4	37.18	0.1892462							
	S2	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	
		4	37.18	0.1892462							
	S3	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S4	4	36.8	0.187312	0.232104	608	8.23	1.91	0.31%	Pass	
		4	8.8	0.044792							
Inverter 2	S1	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	0.51%
		4	37.18	0.1892462							
	S2	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S3	4	54.4	0.276896	0.299292	608	8.23	2.46	0.41%	Pass	
		4	4.4	0.022396							
	S4	4	54.4	0.276896	0.3519226	608	8.23	2.90	0.48%	Pass	
		4	14.74	0.0750266							
	S5	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	
		4	37.18	0.1892462							
	S6	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							

Appendix A.a.ii: DC Cables Voltage Drop Calculations (Proposed Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner										
	string #	Cable Size sqmm	Length (+ & -) m	Resistance	String resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 3	S1	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	0.53%
		4	37.18	0.1892462							
	S2	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S3	4	54.4	0.276896	0.299292	608	8.23	2.46	0.41%	Pass	
		4	4.4	0.022396							
	S4	4	54.4	0.276896	0.394475	608	8.23	3.25	0.53%	Pass	
		4	23.1	0.117579							
	S5	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	
		4	37.18	0.1892462							
	S6	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
Inverter 4	S1	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	0.54%
		4	11.8	0.060062							
	S2	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S3	4	54.4	0.276896	0.4011938	608	8.23	3.30	0.54%	Pass	
		4	24.42	0.1242978							
	S4	4	54.4	0.276896	0.299292	608	8.23	2.46	0.41%	Pass	
		4	4.4	0.022396							
	S5	4	36.8	0.187312	0.3116098	608	8.23	2.56	0.42%	Pass	
		4	24.42	0.1242978							
	S6	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							

Appendix A.a.ii: DC Cables Voltage Drop Calculations (Proposed Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner										
	string #	Cable Size sqmm	Length (+ & -) m	Resistance	String resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 5	S1	4	54.4	0.276896	0.299292	608	8.23	2.46	0.41%	Pass	0.50%
		4	4.4	0.022396							
	S2	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S3	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S4	4	36.8	0.187312	0.3306464	608	8.23	2.72	0.45%	Pass	
		4	28.16	0.1433344							
	S5	4	36.8	0.187312	0.276896	608	8.23	2.28	0.37%	Pass	
		4	17.6	0.089584							
	S6	4	54.4	0.276896	0.36648	608	8.23	3.02	0.50%	Pass	
		4	17.6	0.089584							
Inverter 6	S1	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	0.51%
		4	37.18	0.1892462							
	S2	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	
		4	37.18	0.1892462							
	S3	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S4	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S5	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S6	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							

Appendix A.a.ii: DC Cables Voltage Drop Calculations (Proposed Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner										
	string #	Cable Size sqmm	Length (+ & -) m	Resistance	String resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 7	S1	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	0.51%
		4	37.18	0.1892462							
	S2	4	36.8	0.187312	0.3765582	608	8.23	3.10	0.51%	Pass	
		4	37.18	0.1892462							
	S3	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S4	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S5	4	54.4	0.276896	0.299292	608	8.23	2.46	0.41%	Pass	
		4	4.4	0.022396							
	S6	4	54.4	0.276896	0.3261672	608	8.23	2.68	0.44%	Pass	
		4	9.68	0.0492712							
Inverter 8	S1	4	36.8	0.187312	0.3015316	608	8.23	2.48	0.41%	Pass	0.44%
		4	22.44	0.1142196							
	S2	4	36.8	0.187312	0.3015316	608	8.23	2.48	0.41%	Pass	
		4	22.44	0.1142196							
	S3	4	36.8	0.187312	0.3244366	608	8.23	2.67	0.44%	Pass	
		4	26.94	0.1371246							
	S4	4	36.8	0.187312	0.3244366	608	8.23	2.67	0.44%	Pass	
		4	26.94	0.1371246							
	S5	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S6	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							

Appendix A.a.ii: DC Cables Voltage Drop Calculations (Proposed Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner										
	string #	Cable Size sqmm	Length (+ & -) m	Resistance	String resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 9	S1	4	36.8	0.187312	0.297256	608	8.23	2.45	0.40%	Pass	0.46%
		4	21.6	0.109944							
	S2	4	36.8	0.187312	0.337976	608	8.23	2.78	0.46%	Pass	
		4	29.6	0.150664							
	S3	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S4	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S5	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S6	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
Inverter 10	S1	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	0.37%
		4	11.8	0.060062							
	S2	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S3	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S4	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S5	4	36.8	0.187312	0.2545	608	8.23	2.09	0.34%	Pass	
		4	13.2	0.067188							
	S6	4	36.8	0.187312	0.2746564	608	8.23	2.26	0.37%	Pass	
		4	17.16	0.0873444							

Appendix A.a.ii: DC Cables Voltage Drop Calculations (Proposed Case), (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner										
	string #	Cable Size sqmm	Length (+ & -) m	Resistance	String resistance	String Voltage mpp @ STC (V)	Amps	Voltage Drop (V)	Voltage Drop Percentage %	Pass / Failed	Max. VD %
Inverter 11	S1	4	36.8	0.187312	0.3418444	608	8.23	2.81	0.46%	Pass	0.46%
		4	30.36	0.1545324							
	S2	4	36.8	0.187312	0.3214844	608	8.23	2.65	0.44%	Pass	
		4	26.36	0.1341724							
	S3	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S4	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S5	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S6	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
Inverter 12	S1	4	36.8	0.187312	0.284022	608	8.23	2.34	0.38%	Pass	0.38%
		4	19	0.09671							
	S2	4	36.8	0.187312	0.243302	608	8.23	2.00	0.33%	Pass	
		4	11	0.05599							
	S3	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S4	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							
	S5	4	36.8	0.187312	0.247374	608	8.23	2.04	0.33%	Pass	
		4	11.8	0.060062							
	S6	4	36.8	0.187312	0.209708	608	8.23	1.73	0.28%	Pass	
		4	4.4	0.022396							

III.DC Cables Power Losses Calculations

Appendix A.a.iii: DC Cables Power Losses Calculations, (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	string #	Cable Size mm2	Type of cable	Length (+ & -) m	Resistance (ohm)	String resistance (ohm)	String power @ STC (W)	Amps	Power Losses (Watt)	Percentage power losses %	Pass / Failed	Max. VD %
Inverter 1	S1	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	0.42%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S3	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S4	4	module cable	36.8	0.187312	0.217144	5000	8.23	14.71	0.29%	Pass	
		6	String cable	8.8	0.029832							
Inverter 2	S1	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	0.44%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	54.4	0.276896	0.291812	5000	8.23	19.77	0.40%	Pass	
		6	String cable	4.4	0.014916							
	S4	4	module cable	54.4	0.276896	0.3268646	5000	8.23	22.14	0.44%	Pass	
		6	String cable	14.74	0.0499686							
	S5	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S6	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							

Appendix A.a.iii: DC Cables Power Losses Calculations, (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	string #	Cable Size mm2	Type of cable	Length (+ & -) m	Resistance (ohm)	String resistance (ohm)	String power @ STC (W)	Amps	Power Losses (Watt)	Percentage power losses %	Pass / Failed	Max. VD %
Inverter 3	S1	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	0.48%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	54.4	0.276896	0.291812	5000	8.23	19.77	0.40%	Pass	
		6	String cable	4.4	0.014916							
	S4	4	module cable	54.4	0.276896	0.355205	5000	8.23	24.06	0.48%	Pass	
		6	String cable	23.1	0.078309							
	S5	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S6	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
Inverter 4	S1	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	0.49%
		6	String cable	11.8	0.040002							
	S2	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	54.4	0.276896	0.3596798	5000	8.23	24.36	0.49%	Pass	
		6	String cable	24.42	0.0827838							
	S4	4	module cable	54.4	0.276896	0.291812	5000	8.23	19.77	0.40%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.2700958	5000	8.23	18.29	0.37%	Pass	
		6	String cable	24.42	0.0827838							
	S6	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							

Appendix A.a.iii: DC Cables Power Losses Calculations, (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	string #	Cable Size mm2	Type of cable	Length (+ & -) m	Resistance (ohm)	String resistance (ohm)	String power @ STC (W)	Amps	Power Losses (Watt)	Percentage power losses %	Pass / Failed	Max. VD %
Inverter 5	S1	4	module cable	54.4	0.276896	0.291812	5000	8.23	19.77	0.40%	Pass	0.46%
		6	String cable	4.4	0.014916							
	S2	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.2827744	5000	8.23	19.15	0.38%	Pass	
		6	String cable	28.16	0.0954624							
	S5	4	module cable	36.8	0.187312	0.246976	5000	8.23	16.73	0.33%	Pass	
		6	String cable	17.6	0.059664							
	S6	4	module cable	54.4	0.276896	0.33656	5000	8.23	22.80	0.46%	Pass	
		6	String cable	17.6	0.059664							
Inverter 6	S1	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	0.42%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S3	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S4	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S5	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S6	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							

Appendix A.a.iii: DC Cables Power Losses Calculations, (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

	Strings - DC Combiner											
	string #	Cable Size mm2	Type of cable	Length (+ & -) m	Resistance (ohm)	String resistance (ohm)	String power @ STC (W)	Amps	Power Losses (Watt)	Percentage power losses %	Pass / Failed	Max. VD %
Inverter 7	S1	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	0.42%
		6	String cable	37.18	0.1260402							
	S2	4	module cable	36.8	0.187312	0.3133522	5000	8.23	21.22	0.42%	Pass	
		6	String cable	37.18	0.1260402							
	S3	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	54.4	0.276896	0.291812	5000	8.23	19.77	0.40%	Pass	
		6	String cable	4.4	0.014916							
	S6	4	module cable	54.4	0.276896	0.3097112	5000	8.23	20.98	0.42%	Pass	
		6	String cable	9.68	0.0328152							
Inverter 8	S1	4	module cable	36.8	0.187312	0.2633836	5000	8.23	17.84	0.36%	Pass	0.38%
		6	String cable	22.44	0.0760716							
	S2	4	module cable	36.8	0.187312	0.2633836	5000	8.23	17.84	0.36%	Pass	
		6	String cable	22.44	0.0760716							
	S3	4	module cable	36.8	0.187312	0.2786386	5000	8.23	18.87	0.38%	Pass	
		6	String cable	26.94	0.0913266							
	S4	4	module cable	36.8	0.187312	0.2786386	5000	8.23	18.87	0.38%	Pass	
		6	String cable	26.94	0.0913266							
	S5	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S6	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							

Appendix A.a.iii: DC Cables Power Losses Calculations, (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

Strings - DC Combiner

	string #	Cable Size mm2	Type of cable	Length (+ & -) m	Resistance (ohm)	String resistance (ohm)	String power @ STC (W)	Amps	Power Losses (Watt)	Percentage power losses %	Pass / Failed	Max. VD %
Inverter 9	S1	4	module cable	36.8	0.187312	0.260536	5000	8.23	17.65	0.35%	Pass	0.39%
		6	String cable	21.6	0.073224							
	S2	4	module cable	36.8	0.187312	0.287656	5000	8.23	19.48	0.39%	Pass	
		6	String cable	29.6	0.100344							
	S3	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S6	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
Inverter 10	S1	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	0.33%
		6	String cable	11.8	0.040002							
	S2	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S3	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.23206	5000	8.23	15.72	0.31%	Pass	
		6	String cable	13.2	0.044748							
	S6	4	module cable	36.8	0.187312	0.2454844	5000	8.23	16.63	0.33%	Pass	
		6	String cable	17.16	0.0581724							

Appendix A.a.iii: DC Cables Power Losses Calculations, (60 (6 x 10) Cells in One Module, All Inverter except Inverter 1 Have 120 (6x20) Modules and Inverter 1 Has 80 (4x20) Modules)

Strings - DC Combiner

	string #	Cable Size mm2	Type of cable	Length (+ & -) m	Resistance (ohm)	String resistance (ohm)	String power @ STC (W)	Amps	Power Losses (Watt)	Percentage power losses %	Pass / Failed	Max. VD %
Inverter 11	S1	4	module cable	36.8	0.187312	0.2902324	5000	8.23	19.66	0.39%	Pass	0.39%
		6	String cable	30.36	0.1029204							
	S2	4	module cable	36.8	0.187312	0.2766724	5000	8.23	18.74	0.37%	Pass	
		6	String cable	26.36	0.0893604							
	S3	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S6	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
Inverter 12	S1	4	module cable	36.8	0.187312	0.251722	5000	8.23	17.05	0.34%	Pass	0.34%
		6	String cable	19	0.06441							
	S2	4	module cable	36.8	0.187312	0.224602	5000	8.23	15.21	0.30%	Pass	
		6	String cable	11	0.03729							
	S3	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S4	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							
	S5	4	module cable	36.8	0.187312	0.227314	5000	8.23	15.40	0.31%	Pass	
		6	String cable	11.8	0.040002							
	S6	4	module cable	36.8	0.187312	0.202228	5000	8.23	13.70	0.27%	Pass	
		6	String cable	4.4	0.014916							

b) AC Cable Calculations

Appendix A.b: AC Cables Voltage Drop and Power Losses Calculations

A) Inverters - MDB

Cable Route	Cable Cross Section Area	Max Cable Length (m)	Rated Voltage (V)	Full Load Current (A)	Voltage Drop (V)	Voltage Drop (%)	Power Losses (W)	Rated power (W)	Power Losses (%)	Pass / Failed in Power Losses
Inverter (1)	4 x 16 mm2	39	400	33	2.56	0.64%	253.79	20.00	1.27%	Pass
Inverter (2)	4 x 16 mm2	38.5	400	45	3.45	0.86%	465.87	30.00	1.55%	Pass
Inverter (3)	4 x 16 mm2	49	400	45	4.39	1.10%	592.93	30.00	1.98%	Pass
Inverter (4)	4 x 16 mm2	75	400	45	6.72	1.68%	907.54	30.00	3.03%	Failed
Inverter (5)	4 x 16 mm2	66	400	45	5.92	1.48%	798.64	30.00	2.66%	Pass
Inverter (6)	4 x 25 mm2	100	400	45	5.67	1.42%	764.96	30.00	2.55%	Pass
Inverter (7)	4 x 25 mm2	99	400	45	5.61	1.40%	757.31	30.00	2.52%	Pass
Inverter (8)	4 x 25 mm2	92.3	400	45	5.23	1.31%	706.06	30.00	2.35%	Pass
Inverter (9)	4 x 16 mm2	83.5	400	45	7.48	1.87%	1010.40	30.00	3.37%	Failed
Inverter (10)	4 x 16 mm2	74.6	400	45	6.69	1.67%	902.70	30.00	3.01%	Failed
Inverter (11)	4 x 16 mm2	58	400	45	5.20	1.30%	701.83	30.00	2.34%	Pass
Inverter (12)	4 x 16 mm2	3	400	45	0.27	0.07%	36.30	30.00	0.12%	Pass

B) MDB - Transfromer

Cable Route	Cable Cross Section Area	Max Cable Length (m)	Rated Voltage (V)	Full Load Current (A)	Voltage Drop (V)	Voltage Drop (%)	Power Losses (W)	Rated power (W)	Power Losses (%)	Pass / Failed in Power Losses
MDB-Transfromer	4 x240mm2	34	400	528	2.34	0.59%	1237.84	350.00	0.35%	Pass

c) NEC Tables

1. Table 690.7 for voltage correction factor from NEC

Table 690.7 Voltage Correction Factors		
Lowest-Expected Ambient Temperature °C	°F	Temperature Correction Factor
0 to 4	32 to 40	1.10
-1 to -5	23 to 31	1.12
-6 to -10	14 to 22	1.14
-11 to -15	5 to 13	1.16
-16 to -20	4 to -4	1.18
-21 to -25	-5 to -13	1.20
-26 to -30	-14 to -22	1.21
-31 to -35	-23 to -31	1.23
-36 to -40	-32 to -40	1.25

2.]Maximum fill ratio for conduit less than two 90° bends

CONDUIT			MAXIMUM OCCUPANCY RECOMMENDED			MINIMUM RADIUS OF BENDS	
Conduit Trade Size Designator[1] English (Metric)	Internal Diameter in (mm)	Cross-Sectional Area in^2 (mm^2)	1 Cable = 53% Fill in^2 (mm^2)	2 Cables = 31% Fill in^2 (mm^2)	3+ Cables = 40% Fill in^2 (mm^2)	Layers of Steel within Sheath in (mm)	Other Sheath in (mm)
½ (16)	0.62 (15.7)	0.30 (195)	0.16 (103)	0.09 (60)	0.12 (78)	6 (160)	4 (100)
¾ (21)	0.82 (20.9)	0.53 (345)	0.28 (183)	0.16 (107)	0.21 (138)	8 (210)	5 (130)
1 (27)	1.05 (26.6)	0.87 (559)	0.46 (296)	0.27 (173)	0.35 (224)	11 (270)	6 (160)
1¼ (35)	1.38 (35.1)	1.51 (973)	0.80 (516)	0.47 (302)	0.60 (389)	14 (350)	8 (210)
1½ (41)	1.61 (40.9)	2.05 (1,322)	1.09 (701)	0.64 (410)	0.82 (529)	16 (410)	10 (250)
2 (53)	2.07 (52.5)	3.39 (2,177)	1.80 (1,154)	1.05 (675)	1.36 (871)	21 (530)	12 (320)
2½ (63)	2.47 (62.7)	4.82 (3,106)	2.56 (1,646)	1.49 (963)	1.93 (1,242)	25 (630)	25 (630)
3 (78)	3.07 (77.9)	7.45 (4,794)	3.95 (2,541)	2.31 (1,486)	2.98 (1,918)	31 (780)	31 (780)
3½ (91)	3.55 (90.1)	9.96 (6,413)	5.28 (3,399)	3.09 (1,988)	3.98 (2,565)	36 (900)	36 (900)
4 (103)	4.03 (102.3)	12.83 (8,268)	6.80 (4,382)	3.98 (2,563)	5.13 (3,307)	40 (1,020)	40 (1,020)
5 (129)	5.05 (128.2)	20.15 (12,984)	10.68 (6,882)	6.25 (4,025)	8.06 (5,194)	50 (1,280)	50 (1,280)
6 (155)	6.07 (154.1)	29.11 (18,760)	15.43 (9,943)	9.02 (5,816)	11.64 (7,504)	60 (1,540)	60 (1,540)

[1]*Identifier only; not an actual dimension*

3. Maximum fill ratio for conduit more than two 90° bends

NUMBER OF CABLES IN CONDUIT	MAXIMUM FILL
1	53%
2	31%
3 or more	40%

Appendix B: Data Sheets

1. PV Module Data Sheet

HSL 60 | Poly

Hanwha Solar

Key Feature Set

1 Robust Design: Module withstands up to 7.000 Pa (>690 kg/m²) Snow / 4.000 Pa (>210 km/h) Wind loads*

2 Anti-PID: Modules are qualified to withstand PID related degradation**

3 Guaranteed Quality: 12 Year Workmanship and 25 Years linear Performance Warranty ***

4 Predictable Output: Positive Power Sorting of 0 to +5 Watt

5 Higher Yield: Module Current Sorting provides up to 2.5% more Energy

6 Innovative Solution: Anti-Reflection Glass with Self-Clean hydrophobic Layer

7 Harsh Environment: Verified against Salt Mist and Ammonia Corrosion (IEC 61701 and IEC 62716)

8 Weak Light: Excellent Performance even under low Irradiation

* Please refer to Hanwha Solar Module Installation Guide

** Test conditions: Module negatively charged with 1000 Volts at 25°C for 168 hours with Al-Foil coverage

*** Please refer to Hanwha Solar Product Warranty for details

Quality and Environmental Certificates

- ISO 9001 quality standards and ISO 14001 environmental standards
- OHSAS 18001 occupational health and safety standards
- IEC 61215 & IEC 61730 Application Class A certifications
- Conformity to CE (low Voltage Directive and EMI), fire tested class E (EN 13501-1)

About Hanwha Solar

Hanwha Solar is a vertically integrated manufacturer of photovoltaic modules designed to meet the needs of the global energy consumer.

- High reliability, guaranteed quality, and excellent cost-efficiency due to vertically integrated production and control of the supply chain
- Optimization of product performance and manufacturing processes through a strong commitment to research and development
- Global presence throughout Europe, North America and Asia, offering regional technical and sales support

Hanwha Solar

2. Inverter Data Sheet

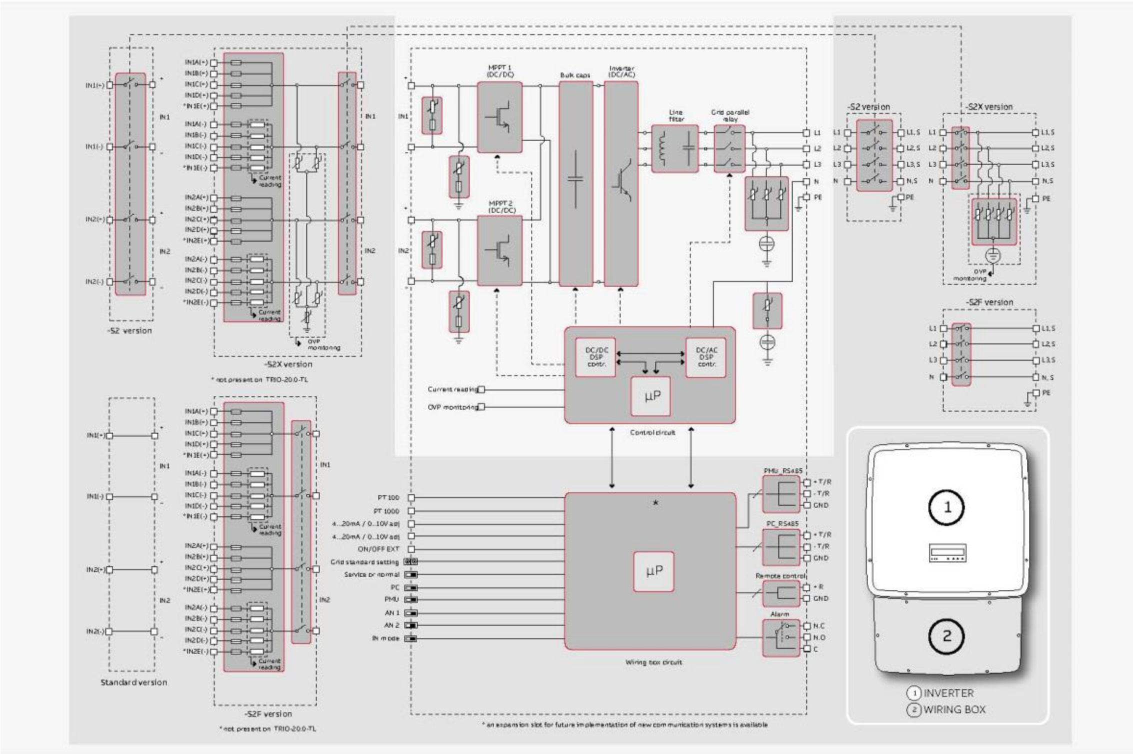
PRODUCT FLYER FOR TRIO-20.0/27.6-TL-OUTD ABB SOLAR INVERTERS

ABB string inverters
TRIO-20.0/27.6-TL-OUTD
20 to 27.6 kW

Technical data and types

Type code	TRIO-20.0-TL-OUTD	TRIO-27.6-TL-OUTD
Input side		
Absolute maximum DC input voltage ($V_{max,abs}$)	1000 V	
Start-up DC input voltage (V_{start})	430 V (adj. 250...500 V)	
Operating DC input voltage range ($V_{dcmin}...V_{dcmax}$)	0.7 x V_{start}...950 V (min 200 V)	
Rated DC input voltage (V_{dcr})	620 V	
Rated DC input power (P_{dcr})	20750 W	28600 W
Number of independent MPPT	2	
Maximum DC input power for each MPPT ($P_{MPPTmax}$)	12000 W	16000 W
DC input voltage range with parallel configuration of MPPT at P_{acr}	440...800 V	500...800 V
DC power limitation with parallel configuration of MPPT	Linear derating from max to null [800 V≤V_{MPPT}≤950 V]	
DC power limitation for each MPPT with independent configuration of MPPT at P_{acr}, max unbalance example	12000 W [480 V≤V_{MPPT}≤800 V] the other channel: P_{dcr}-12000 W [350 V≤V_{MPPT}≤800 V]	16000 W [500 V≤V_{MPPT}≤800 V] the other channel: P_{dcr}-16000 W [400 V≤V_{MPPT}≤800 V]
Maximum DC input current (I_{dcmax}) / for each MPPT ($I_{MPPTmax}$)	50.0 A / 25.0 A	64.0 A / 32.0 A
Maximum input short circuit current for each MPPT	30.0 A	40.0 A
Number of DC input pairs for each MPPT	1 (4 in -S2X, -S2F, -S1J, -S2J versions)	1 (5 in -S2X and -S2F versions, 4 in -S1J and -S2J)
DC connection type	PV quick fit connector [3] / Screw terminal block on Standard and -S2 versions	
Input protection		
Reverse polarity protection	Yes, from limited current source	
Input over voltage protection for each MPPT - varistor	Yes, 4	
Input over voltage protection for each MPPT - plug In modular surge arrester (-S2X, -S1J and -S2J versions)	-S2X: Type 2; -S1J, -S1J: Type 1+2	
Photovoltaic array isolation control	According to local standard	
DC switch rating for each MPPT (version with DC switch)	40 A / 1000 V	
Fuse rating (versions with fuses)	15 A / 1000 V	
Output side		
AC grid connection type	Three-phase 3W+PE or 4W+PE	
Rated AC power (P_{acr} @cosϕ=1)	20000 W	27600 W
Maximum AC output power (P_{acmax} @cosϕ=1)	22000 W [4]	30000 W [5]
Maximum apparent power (S_{max})	22200 VA	30670 VA
Rated AC grid voltage ($V_{ac,r}$)	400 V	
AC voltage range	320...480 V [1]	
Maximum AC output current ($I_{ac,max}$)	33.0 A	45.0 A
Contributory fault current	35.0 A	46.0 A
Rated output frequency (f_r)	50 Hz / 60 Hz	
Output frequency range ($f_{min}...f_{max}$)	47...53 Hz / 57...63 Hz [2]	
Nominal power factor and adjustable range	> 0.995, adj. ± 0.9 with P_{acr}=20.0 kW, ± 0.8 with max 22.2 kVA	> 0.995, adj. ± 0.9 with P_{acr}=27.6 kW, ± 0.8 with max 30 kVA
Total current harmonic distortion	< 3%	
AC connection type	Screw terminal block, cable gland PG36	
Output protection		
Anti-islanding protection	According to local standard	
Maximum external AC overcurrent protection	50.0 A	63.0 A
Output overvoltage protection - varistor	4	
Output overvoltage protection - plug in modular surge arrester (-S2X version)	4 (Type 2)	
Operating performance		
Maximum efficiency (η_{max})	98.2%	
Weighted efficiency (EURO/CEC)	98.0% / 98.0%	
Feed in power threshold	40 W	
Night consumption	< 0.6 W	
Communication		
Wired local monitoring	PVI-USB-RS232_485 (opt.)	
Remote monitoring	VSN300 Wifi Logger Card (opt.), VSN700 Data Logger (opt.)	
Wireless local monitoring	VSN300 Wifi Logger Card (opt.)	
User interface	Graphic display	

—
ABB TRIO-20.0/27.6-TL-OUTD string inverter block diagram



—
Technical data and types

Type code	TRIO-20.0-TL-OUTD	TRIO-27.6-TL-OUTD
Environmental		
Ambient temperature range	-25...+60°C /-13...140°F with derating above 45°C/113°F	
Relative humidity	0...100% condensing	
Sound pressure level, typical	50 dBA @ 1 m	
Maximum operating altitude without derating	2000 m / 6560 ft	
Physical		
Environmental protection rating	IP65	
Cooling	Natural	
Dimension (H x W x D)	1061 mm x 702 mm x 292 mm / 41.7" x 27.6" x 11.5"	
Weight	< 70.0 kg / 154.3 lbs (Standard version)	< 75.0 kg / 165.4 lbs (Standard version)
Mounting system	Wall bracket	
Safety		
Isolation level	Transformerless	
Marking	CE (50 Hz only), RCM	
Safety and EMC standard	EN 50178, IEC/EN 62109-1, IEC/EN 62109-2, AS/NZS 3100, AS/NZS 60950.1, EN 61000-6-2, EN 61000-6-3, EN 61000-3-11, EN 61000-3-12	
Grid standard (check your sales channel for availability)	CEI 0-21, CEI 0-16, DIN V VDE V 0126-1-1, VDE-AR-N 4105, G59/3, C10/11, EN 50438 (not for all national appendices), RD 1699, RD 413, RD 661, P.O. 12.3, AS 4777, BDEW, NRS-097-2-1, MEA, IEC 61727, IEC 62116, Ordinul 30/2013, VFR 2014	
Available products variants		
Standard	TRIO-20.0-TL-OUTD-400	TRIO-27.6-TL-OUTD-400
With DC+AC switch	TRIO-20.0-TL-OUTD-S2-400	TRIO-27.6-TL-OUTD-S2-400
With DC+AC switch and fuse	TRIO-20.0-TL-OUTD-S2F-400	TRIO-27.6-TL-OUTD-S2F-400
With DC+AC switch, fuse and surge arrester	TRIO-20.0-TL-OUTD-S2X-400	TRIO-27.6-TL-OUTD-S2X-400
With DC+AC switch, fuse and 1 DC surge arrester Type 1 + 2	TRIO-20.0-TL-OUTD-S1J-400	TRIO-27.6-TL-OUTD-S1J-400
With DC+AC switch, fuse and 2 DC surge arrester Type 1 + 2	TRIO-20.0-TL-OUTD-S2J-400	TRIO-27.6-TL-OUTD-S2J-400

[1] The AC voltage range may vary depending on specific country grid standard
[2] The Frequency range may vary depending on specific country grid standard
[3] Please refer to the document "String inverters – Product manual appendix" available at www.abb.com/solarinverters for information on the quick-fit connector brand and model used in the inverter
[4] Limited to 20000 W for Germany
[5] Limited to 27600 W for Germany

Remark. Features not specifically listed in the present data sheet are not included in the product

3. AC Cable Data Sheet

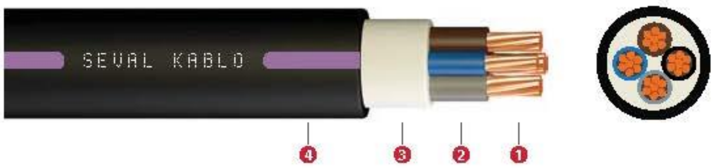
U-1000 R2V

STANDARTLAR
STANDARDS
XP C 32-321:2014

SERTİFİKALAR
CERTIFICATES

XLPE İZOLELİ, ÇOK DAMARLI, BAKIR İLETKENLİ KABLOLAR
XLPE INSULATED, MULTI-CORE CABLES WITH COPPER CONDUCTOR

Enerji Kabloları / *Energy Cables* (XLPE)



YAPISI / *CONSTRUCTION*

iletken / **conductor**
1 Som veya örgülü bakır
Solid or stranded copper (Class 1 or Class 2)

dolgu / **filler**
3 PVC Polivinil klorür
Polyvinyl chloride

izole / **insulation**
2 XLPE Çapraz bağlı polietilen
Cross linkable polyethylene

dış kılıf / **outer sheath**
4 PVC Polivinil klorür
Polyvinyl chloride

TEKNİK ÖZELLİKLER / *SPECIFICATIONS*

- 12 x D — Min. bükülme yarıçapı / *Min. bending radius*
- 90° — Maks. çalışma sıcaklığı / *Max. operating temperature*
- 250° — Maks. kısa devre sıcaklığı / *Max. short circuit temperature*
- UV — UV dayanıklı / *UV resistant*
- 0.6/1 kV — Beyan gerilimi Uo/U / *Rated voltage Uo/U*
- 3.5 kV — Deney gerilimi / *AC test voltage*
- Tek kablo düşey alev yayılma testi / *Flame propagation test on single cable - EN 60332-1*
- Pb — **Kurşunsuz** / *Lead free*
- -25° — Min. çalışma sıcaklığı / *Min. operating temperature*

UYGULAMA ALANLARI / *APPLICATIONS*

Dielektrik kaybı çok düşük olan bu kablolar bina içinde, boru içinde ve endüstri bölgelerinde ya da mekanik hasar beklenmeyen dağıtım merkezlerinde ve ani yük değişimlerinin olduğu enerji tesislerinde kullanılır. Yüksek çalışma sıcaklıklarına uyum gösterir, daha dayanıklı ve daha uzun ömürlüdür.
This cable having very low dielecrtic loss is used indoor, in cable ducts and in industrial plants or switching stations where mechanical damage is not anticipated. Suitable for comparatively high ambient temperature due to high maximum permissible conductor temperature.

TEKNİK VERİLER / *TECHNICAL DATA* — Cu/XLPE/PVC/PVC

Nominal Kesit mm² / *Nominal Cross Section mm²*	Yaklaşık Dış Çap mm / *Overall Diameter mm approximately*	Yaklaşık Net Ağırlık kg/km / *Net Weight kg/km approximately*	İletken Direnci Max. ohm/km (20°C) / *Conductor DC Resistance at (20°C) max. ohm/km*	Akım Taşıma Kapasitesi / *Current Carrying Capacity in* Toprakta (A) / *Ground (A)*	Havada (A) / *Air (A)*
R2V (0,6/1 kV)					
3x16/10	19,8	858	1,15/1,83	112	98
3x25/16	23,0	1247	0,727/1,15	145	133
3x35/16	25,4	1574	0,524/1,15	174	162
3x50/25	28,9	2117	0,387/0,727	206	197
3x70/35	32,8	2912	0,268/0,524	254	250
3x95/50	37,2	3909	0,193/0,387	305	308
3x120/70	42,0	5018	0,153/0,268	348	359
3x150/70	45,2	5905	0,124/0,268	392	412
3x185/95	52,0	7677	0,0991/0,193	444	475
3x240/120	58,4	9776	0,0754/0,153	517	564
3x300/150	61,8	11953	0,0601/0,124	585	649
3x400/185	67,5	14950	0,0470/0,0991	671	761
4x1,5	11,1	186	12,1	31	24
4x2,5	12,0	236	7,41	40	32
4x4	13,1	316	4,61	52	42
4x6	14,6	422	3,08	64	53
4x10	17,4	639	1,83	86	74
4x16	19,7	906	1,15	112	98
4x25	23,0	1333	0,727	145	133
4x35	26,1	1799	0,524	174	162
4x50	29,9	2404	0,387	206	197
4x70	34,4	3374	0,268	254	250
4x95	38,8	4509	0,193	305	308
4x120	44,2	5748	0,153	348	359
4x150	48,2	7013	0,124	392	412
4x185	53,6	8730	0,0991	444	475
4x240	62,3	11535	0,0754	517	564
4x300	68,9	14712	0,0601	585	649
4x400	75,6	18280	0,0470	671	761

www.sevalkablo.com

RoHS'a uygundur.
RoHS Compliant

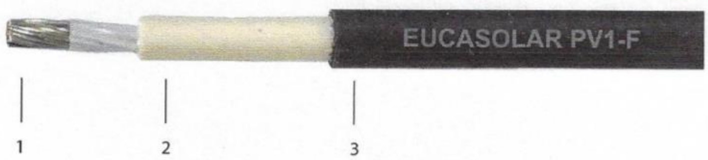
79

4. DC Cable Data Sheet

LV POWER CABLES DATA SHEET Ed. 04/2012-05-21 | Kabelwerk EUPEN AG cable

EUCASOLAR PV1-F

gemäß / according to
2PfG 1169/08.07
TÜV
RoHS
CE



Aufbau

1. Leiter : Kupfer verzinnt, flexibel gemäß IEC/EN 60228 Klasse 5
2. Isolation : halogenfreie, vernetzte Polyolefin-Mischung Aderfarbe : siehe Farbschema
3. Mantel : halogenfreie, vernetzte Spezial-Mischung, flammwidrig Mantelfarbe : siehe Farbschema

Farbvarianten:

* Standardtypen
** auf Anfrage

Anwendung

Witterungsbeständiges, flexibles Energiekabel.
Unser Premium - Produkt, speziell für den anspruchsvollen Einsatz in photovoltaischen Anlagen konzipiert. Das optimale Verbindungskabel zwischen Solarmodulen sowie zwischen Modulen und Wechselrichter. Für Dach- und Freilandanlagen geeignet. Verlegung im Freien, in Gebäuden und in Rohren. Nicht geeignet für direkte Verlegung im Erdreich.
Doppelt isoliert und somit geeignet für die Verwendung in Installationen der Schutzklasse II.

Technische Daten

- Umgebungstemperatur : -40°C bis +90°C
- Max. Betriebstemperatur am Leiter : 120°C (20000h) gemäß IEC/EN 60216-1
- Nennspannung U_0/U : AC 0,6/1 kV
- Nennspannung U_0/U : DC 0,9/1,5 kV
- Höchstzulässige Spannung U_{max} : DC 1,8 kV (Leiter/Leiter, nicht geerdetes System, unbelasteter Stromkreis)
- Prüfspannung : AC 6,5 kV gemäß EN 50395
- Mindest Biegeradius : 4 x Ø
- Zu erwartende Lebensdauer > 25 Jahre gemäß IEC/EN 60216-1

Construction

1. Conductor : tinned copper, flexible acc. to IEC/EN 60228 class 5
2. Insulation : halogen free, crosslinked polyolefin-compound Core colours : see colour scheme
3. Outer sheath : special halogen free, crosslinked compound, flame retardant Sheath colours : see colour scheme

Colour scheme:

* Standard items
** on request

Applications

Flexible, weather resistant power cable.
Our premium product, especially designed for the demanding applications in photovoltaic systems. The optimal cable link between solar modules and between modules and the inverter. Suitable for rooftop and ground mounted systems. Suitable for laying outdoors, indoors and in pipe conducts. Not suitable for direct burying in ground.
Double insulated and therefore suitable for use in installations of safety class II.

Technical Data

- Ambient temperature : -40°C up to +90°C
- Max. conductor temperature : 120°C (20000h) acc. to IEC/EN 60216-1
- Rated voltage U_0/U : AC 0,6/1 kV
- Rated voltage U_0/U : DC 0,9/1,5 kV
- Max. voltage U_{max} : DC 1,8 kV (conductor/conductor, non earthed system, circuit not under load)
- Test voltage : AC 6,5 kV acc. to EN 50395
- Min. bending radius : 4 x Ø
- Expected lifetime > 25 years acc. to IEC/EN 60216-1

ISO Certified Company KABELWERK EUPEN AG - Malmedyer Straße 9 - 4700 EUPEN - BELGIUM Tel.: +32(0)87.59.70.00 - Fax : +32(0)87.59.71.00 - http://www.eupen.com

LV POWER CABLES DATA SHEET Ed. 04/2012-05-21 Kabelwerk EUPEN AG cable

EUCASOLAR PV1-F

Besondere Eigenschaften

- Hervorragende UV-Beständigkeit gemäß HD 605/A1
- Hervorragende Witterungs- und Ozonbeständigkeit gemäß EN 50396
- Hervorragende Säure- und Laugenbeständigkeit gemäß IEC/EN 60811-2-1
- Hervorragende Kältebeständigkeit gemäß IEC/EN 60811-1-4
- Hervorragende Mikrobenbeständigkeit
- Hervorragende Ammoniakbeständigkeit
- Hervorragende Beständigkeit gegen Öle und Fette
- Hydrolysebeständig
- Geringe Wasseraufnahme
- Hohe Verschleiß- und Abriebfestigkeit
- Einfache Abisolierbarkeit
- Gutes Einziehverhalten
- Verzinnter Leiter, verhindert Korrosionsprobleme an Anschluß- und Verbindungsschellen

Special properties

- Outstanding UV-resistance acc. to HD 605/A1
- Outstanding ozone and weather resistance acc. to EN 50396
- Outstanding acid and alkaline resistance acc. to IEC/EN 60811-2-1
- Outstanding cold resistance acc. to IEC/EN 60811-1-4
- Outstanding microbe resistance
- Outstanding ammoniac resistance
- Outstanding oil- and grease resistance
- Hydrolysis resistance
- Very low water absorption
- High wear and abrasion resistance
- Easy cable stripping
- Easy feeding
- Tinned conductors prevent corrosion at junction and connection point

Eigenschaften im Brandfall

- Geringe Rauchentwicklung gemäß IEC/EN 61034
- Geringe Brandfortleitung gemäß IEC/EN 60332-1-2
- Halogenfrei gemäß EN 50267-2-1, IEC/EN 60684-2
- Geringe Korrosivität der Brandgase gemäß EN 50267-2-2
- Geringe Toxizität der Brandgase gemäß NF X70-100-1+2

Properties in case of fire

- Low smoke emission acc. to IEC/EN 61034
- Flame retardant acc .to IEC/EN 60332-1-2
- Halogen free acc. to EN 50267-2-1, IEC/EN 60684-2
- Low corrosivity of gases acc. to EN 50267-2-2
- Low toxicity of gases acc. to NF X70-100-1+2

Querschnitt Section mm^2	Außendurchmesser Outer diameter mm	Gewicht Weight kg/km	Leiterwiderstand bei 20°C Conductor resistance at 20°C Ω/km
4	5,1	53	5,09
6	5,8	75	3,39
10	7,5	130	1,95
16	8,5	185	1,24
25	9,8	268	0,795
35	10,9	363	0,565

Strombelastbarkeit / Current carrying capacity

Querschnitt Section	Strombelastbarkeit in Abhängigkeit der Verlegeart Current carrying capacity acc. to the method of installation		
	einzeln frei in Luft Single cable free in air	einzeln an Flächen single cable on a surface	2 berührend an Flächen 2 cables in contact on a surface
mm^2	A	A	A
4	55	52	44
6	70	67	57
10	98	93	79
16	132	125	107
25	176	167	142
35	218	207	176

Umrechnungsfaktoren für abweichende Umgebungstemperaturen / Conversion factor for temperature variations

Umgebungstemperatur Ambient temperature	Umrechnungsfaktor Conversion factor
bis 60 °C / up to 60°C	1,00
70°C	0,91
80°C	0,82
90°C	0,71
100°C	0,58
110°C	0,41

Reduktionsfaktoren bei Häufung
Siehe IEC 60364-5-52 Tabelle A.52-17

Groups rating factors
Refer to IEC 60364-5-52 Table A.52-17

5. Weather Station Data Sheet

Specifications

Material Specifications

Sensor Assembly:

RoHS Compliant

Mast:	Polyvinyl Chloride
Heat Shields:	Acrylonitrile Butadiene Styrene
Insolation Sensor Bracket:	Delrin
Hardware:	Stainless Steel and Nylon Locknut
Foam Gasket:	Vinyl and Acrylic

Enclosure:

RoHS Compliant

IP65 Rated Outdoor Enclosures

UL 94 V-2

Polycarbonate Body

Pyranometer Sensor:

RoHS Compliant

Body:	Anodized Aluminum with Cast Acrylic Lens
Cable:	Santoprene Jacket

Ambient Air Temperature Sensor:

RoHS Compliant

PV Panel Temperature Sensors:

RoHS Compliant

Body:	Anodized Aluminum
Adhesive Tape:	Acrylic, Titanium Diboride, and Aluminum
Cable:	Polyvinyl Chloride Jacket

Power and Communications Cable:

Cable:	Polyvinyl Chloride

Physical:

Packaged Weight:	7 lbs.
Packaged Dimensions:	6cm x 20.3cm x 20.3cm (10.25" x 8" x 8")

Electronics:

RoHS Compliant

Hardware Specifications

Power Specifications:

Power Requirements:	10 to 30VDC at 50mA

Operating Environment:

Temperature:	-40°C to 60°C (-40 to 140°F)
Humidity:	0-100% Condensing

Pyranometer Sensors:

Range:	0 to 1750 W/m^2
Accuracy:	+/-5%
Cosine Response 45°	+/-1%
Cosine Response 75°	+/-5%
Operational Temperature:	-25 to 55°C (-13 to 131°F)

Ambient Air Temperature Sensor:

Range:	-40° to 80°C (-40 to 176°F)
Accuracy:	+/- 0.3°C (0.54°F)
Thermal Time Constant	30 sec.

PV Panel Temperature Sensor:

Range:	-40° to 80°C (-40 to 176°F)
Accuracy:	+/- 0.3°C (0.54°F)
Thermal Time Constant:	270 sec.
Cable Length	7.62m (25 ft.)

Anemometer:

Operational Temperature:	-40 to 60°C (-40 to 140°F)

Speed

Range: 0	– 67 meters per second (150 mph)
Accuracy:	Greater of 0.45m/sec. (1 mph) or 5%
Threshold:	0.89m/sec. (2 mph)

Direction

Range:	360°
Resolution:	22.5°
Accuracy:	+/- 22.5°
Threshold:	0.9 m/sec. (2 mph) at a 10° deflection.

RS-485/422 Serial Specifications:

Mode:	2-wire half duplex
Connector:	4-position screw terminal
Max Speed:	19200 bps
Max. Modbus Poll Rate:	100 ms
Termination:	120 ohms (internal jumper enable)

6. Transformer Data Sheet

Distribution Transformers

Standart Dağıtım Trafoları (TEDAŞ-MYD/95-012.E)

33/0.4 kV AL Genleşme Depolu Trafolar / *Transformers with Conservator Tank*

Güç (kVA) *Power (kVA)*	50	100	160	250	400	630	800	1000	1250	1600
En (mm) *Width (mm)*	865	905	1000	960	990	1160	1040	1080	1070	1100
Boy (mm) *Length (mm)*	790	880	950	1405	1650	1690	1978	2068	2090	2095
Yükseklik (mm) *Height (mm)*	1510	1600	1620	1570	1940	1940	1960	1990	2090	2300
Ağırlık (kg) *Weight (kg)*	470	640	890	1090	1490	1980	2360	2690	3050	3560
Boşta Kayıp (W) No-Load Loss (W)	160	270	390	550	790	1100	1300	1450	1750	2200
Yükte Kayıp (W) Load Loss (W)	1050	1650	2150	3000	4150	5500	7000	8900	11500	14500
uk (%)	4,5	4,5	4,5	4,5	4,5	4,5	6	6	6	6

Standart Dağıtım Trafoları (TEDAŞ-MLZ/95-012.F)

33/0.4 kV AL Genleşme Depolu Trafolar / *Transformers with Conservator Tank*

Güç (kVA) *Power (kVA)*	25	50	100	160	250	400	630	800	1000	1250	1600
En (mm) *Width (mm)*	870	1055	1035	1085	830	820	1010	1070	1110	1100	1170
Boy (mm) *Length (mm)*	760	870	910	1030	1595	1690	1690	2058	2090	2080	2090
Yükseklik (mm) *Height (mm)*	1470	1410	1630	1570	1710	1940	2090	2100	2220	2290	2440
Ağırlık (kg) *Weight (kg)*	402	674	868	1020	1230	1660	2250	2790	3230	3360	3990
Boşta Kayıp (W) No-Load Loss (W)	81	105	170	242	345	495	690	750	885	1095	1380
Yükte Kayıp (W) Load Loss (W)	660	825	1375	1925	2585	3575	5060	6600	8360	10450	13200
uk (%)	4,5	4,5	4,5	4,5	4,5	4,5	4,5	6	6	6	6

** Dimensions and weights are approximate. They can vary according to customer request and accessories.*

Appendix C: Certifications

1. PV Module Palestine Standards Institution Certification

STATE OF PALESTINE
Palestine Standards Institution
Technical Services Dept.

دولة فلسطين
مؤسسة المواصفات والمقاييس الفلسطينية
دائرة الخدمات الفنية

شهادة مطابقة رقم : C-347-S/E-2017

تفاصيل الفحص :

التاريخ : 2017/12/12

رقم الطلب : E82/2017	
اسم طالب الفحص : تربيل كي سولار للتجارة والتعهدات.	العنوان : رام الله.
هاتف :02-2958410	فاكس : 02-2958415

تفاصيل العينة :

اسم المنتوج	الرقم الكتالوجي	اسم الشركة الصانعة	العنوان
Photovoltaic (PV) Module	Hanwha Q.POWER L-G5 XXX Where (XXX= 310-335 W)	Hanwha	China

هدف الفحص :

التحقق من مطابقة المنتوجات أعلاه للمواصفات الفلسطينية :

- PS-2684:2012 IEC 61730-1-2011 (Photovoltaic (PV) module safety qualification- Part 1: requirements for construction).
- PS 2685:2012 IEC 61730-2 (clauses: 10.1, 10.4, 10.6-1) Photovoltaic (PV) module safety qualification - Part 2: requirements for testing.
- PS 2951:2012 IEC 61215 (clause 10.17) crystalline silicon terrestrial photovoltaic (PV) modules (Hail Test) Design qualification and type approval.

نتيجة الفحص :

تم التحقق من المنتجات أعلاه ووجدت بأنها مطابقة للمواصفات الفلسطينية المذكورة .

ملاحظات:

1. تم الفحص بمؤسسة المواصفات الاسرائيلية بناءاً على طلب (Hanwha Solar one Gmbh-Israel) .
2. أصدرت هذه الشهادة بناءاً على تقرير فحص مؤسسة المواصفات الاسرائيلية رقم :9713209520.
3. فحصت المنتجات أعلاه وفق المواصفات المرجعية التالية :
   - IEC 61730-1-2017 which is equivalent to PS-2684:2012 IEC 61730-1.
   - IEC 61730-2 which is equivalent to PS-2685:2012 IEC 61730-2.
   - IEC 61215 which is equivalent to PS-2951:2012 IEC 61215.

This certificate is valid till: 12. 12.2018.

مدقق أول: م. نور الدين ناصر

مدقق ثاني: م. تحسين سليمان
رئيس قسم الكهرباء

م . أحمد الأحمد
مدير دائرة الخدمات الفنية

Palestine Standards Institution
مؤسسة المواصفات والمقاييس الفلسطينية
دائرة الخدمات الفنية

Ramallah – Jerusalem St – Attal District – P O Box 2258 رام الله – شارع القدس – حي التل - ص ب
Tel:+970-(0)2-2984144\2965191 Fax:+970-(0)2-2964433 info@psi.pna.ps www.psi.pna.ps

1/1

2. Inverter PSI Certification

State of Palestine
Palestine Standards Institution
Technical Services Dept.

دولة فلسطين
مؤسسة المواصفات والمقاييس الفلسطينية
دائرة الخدمات الفنية

شهادة مطابقة رقم : C-91-S/E-2018

تفاصيل الفحص :

التاريخ : 2018/08/16

رقم الطلب : 357/2017	
اسم طالب الفحص : 3K SOLAR Trading & Contracting Company Ltd	العنوان : رام الله.
هاتف : 02-958410	فاكس : 02-2958415

تفاصيل العينة :

اسم المنتوج	الرقم الكتالوجي	اسم الشركة الصانعة	العنوان
Photovoltaic Grid Tied Inverter	1. ABB PVI-10.0-TL-OUTD PVI-10.0-TL-OUTD-S PVI-10.0-TL-OUTD-FS PVI-12.5-TL-OUTD PVI-12.5-TL-OUTD-S PVI-12.5-TL-OUTD-FS PVI-12.5-TL-OUTD-W	Power-One Italy S.p.a	Italy
	2. POWER-ONE TRIO-20.0-TL-OUTD-400 TRIO-20.0-TL-OUTD-S2-400 TRIO-20.0-TL-OUTD-S2X-400 TRIO-20.0-TL-OUTD-S2F-400 TRIO-27.6-TL-OUTD-400 TRIO-27.6-TL-OUTD-S2-400 TRIO-27.6-TL-OUTD-S2X-400 TRIO-27.6-TL-OUTD-S2F-400		

هدف الفحص :

التحقق من مطابقة المنتوجات أعلاه للمواصفة الفلسطينية التالية:
- م ف 2691 ج1: 2017 أمان عواكس القدرة المستخدمة في أنظمة الطاقة الكهروضونية – (ج1: متطلبات عامة).

نتيجة الفحص :

تم التحقق من المنتجات أعلاه ووجدت بأنها مطابقة للمواصفة الفلسطينية المذكورة .

ص 2192/2018

Ramallah – Jerusalem St – Attal District – P O Box 2258 حي التل - ص ب
Tel: +970-(0)2-2984144\2965191 Fax:+970-(0)2-2964433 info@psi.pna.ps

1/2 C-91-S/E-2018

State of Palestine
Palestine Standards Institution
Technical Services Dept.

دولة فلسطين
مؤسسة المواصفات والمقاييس الفلسطينية
دائرة الخدمات الفنية

الفاحص:

- The testing Lab. of the above mentioned products in clauses no. 1 is Standards Institution of Israel (SII) – Israel, upon the request of (Power One Renewable Energy Solutions Israel Ltd. – Israel) according to test certificates no. : 9312328884.
- The testing Lab. of the above mentioned products clauses no. 2 is TÜV Rheinland Italia Srl – Italy.

Note:

- The above mentioned products have been tested according to the standard: IEC 62109-1:2010 (Safety of power converters for use in photovoltaic power systems Part 1: General requirements) which is equivalent to PS 2691 P1.

■ **This certificate is valid till 16.08.2019**

مدقق أول: م. مصعب تقيوي

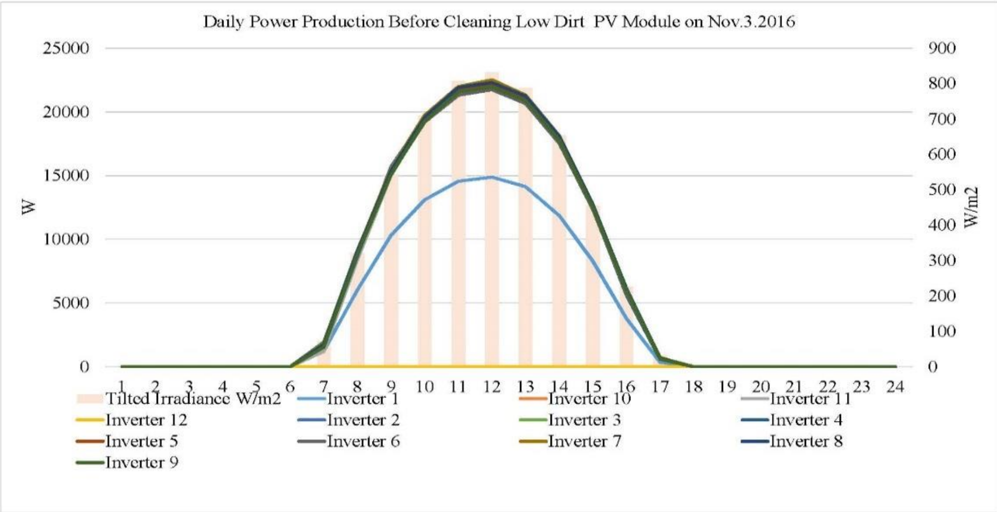
مدقق ثاني : م. تحسين سليمان
رئيس قسم الكهرباء

م. احمد الأحمد
مدير دائرة الخدمات الفنية

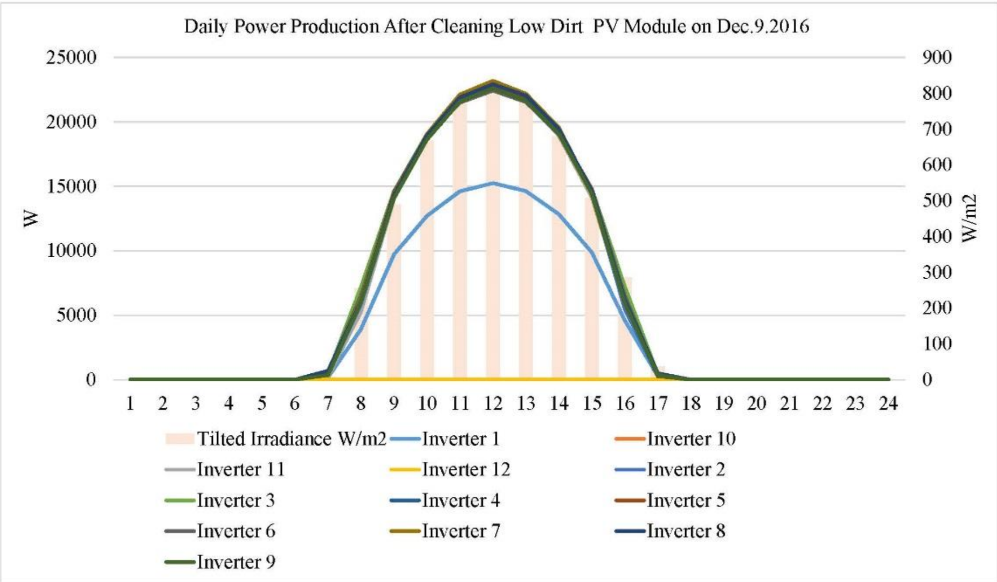
Ramallah – Jerusalem St – Attal District – P O Box 2258 رام الله – شارع القدس – حي التل – ص ب
Tel:+970-(0)2-2984144/2965191 Fax:+970-(0)2-2964433 info@psi.pna.ps www.psi.pna.ps

Appendix D: Effect of Dirt, Dust and Soiling on PV Power Station Performance

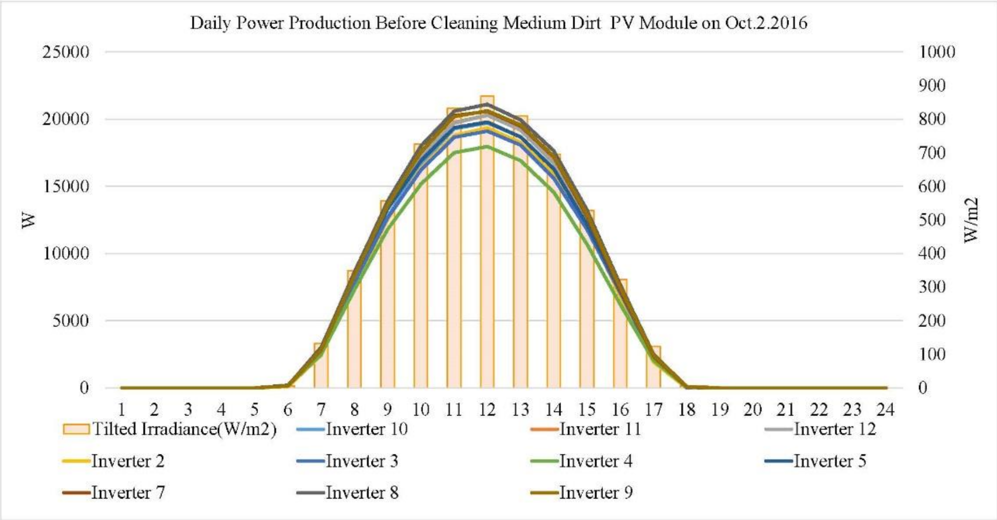
1. Before Cleaning Low Dirt PV Module



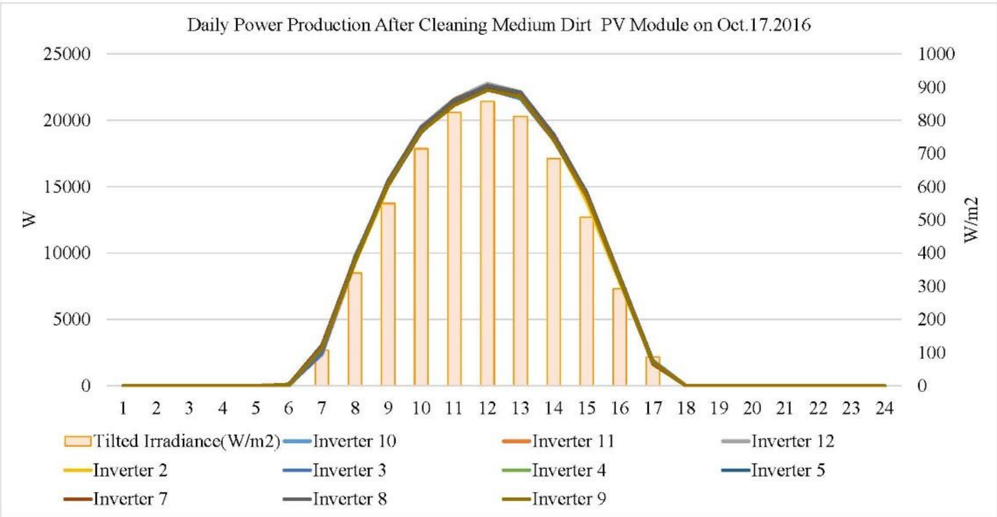
2. After Cleaning Low Dirt PV Module.



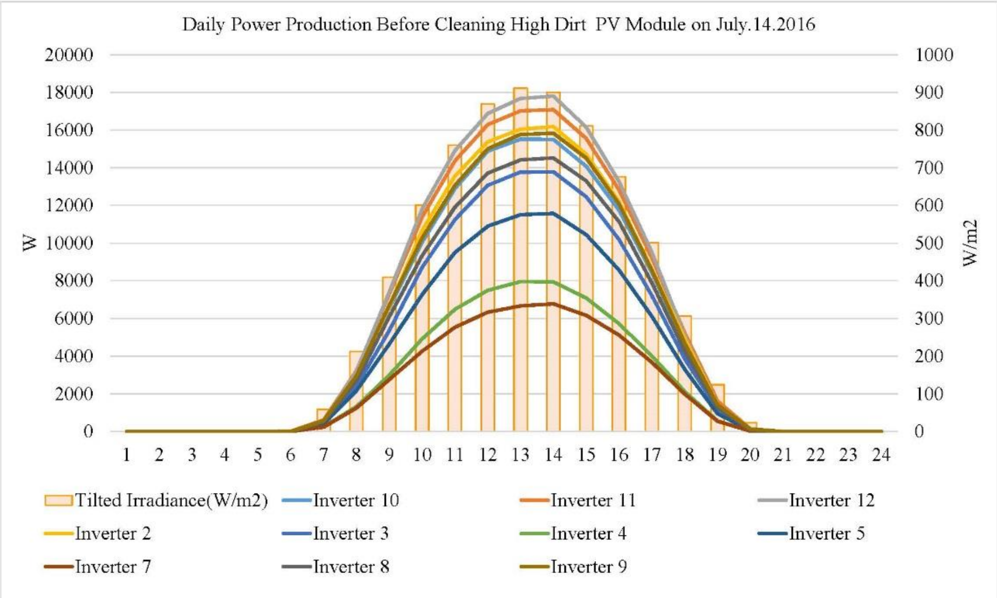
3. Before Cleaning Medium Dirt PV Module



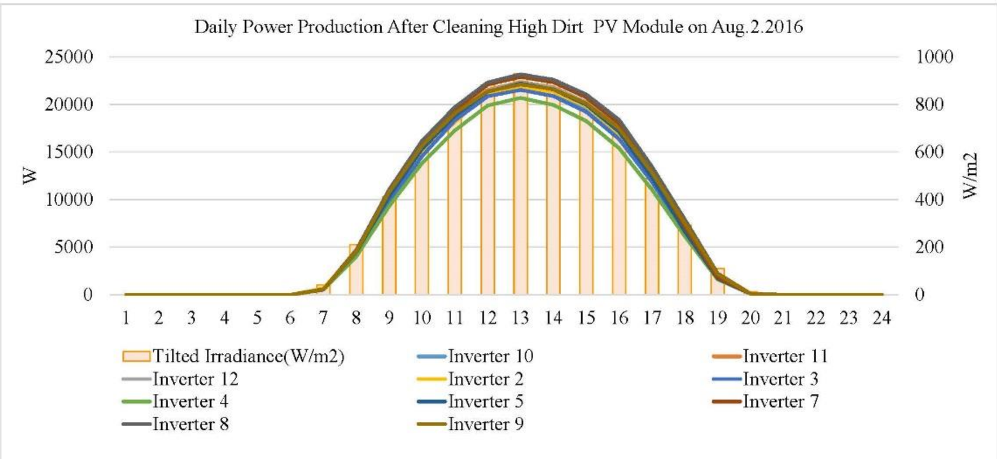
4. After Cleaning Medium Dirt PV Module



5. Before Cleaning High Dirt PV Module



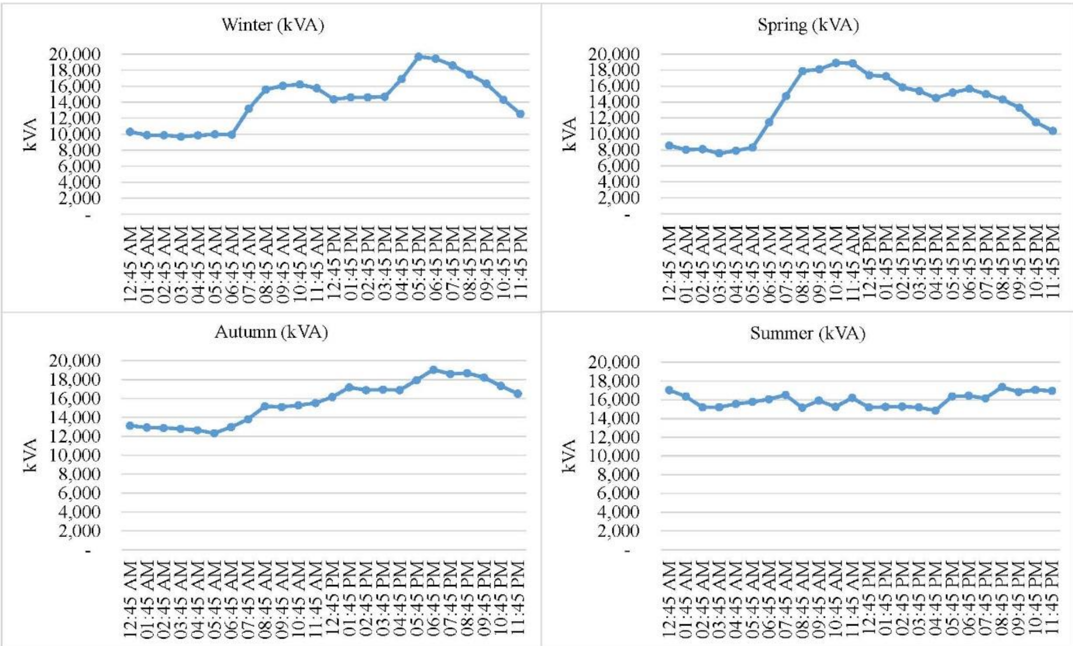
6. After Cleaning High Dirt PV Module



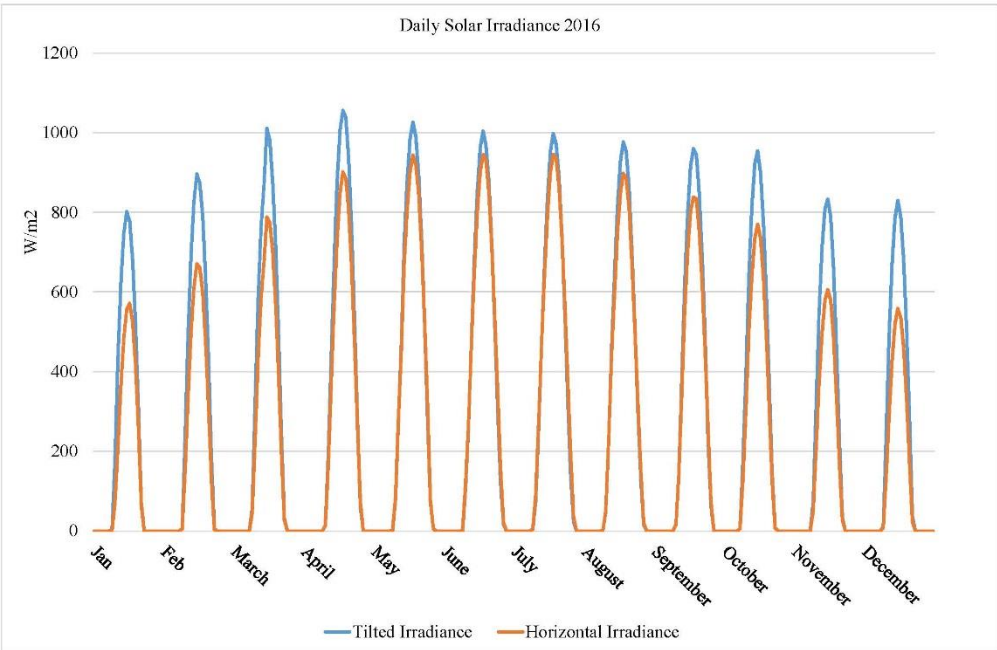
Appendix E: Schematics Diagrams and Tables

1. TDECO Load Curve in 2017

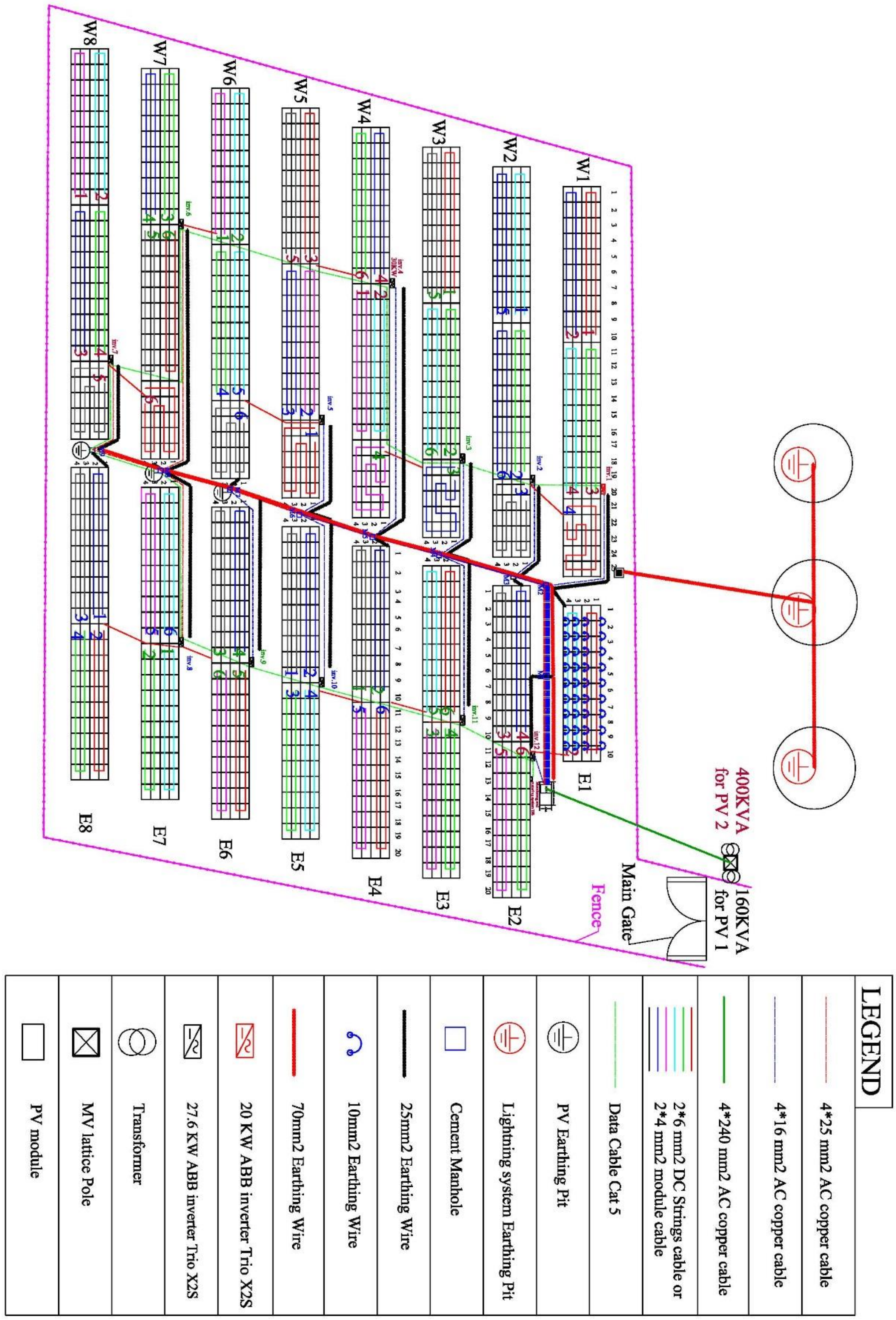
TDECO Daily Load Curve for Four Sesons in 2017



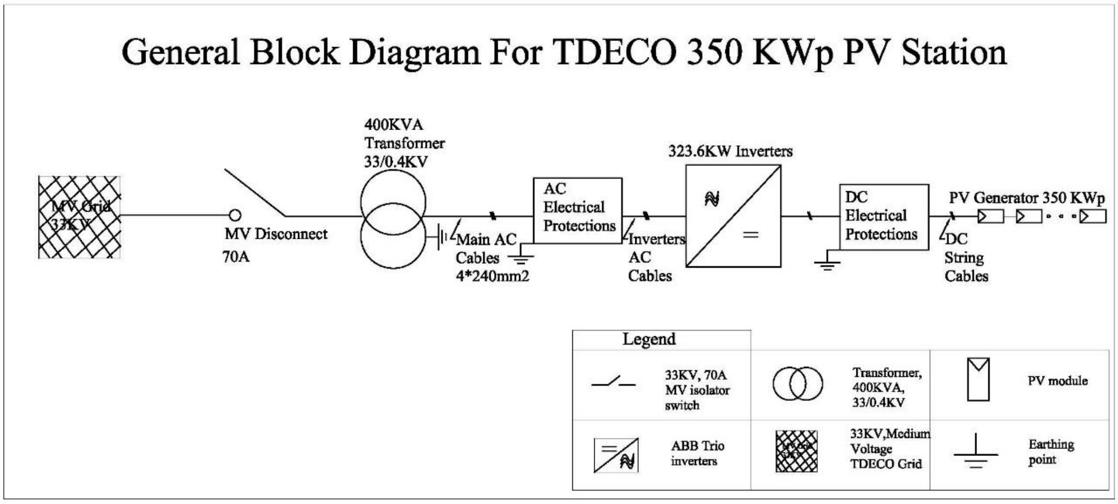
2. Daily Solar Irradiance in 2016



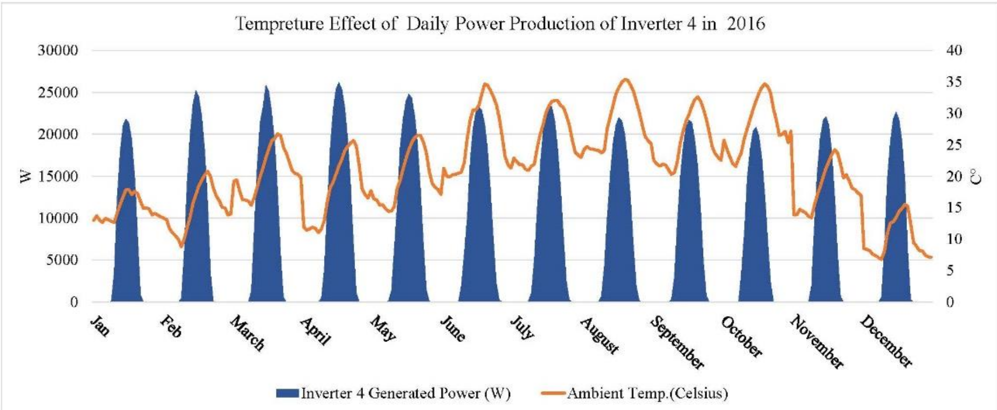
3. Top View of the 350KWp PV Power Station-A3



4. General Block Diagram



5. Temperature Effect of Daily Power Production of Inverter 4



6. The Daily Measurements of Actual Power Production

Appendix E.6: The Daily Measurements of Actual Power Production of the PV Station, for a Typical Clear Day of Each Month Performed on Hourly Basis.

Month	Timestamp	Actual Invertes Total power (W)	Month	Timestamp	Actual Invertes Total power (W)
Jan	06/01/2016 0:00	0	Feb	04/02/2016 0:00	0
	06/01/2016 1:00	0		04/02/2016 1:00	0
	06/01/2016 2:00	0		04/02/2016 2:00	0
	06/01/2016 3:00	0		04/02/2016 3:00	0
	06/01/2016 4:00	0		04/02/2016 4:00	0
	06/01/2016 5:00	0		04/02/2016 5:00	0
	06/01/2016 6:00	1548.37		04/02/2016 6:00	3900.41
	06/01/2016 7:00	43478.43		04/02/2016 7:00	69510.03
	06/01/2016 8:00	145615.95		04/02/2016 8:00	169271.36
	06/01/2016 9:00	207750.73		04/02/2016 9:00	235919.77
	06/01/2016 10:00	244400.33		04/02/2016 10:00	276944.66
	06/01/2016 11:00	254097.47		04/02/2016 11:00	294381.69
	06/01/2016 12:00	250007.46		04/02/2016 12:00	285410.76
	06/01/2016 13:00	226588.43		04/02/2016 13:00	259912.02
	06/01/2016 14:00	177034.69		04/02/2016 14:00	212932.72
	06/01/2016 15:00	95688.18		04/02/2016 15:00	142309.79
	06/01/2016 16:00	11573.1		04/02/2016 16:00	46386.95
	06/01/2016 17:00	0		04/02/2016 17:00	593.63
	06/01/2016 18:00	0		04/02/2016 18:00	0
	06/01/2016 19:00	0		04/02/2016 19:00	0
	06/01/2016 20:00	0		04/02/2016 20:00	0
	06/01/2016 21:00	0		04/02/2016 21:00	0
	06/01/2016 22:00	0		04/02/2016 22:00	0
	06/01/2016 23:00	0		04/02/2016 23:00	0

Appendix E.6: The Daily Measurements of Actual Power Production of the PV Station, for a Typical Clear Day of Each Month Performed on Hourly Basis.

Month	Timestamp	Actual Invertes Total power (W)	Month	Timestamp	Actual Invertes Total power (W)
March	01/03/2016 0:00	0	April	01/04/2016 1:00	0
	01/03/2016 1:00	0		01/04/2016 1:00	0
	01/03/2016 2:00	0		01/04/2016 2:00	0
	01/03/2016 3:00	0		01/04/2016 3:00	0
	01/03/2016 4:00	0		01/04/2016 4:00	0
	01/03/2016 5:00	0		01/04/2016 5:00	0
	01/03/2016 6:00	16494.31		01/04/2016 6:00	4597.2
	01/03/2016 7:00	101334.45		01/04/2016 7:00	46409.29
	01/03/2016 8:00	186928.59		01/04/2016 8:00	136508.86
	01/03/2016 9:00	241868.5		01/04/2016 9:00	213485.64
	01/03/2016 10:00	264003.71		01/04/2016 10:00	264303.85
	01/03/2016 11:00	301884.71		01/04/2016 11:00	295908.66
	01/03/2016 12:00	293388.67		01/04/2016 12:00	305870.56
	01/03/2016 13:00	265711.33		01/04/2016 13:00	298233.99
	01/03/2016 14:00	222047.23		01/04/2016 14:00	272973.3
	01/03/2016 15:00	154057.07		01/04/2016 15:00	229527.78
	01/03/2016 16:00	66211.49		01/04/2016 16:00	164040.85
	01/03/2016 17:00	5127.64		01/04/2016 17:00	80125.84
	01/03/2016 18:00	0		01/04/2016 18:00	11885.71
	01/03/2016 19:00	0		01/04/2016 19:00	0
	01/03/2016 20:00	0		01/04/2016 20:00	0
	01/03/2016 21:00	0		01/04/2016 21:00	0
	01/03/2016 22:00	0		01/04/2016 22:00	0
	01/03/2016 23:00	0		01/04/2016 23:00	0

Appendix E.6: The Daily Measurements of Actual Power Production of the PV Station, for a Typical Clear Day of Each Month Performed on Hourly Basis.

Month	Timestamp	Actual Invertes Total power (W)	Month	Timestamp	Actual Invertes Total power (W)
May	11/05/2016 0:00	0	June	01/06/2016 0:00	0
	11/05/2016 1:00	0		01/06/2016 1:00	0
	11/05/2016 2:00	0		01/06/2016 2:00	0
	11/05/2016 3:00	0		01/06/2016 3:00	0
	11/05/2016 4:00	0		01/06/2016 4:00	0
	11/05/2016 5:00	813.59		01/06/2016 5:00	266.7
	11/05/2016 6:00	13900.45		01/06/2016 6:00	23400.27
	11/05/2016 7:00	70256.81		01/06/2016 7:00	67785.05
	11/05/2016 8:00	137270.57		01/06/2016 8:00	129223.14
	11/05/2016 9:00	214407.77		01/06/2016 9:00	196778.74
	11/05/2016 10:00	253122.21		01/06/2016 10:00	241140.87
	11/05/2016 11:00	277122.89		01/06/2016 11:00	264350.79
	11/05/2016 12:00	287566.22		01/06/2016 12:00	270561.78
	11/05/2016 13:00	280791.27		01/06/2016 13:00	264713.12
	11/05/2016 14:00	259409.48		01/06/2016 14:00	247485.55
	11/05/2016 15:00	219201.78		01/06/2016 15:00	211554.07
	11/05/2016 16:00	158785.19		01/06/2016 16:00	155163.37
	11/05/2016 17:00	80702.21		01/06/2016 17:00	84447.05
	11/05/2016 18:00	18041.19		01/06/2016 18:00	24702.81
	11/05/2016 19:00	1142.09		01/06/2016 19:00	2357.48
	11/05/2016 20:00	0		01/06/2016 20:00	0
	11/05/2016 21:00	0		01/06/2016 21:00	0
	11/05/2016 22:00	0		01/06/2016 22:00	0
	11/05/2016 23:00	0		01/06/2016 23:00	0

Appendix E.6: The Daily Measurements of Actual Power Production of the PV Station, for a Typical Clear Day of Each Month Performed on Hourly Basis.

Month	Timestamp	Actual Invertes Total power (W)	Month	Timestamp	Actual Invertes Total power (W)
July	01/07/2016 0:00	0	August	03/08/2016 0:00	0
	01/07/2016 1:00	0		03/08/2016 1:00	0
	01/07/2016 2:00	0		03/08/2016 2:00	0
	01/07/2016 3:00	0		03/08/2016 3:00	0
	01/07/2016 4:00	0		03/08/2016 4:00	0
	01/07/2016 5:00	1014.29		03/08/2016 5:00	10.7
	01/07/2016 6:00	12141.01		03/08/2016 6:00	6925.7
	01/07/2016 7:00	58408.9		03/08/2016 7:00	47620.99
	01/07/2016 8:00	129322.53		03/08/2016 8:00	122433.72
	01/07/2016 9:00	189329		03/08/2016 9:00	174238.92
	01/07/2016 10:00	234949.38		03/08/2016 10:00	217719.09
	01/07/2016 11:00	264457.95		03/08/2016 11:00	244730.06
	01/07/2016 12:00	273902.46		03/08/2016 12:00	253303.74
	01/07/2016 13:00	269641.93		03/08/2016 13:00	249476.58
	01/07/2016 14:00	251403.6		03/08/2016 14:00	231197.29
	01/07/2016 15:00	213997.27		03/08/2016 15:00	190597.06
	01/07/2016 16:00	159999.53		03/08/2016 16:00	140386.11
	01/07/2016 17:00	91090.99		03/08/2016 17:00	76114.64
	01/07/2016 18:00	26938.99		03/08/2016 18:00	22555.41
	01/07/2016 19:00	2527.04		03/08/2016 19:00	1717.52
	01/07/2016 20:00	0		03/08/2016 20:00	0
	01/07/2016 21:00	0		03/08/2016 21:00	0
	01/07/2016 22:00	0		03/08/2016 22:00	0
	01/07/2016 23:00	0		03/08/2016 23:00	0

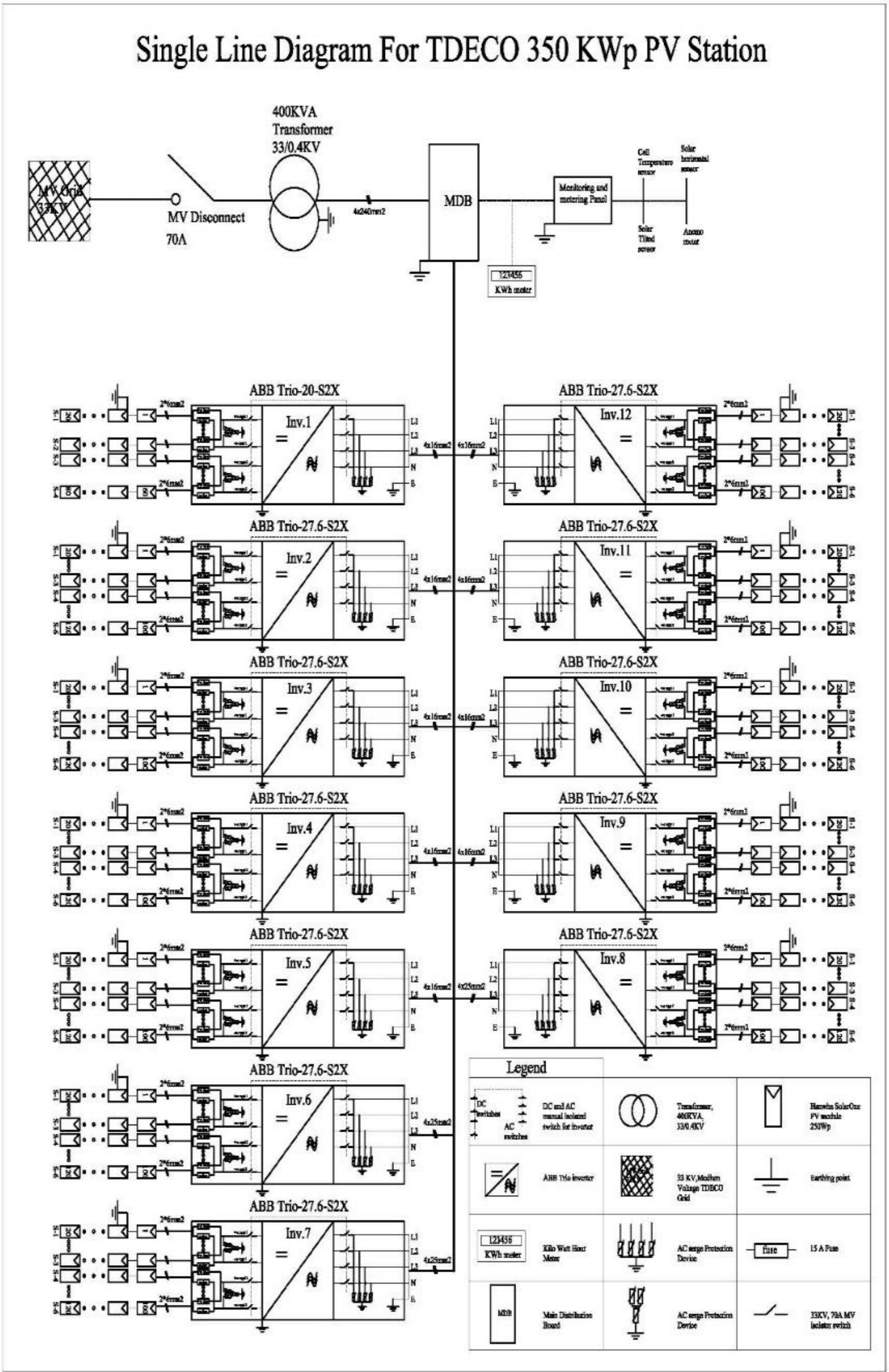
Appendix E.6: The Daily Measurements of Actual Power Production of the PV Station, for a Typical Clear Day of Each Month Performed on Hourly Basis.

Month	Timestamp	Actual Invertes Total power (W)	Month	Timestamp	Actual Invertes Total power (W)
September	01/09/2016 0:00	0	October	09/10/2016 0:00	0
	01/09/2016 1:00	0		09/10/2016 1:00	0
	01/09/2016 2:00	0		09/10/2016 2:00	0
	01/09/2016 3:00	0		09/10/2016 3:00	0
	01/09/2016 4:00	0		09/10/2016 4:00	0
	01/09/2016 5:00	0		09/10/2016 5:00	1231.12
	01/09/2016 6:00	3740.98		09/10/2016 6:00	24485.97
	01/09/2016 7:00	32291.65		09/10/2016 7:00	99666.02
	01/09/2016 8:00	97436.58		09/10/2016 8:00	167139.47
	01/09/2016 9:00	154295		09/10/2016 9:00	208809.04
	01/09/2016 10:00	194594.25		09/10/2016 10:00	232524.85
	01/09/2016 11:00	219300.75		09/10/2016 11:00	237443.89
	01/09/2016 12:00	229195.58		09/10/2016 12:00	232284.02
	01/09/2016 13:00	226013.81		09/10/2016 13:00	208007.45
	01/09/2016 14:00	204858.13		09/10/2016 14:00	160239.91
	01/09/2016 15:00	170198.85		09/10/2016 15:00	93304.46
	01/09/2016 16:00	118233.5		09/10/2016 16:00	24757.73
	01/09/2016 17:00	54260.75		09/10/2016 17:00	352.83
	01/09/2016 18:00	8604.82		09/10/2016 18:00	0
	01/09/2016 19:00	0		09/10/2016 19:00	0
	01/09/2016 20:00	0		09/10/2016 20:00	0
	01/09/2016 21:00	0		09/10/2016 21:00	0
	01/09/2016 22:00	0		09/10/2016 22:00	0
	01/09/2016 23:00	0		09/10/2016 23:00	0

Appendix E.6: The Daily Measurements of Actual Power Production of the PV Station, for a Typical Clear Day of Each Month Performed on Hourly Basis.

Month	Timestamp	Actual Invertes Total power (W)	Month	Timestamp	Actual Invertes Total power (W)
November	03/11/2016 0:00	0	December	09/12/2016 0:00	0
	03/11/2016 1:00	0		09/12/2016 1:00	0
	03/11/2016 2:00	0		09/12/2016 2:00	0
	03/11/2016 3:00	0		09/12/2016 3:00	0
	03/11/2016 4:00	0		09/12/2016 4:00	0
	03/11/2016 5:00	0		09/12/2016 5:00	0
	03/11/2016 6:00	18264.32		09/12/2016 6:00	4802.48
	03/11/2016 7:00	94945.22		09/12/2016 7:00	65765.23
	03/11/2016 8:00	163852.39		09/12/2016 8:00	152943.89
	03/11/2016 9:00	207923.04		09/12/2016 9:00	201277.66
	03/11/2016 10:00	231633.54		09/12/2016 10:00	232121.32
	03/11/2016 11:00	236032.42		09/12/2016 11:00	242547.1
	03/11/2016 12:00	224315.77		09/12/2016 12:00	232415.79
	03/11/2016 13:00	190305.04		09/12/2016 13:00	204506.86
	03/11/2016 14:00	133951.44		09/12/2016 14:00	155339.22
	03/11/2016 15:00	62803.5		09/12/2016 15:00	66208.85
	03/11/2016 16:00	6701.01		09/12/2016 16:00	3898.53
	03/11/2016 17:00	0		09/12/2016 17:00	0
	03/11/2016 18:00	0		09/12/2016 18:00	0
	03/11/2016 19:00	0		09/12/2016 19:00	0
	03/11/2016 20:00	0		09/12/2016 20:00	0
	03/11/2016 21:00	0		09/12/2016 21:00	0
	03/11/2016 22:00	0		09/12/2016 22:00	0
	03/11/2016 23:00	0		09/12/2016 23:00	0

7. 350KWp SLD

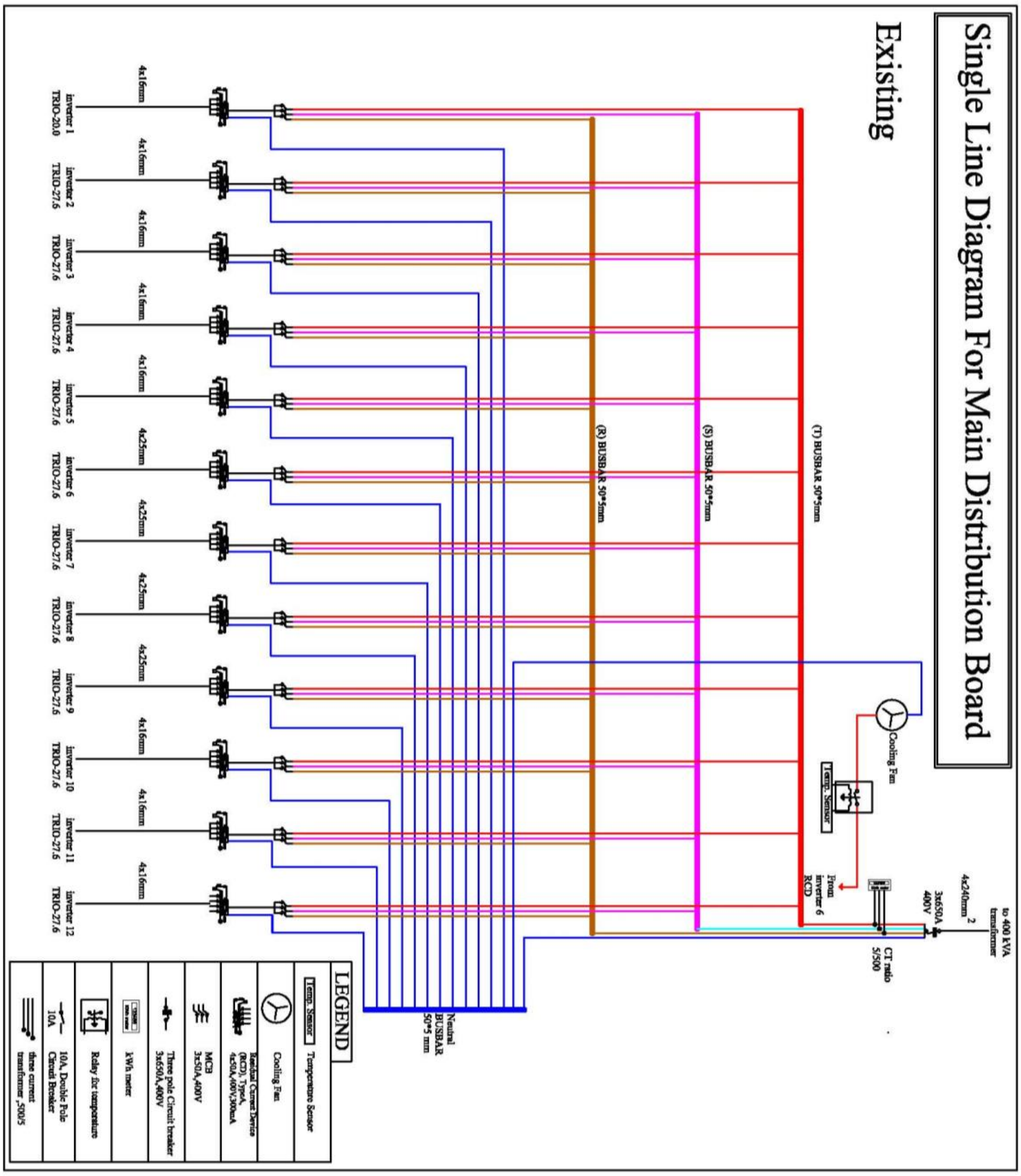


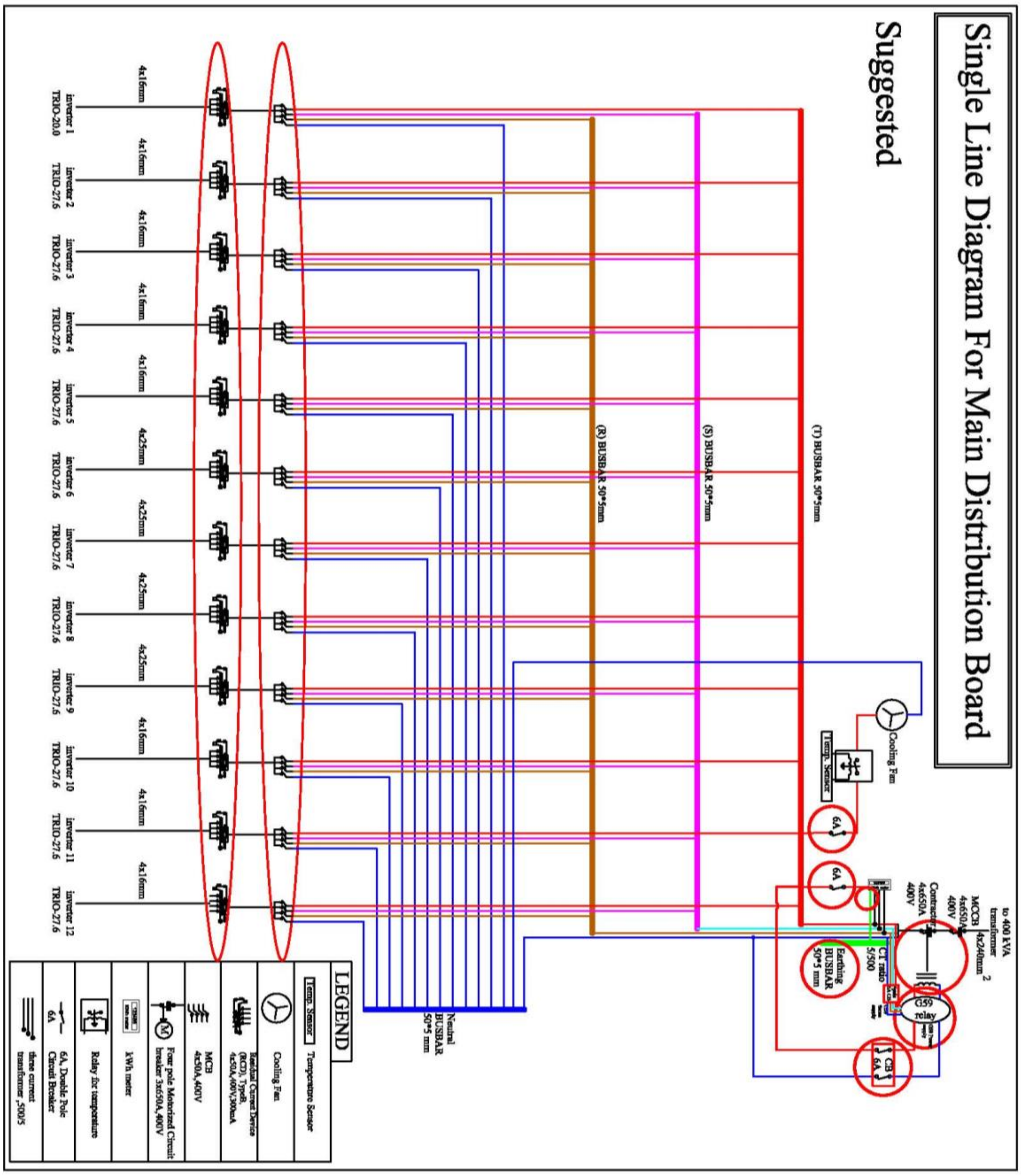
Single Line Diagram For TDECO 350 KWp PV Station
400KVA
Transformer
33/0.4KV
MV Grid
33KV
MV Disconnect
70A
4x240mm2
MDB
Monitoring and metering Panel
KWh meter
ABB Trio-20-S2X
Inv.1
ABB Trio-27.6-S2X
Inv.2
Inv.3
Inv.4
Inv.5
Inv.6
Inv.7
Inv.8
Inv.9
Inv.10
Inv.11
Inv.12
4x16mm2
4x25mm2
L1
L2
L3
N
E
Legend
DC and AC manual isolated switch for Inverter
ABB Trio inverter
Kilo Watt Hour Meter
Main Distribution Board
AC surge Protection Device
Earthing point
15 A Fuse

8. Comparison of Supply Voltage Requirements According to EN 50160 and the EMC Standards EN 61000

No	Parameter	Supply voltage characteristics according to EN 50160	Low voltage characteristics according to EMC standard EN 61000	
			EN 61000-2-2	Other parts
1	Power frequency	LV, MV: mean value of fundamental measured over 10 s ±1% (49.5 - 50.5 Hz) for 99.5% of week -6%/+4% (47- 52 Hz) for 100% of week	2%	
2	Voltage magnitude variations	LV, MV: ±10% for 95% of week, mean 10 minutes rms values (Figure 1)		±10% applied for 15 minutes
3	Rapid voltage changes	LV: 5% normal 10% infrequently $P_{lt} \leq 1$ for 95% of week MV: 4% normal 6% infrequently $P_{lt} \leq 1$ for 95% of week	3% normal 8% infrequently $P_{st} < 1.0$ $P_{lt} < 0.8$	3% normal 4% maximum $P_{st} < 1.0$ $P_{lt} < 0.65$ (EN 61000-3-3) 3% (IEC 61000-2-12)
4	Supply voltage dips	Majority: duration <1s, depth <60%. Locally limited dips caused by load switching on: LV: 10 - 50%, MV: 10 - 15% (Figure 1)	urban: 1 - 4 months	up to 30% for 10 ms up to 60% for 100 ms (EN 61000-6-1, 6-2) up to 60% for 1000 ms (EN 61000-6-2)
5	Short interruptions of supply voltage	LV, MV: (up to 3 minutes) few tens - few hundreds/year Duration 70% of them < 1 s		95% reduction for 5 s (EN 61000-6-1, 6-2)
6	Long interruption of supply voltage	LV, MV: (longer than 3 minutes) <10 - 50/year		
7	Temporary, power frequency overvoltages	LV: <1.5 kV rms MV: 1.7 U_c (solid or impedance earth) 2.0 U_c (unearthed or resonant earth)		
8	Transient overvoltages	LV: generally < 6kV, occasionally higher; rise time: ms - µs. MV: not defined		±2 kV, line-to-earth ±1 kV, line-to-line 1.2/50(8/20) Tr/Th µs (EN 61000-6-1, 6-2)
9	Supply voltage unbalance	LV, MV: up to 2% for 95% of week, mean 10 minutes rms values, up to 3% in some locations	2%	2% (IEC 61000-2-12)
10	Harmonic voltage	LV, MV: see Table 2	6%-5th, 5%-7th, 3.5%-11th, 3%-13th, THD <8%	5% 3rd, 6% 5th, 5% 7th, 1.5% 9th, 3.5% 11th, 3% 13th, 0.3% 15th, 2% 17th (EN 61000-3-2)
11	Interharmonic voltage	LV, MV: under consideration	0.2%	

9. SLD for MDB


Single Line Diagram For Main Distribution Board
Existing
(T) BUSBAR 50*5mm
(S) BUSBAR 50*5mm
(R) BUSBAR 50*5mm
Neutral BUSBAR 50*5 mm
Cooling Fan
Temp. Sensor
to 400 kVA transformer
4x240mm 2
3x650A 400V
CT ratio 5/500
From inverter 6 RCD
inverter 1 TRIO-20.0
inverter 2 TRIO-27.6
inverter 3 TRIO-27.6
inverter 4 TRIO-27.6
inverter 5 TRIO-27.6
inverter 6 TRIO-27.6
inverter 7 TRIO-27.6
inverter 8 TRIO-27.6
inverter 9 TRIO-27.6
inverter 10 TRIO-27.6
inverter 11 TRIO-27.6
inverter 12 TRIO-27.6
4x16mm
4x25mm
LEGEND
Temperature Sensor
Cooling Fan
Residual Current Device (RCD), TypeA, 4x50A,400V,300mA
MCB 3x50A,400V
Three pole Circuit breaker 3x650A,400V
kWh meter
Relay for temperature
10A, Double Pole Circuit Breaker
three current transformer ,500/5


Single Line Diagram For Main Distribution Board
Suggested
(T) BUSBAR 50*5mm
(S) BUSBAR 50*5mm
(R) BUSBAR 50*5mm
LEGEND
Temperature Sensor
Cooling Fan

Appendix F: Checklists

1. Site Selection Checklist

	Inspection Point	Available or Not	Notes and Recommendations
1	Is the grid connection assessed (capacity, proximity, right-of-way, stability and availability?	Available	
2	Is the area enough for the PV power station?	Available	
3	Is the site soil stable for installing PV power station by soil sampling and in-situ testing, at a depth appropriate for the foundation design, usually around 2.5m to 3m below ground level to assess load-bearing properties of the soil, soil pH and chemical constituents in order to assess the degree of corrosion protection?	Available	
4	Is the site classified as low average number of lightning strikes?	Available	
5	Is the site classified as area A or B according to Oslo classification?	Available	
6	Is the site land use classified as low agricultural value?	Available	
7	Has the site suitable orientation toward the south?	Available	
8	Aren’t there high building, trees or any shading resources near the site?	Available	
9	Is the site need acceptable land preparation cost?	Not Available	The site was very rocky area and part of land facing to the north that needs a lot

	Inspection Point	Available or Not	Notes and Recommendations
			of land preparation cost.
10	Are the potential access routes to site assessed?	Available	
11	Are the water supply available in the site?	Not Available	It needs mobile water tank.
12	Are there internet access in the site?	Not Available	It needs wireless communication from the TDECO's main center.
13	Aren’t there shading on the site during the daytime?	Available	
14	Is the ownership of land determined?	Available	It is governmental area customized for TDECO for 20 years.
15	Is the site topology suitable for PV power station?	Not Available	Before land preparation, the site was harsh topology and part of it facing to the north
16	Are there financial incentives of installing PV power station?	Available	AS mentioned in section 7.1.2
17	Aren’t there risk of a high wind in the site?	Available	
18	Aren’t there in the site local air pollution sources like industries that may reduce the irradiation received or contain significant levels of airborne sulphur or other potentially corrosive substances?	Available	

2. PV Module Checklist

	Inspection point	Current situation	Notes and recommended modifications
1	Has the silicone sealing of the junction box and module frame edges regular (No too much silicon)?	Yes	
2	Have inside PV module junction box good insulator sealed?	Yes	
3	Have module junction box durable fixed to the backside of the module?	Yes	
4	Are the PV junction boxes covering closed well?	Yes	
5	Doesn't have any silicone on the front (glass) side of a module?	Yes	
6	Are there no object (grain of sand or similar) laminated between a cell and the foil that could cause a lack of cleanliness of the production process?	Yes	
7	Have PV module Power Output Tolerance – P_{max} (%) ≤ +3?	Yes	
8	Has module efficiency at STC more than 15%?	Yes	These modules have 15.5% at STC
9	Are STC fill factor between 0.75and 0.85?	Yes	The FF is 0.755

	Inspection point	Current situation	Notes and recommended modifications
10	Has Aluminum Frame?	Yes	
11	Has Operational Temperature -40 ~ +85 °C; Maximum System Voltage 1000 VDC; Max Series Fuse rating 15 A?	Yes	
12	Has Fire Safety Classification class A or C according to IEC 61730?	Yes	It has class C
13	Has protection class IP 65 for junction box?	Yes	It has IP67
14	Have junction box sets of diodes?	Yes	JB have 3 diodes set
15	Have MC4 solar connectors considered highest DC voltage and current of the PV system?	Yes	
16	Has the PV module suitable operating temperature of this site?	Yes	According to Table (3.7) “cell temperature on 2016” this PV module was on the accepted rang. Site temperature was -4.7°C to 69.1°C and the operating temperature was -40°C to 85°C.
17	Certifications:		
17.1	IEC61215: "design qualification and type approval "	Yes	

	Inspection point	Current situation	Notes and recommended modifications
17.2	IEC 61730: "PV module safety qualification	Yes	
17.3	IEC 61701: "Salt mist corrosion testing of PV modules "	Not Required	This is for PV modules were installed in coastal areas
17.4	IEC 62716: “PV modules- Ammonia corrosion testing "	Not Required	This is for PV modules were installed in wet, highly corrosive agricultural atmospheres
17.5	BS EN 50521: PV connector requirements	No	Its additional requirement
17.6	BS EN50548 : Junction boxes for PV Modules requirements	No	Its additional requirement
18	Have At least 25-year linear power warranty for min. 82% power output after 25 years and 90% after 10 years?	Yes	
19	Are there clear process for the handling of a warranty claim defined by the installation company and the manufacturer?	Yes	

3. Inverter Checklist

	Inspection Point	Available or Not	Notes and Recommendations
1	Have inverters environmental protection rating IP56 or more?	Available	This is required for outside inverters as these PV power station inverters.
2	Is the clearance distance from front, side, top and bottom considered in inverter installation?	Available	
3	Are the inverters installed in easy and safe access location?	Available	
4	Are this inverters orientation avoided the direct sun light?	Available	This is preferable inspection point unless inverter manufacturer specify orientation limitation
5	Are the inverters fixed on non-flammable surface?	Available	Inverts were fixed on galvanized steel stand
6	Can inverters' stand hold out inverter weight?	Available	
7	Are national grid codes specified in inverter specifications like frequency limitation, voltage limitation, reactive power control capability, harmonic distortion limitation and fault ride through capability?	Available	
8	Can the inverter be accessed by monitoring system?	Available	
9	Is connected to dedicated branch circuit with back-fed overcurrent protection?	Available	
10	Is it mechanically secured and provided with adequate ventilation or cooling?	Available	As shown in Figure (5.5):

	Inspection Point	Available or Not	Notes and Recommendations
11	Have all inverters suitable capacity for project size?	Not available	All inverters have suitable size except the new inverter(number 1) as mentioned in section 5.4
12	Has the inverter protection against incorrect polarity for the DC cable?	Available	
13	Has the inverter protection against over-voltage and overload?	Available	
14	Has the inverter islanding detection?	Available	
15	Has the inverter Insulation monitoring?	Available	
16	Is it compatible with the following certificates according to national grid code :		
16.1	PS 2707-2: AS 4777-2: Grid connection of energy systems via inverters inverter requirements.	Available	
16.2	PS 2707-3: AS 4777-3: Grid connection of energy systems via inverters grid protection requirements	Available	
17	Is it compatible with other standards:		
17.1	EN 50178	Available	
17.2	AS/NZS3100	Available	
17.3	AS/NZS 60950	Available	
17.4	EN61000-6-2	Available	
17.5	EN61000-6-3	Available	
17.6	EN61000-3-11	Available	
17.7	EN61000-3-12	Available	

	Inspection Point	Available or Not	Notes and Recommendations
17.8	IEC61727: Solar PV inverters characteristics of the utility interface	Available	
17.9	IEC60529: Solar PV inverters degree of protection	Not sure for availability	
17.10	IEC60664-1: Solar PV inverters protection class	Not sure for availability	
17.1	IEC62109: Solar PV inverters power converting equipment safety	Available	

4. PV and Inverter Design Evaluation Checklist

	Inspection Point	The Designed value	Limits	Notes and Recommendation
1	Maximum string voltage for inverter inputs	821.8V	1000V	Pass
2	Minimum string voltage for inverter inputs	651	430	Pass
3	Maximum Inverter Input Current (Trio20/Trio27.6)	17.58 A /26.37A	25A/32A	Pass/Pass
4	Maximum string power for each inverter MPPT(Trio20/Trio27.6)	10kW /15kW	12kW/16kW	Pass/Pass
5	Inverter sizing(Trio20/Trio27.6)	20kWp/ 30kWp	16-24kWp/24-36kWp	Pass/Pass

5. Electrical Panels Evaluation Checklist

	Inspection Point	Available or Not	Notes and Recommendations
1	Have string DC overcurrent protection devices with suitable size?	Available	there are 15A fuse for each string
2	Have array DC overcurrent protection devices with suitable size?	Not available	
3	Are the OCPDs like fuses installed on positive and negative for each string?	Available	Since an error can occur both on the positive and the negative voltage sides, the fuses must be installed along all unearthed cables.
4	Have DC isolator switch with suitable size?	Available	
5	Have AC overcurrent protection devices for each inverter with suitable size?	Available	
6	Are the RCD installed as close as possible to inverter?	Not available	AC boxes aren't installed in this PV power station.
7	Have the fuse holders, fuses, CBs and isolator switches suitable voltage and current ratings?	Available	
8	Is user-accessible fuses in "touch-safe" holders or fuses capable of being changed without touching live contacts?	Available	
9	Are the pressure terminals tightened according to recommended torque specification?	Not available	
10	Are pressure connectors using a set screw have required tightening torques, and these	Not available	

	Inspection Point	Available or Not	Notes and Recommendations
	values should be recorded and verified at commissioning.		
11	Are pressure lugs or other terminals listed for the environment (i.e. inside, outside, wet, direct burial)?	Available	
12	Are connectors or terminals using flexible, fine-stranded conductors listed for use with such conductors?	Not available	there are many solid cables used inside MDB
13	Are there suitable DC and CB or Isolator switch beside each inverter?	Available	It is built in the inverter
14	Is PV disconnect readily accessible and located at first point of penetration of PV conductors?	Available	
15	Are PV conductors outside structure until reaching first readily accessible disconnect unless in metallic raceway?	Available	According NEC690.14, 690.31(F).
16	Are the grounding conductors not fused or switched?	Available	
17	Are all equipment shall be mechanically secured and provided with adequate ventilation or cooling as required?	Not available	MDB needs sunshade to protect that panel from direct sun specially in the summer
18	Are all electrical protection devices marked with the manufacturer's identification and applicable specifications and ratings?	Available	
19	Are there clear and dedicated spaces between electrical equipment inside electrical panels?	Available	

	Inspection Point	Available or Not	Notes and Recommendations
20	Are there AC and DC SPD in DC box, AC box and MDB?	Not available	It is absent in MDB
21	Are all electrical panel water proof?	Not available	MDB has some holes because the fan is not fixed correctly
22	Are all electrical panels' enclosure and doors connected to the grounding wire?	Not available	
23	Are the PV power station remote controllable?	Not available	According TDECO requirements
24	Are there reinforced concrete workspace base on front of all electrical panels?	Available	
25	Is the concrete workspace connected to the grounding manholes directly?	Available	
26	Are there busbar for 3 phases, neutral and ground in MDB?	Available	
27	Are all fixed on suitable isolator pin?	Available	
28	Have the busbars been sized?	Available	

6. Grounding System Checklist

	Inspection Point	Available or Not	Notes and Recommendations
A	General		
A.1	Verify the continuity of the equipment grounding conductor is first-make last-break for any plug and receptacle equipment, and is not opened by any disconnect device?	Available	
A.2	Are not there physical connection between PV grounding, lightning grounding, grid neutral and grid grounding?	Available	There are not physical connection
A.3	Are the pure copper electrodes used in grounding pits?	Available	
A.4	Are the suitable distance used between grounding pits?	Available	the suitable distance is approximately twice of electrode length, which is 3 meters in this PV power station
A.5	Are there grounding DB (grounding checkpoint) for each tables in PV grounding and lightning grounding?	Not available	Grounding check point should be installed with suitable electrical panel and suitable grounding busbar
A.6	Are there suitable distance between the grounding systems?	Available	The distance between the lightning and PV grounding system is more than 20 m that is according to NEC 250.53, which said "Electrode spacing where more than one of the electrodes of the types, each

	Inspection Point	Available or Not	Notes and Recommendations
			electrode of one grounding system shall not be less than 1.83m from any other electrode of another grounding system"
A.7	Are the electrodes driven into the soil at an angle no greater than 45 degrees from the vertical according to NEC 250.53?	Available	
A.8	Are there grounding checkpoint connected to each grounding pit with appropriate copper busbar for each PV and lightning grounding?	Not available	Grounding checkpoint should be connected to each PV and lightning grounding pits with appropriate copper bus bare.
B	PV Grounding		
B.1	Are AC and dc grounding electrode conductors connected properly?	Available	
B.2	Are grounding equipment conductors properly sized?	Available	According to NEC "The minimum code requirement is for the equipment grounding conductor for PV source and output circuits to be sized to carry 1.25 times the short-circuit currents at that point".

	Inspection Point	Available or Not	Notes and Recommendations
B.3	Verify that all non-current-currying metal parts of the PV power station like PV module frames, support structures, fence, enclosures and other equipment are bonded to the equipment grounding system?	Not available	All metallic parts are connected to the grounding system except the fence, DB enclosure, monitoring DB enclosure and the main door
B.4	Verify the continuity of equipment grounding connections and bonding jumpers when PV modules or inverters are removed from a circuit for service?	Available	
B.5	Are there two grounding electrodes at least to achieve maximum protection against lightning-induced surges according to NEC 250.54?	Available	
C	Lightning Grounding		
C.1	Is parallel configuration grounding of three electrodes used for lightning grounding pits?	Available	To minimize the grounding system impedance value, a parallel configuration of three electrodes is strongly recommended instead of just one excessively long electrode.
C.2	Is the distance between the lightning grounding pits and any buried metal pipe or electrical conduit at least 2 m (if	Available	The distance of the nearest metallic part is 20m.

	Inspection Point	Available or Not	Notes and Recommendations
	soil resistivity is over 500 ohms/m)		
C.3	Is lightning grounding not connected to the main equipotential bonding of the structure?	Available	
C.4	Can the Inspection grounding pit of lightning system be accessed?	Not available	
C.5	Are 3 copper grounding rods at least used for lightning grounding that a minimum length of 2 m, buried vertically in the ground?	Available	

7. Lightning Protection System Checklist

	Inspection Point	Available or Not	Notes and Recommendations
1	Is the down conductor or cable protected by conduit placed about 2 m above ground level?	Available	It is protected by installing it inside the steel pole
2	Is down-conductor insulated by 100 kV, 1.2/50 µs impulse withstand voltage insulator?	Available	
3	Is tin-plated 30 x 2 mm copper strip or equivalent used as down conductor?	Available	
4	Is the lightning protection equipment (Air terminal and steel pole) not shading the PV modules?	Available	The lightning steel pole installed in the far northern of this PV power station
5	Is the lightning air terminal connected to the down conductor by a connecting clamp that tightly secured on to the mast?	Available	
6	Is the down conductor secured by at least 3 fasteners per linear meter?	Not available	No need; because the down conductor lays inside the steel pole
7	Are the Insulators used to distance the conductors and prevent contact with easily flammable material (thatch, wood… etc.)?	Not available	No need; because there are no easily flammable material near the conductor
8	Does this lightning protection system cover the area of this PV power station?	Available	
9	Is the lightning protection system compatible with the NF C 17-102 and IEC62305 standards?	Available	

8. Mounting Structure Checklist

	Inspection Point	Available or Not	Notes and Recommendations
1	Are the suitable slots insertion undertake inside base foundation for cables route?	Available	
2	Are there mesh steel inside the slab on grad and connected of the grounding system, if it is existing?	Available	
3	Is the structure checked by approved structural engineer using software like SAP2000 with the suitable parameters (not less than 120km/h wind speed and existing dead load)?	Available	
4	Is the concrete type tested by approved laboratory as required in the design?	Available	
5	Is the galvanic tested for galvanized steel structure?	Not available	It should be checked using Galvan tester
6	Is all bolts tied according to the suitable standard?	Not available	It should be tested using torque wrench
7	Is the design of PV mounting system undertake the modules fixing zones that shall comply with the module manufacturer's instructions?	Available	Some module's manufacture don't allow clamping in the short edges
8	Are the PV frames and fixing made from corrosion resistance materials that suitable or the lifetime of the system?	Available	It is made from galvanized steel. Hence: If it is coated by zinc, it will be better.
9	Is galvanic effect from bolting, insulating washers dissimilar considered?	Not available	As shown in Figure (5.23). The red circle denotes the corrosion between the galvanized steel omega, stain steel

	Inspection Point	Available or Not	Notes and Recommendations
			bolt, stain steel nut and stain steel washer behind the PV module, therefore, to avoid the corrosion, the washers should be replaced by hot deep galvanized washer.
10	Is the PV mounting system allow thermal expansion and contraction like design thermal breaks and expansion gaps?	Available	This point in case of large system where the array stricture required long lengths of supporting rail. There are expansion gap each meters in concert bases in this PV power station.
11	Aren’t there up stands at the module bottom edge that may prevent water, dirt, leaves and other debris accumulation sliding off?	Available	
12	Are there more than 10mm space between PV modules to prevent farms fraction, mechanical strain and reduce the wind force?	Available	
13	Haven’t excessive height modules' clamp that may cause small amount of shade onto the module immediately adjacent to the clamp?	Available	
14	Is the array structure designed to avoid self-shading from structure itself?	Available	

	Inspection Point	Available or Not	Notes and Recommendations
15	Has the PV station future access routes for maintenance and emergency services?	Available	
16	Is inter-row distance suitable for the site?	Available	
17	Is tilt angle and orientation of the PV array suitable for the geographical location?	Available	
18	Aren’t there shading from nearby objects?	Available	
19	Is civil works (foundations, drainage) suitable for environmental risks?	Available	
20	Are all holes' edges and welding points treated by galvanic metals?	Not available	There are many holes' edges and welding points shall be treated by galvanic metals as shown in blue circle in Figure (5.23)

9. Monitoring System Check List

	Inspection Point	Available or Not	Notes and Recommendations
1	Has the monitoring system data storage in case of out of service communication line?	Yes	
2	Has the monitoring system data collected in data logger from the weather station, inverters, and combiner boxes?	Yes	
3	Are there electrical panels for monitoring system?	Yes	There are galvanized steel panels that contains router and three sockets
4	Are there suitable protection devices in monitoring electrical panel?	No	16A circuit breaker and 16A with 30mA sensitivity RCD
5	Are the monitoring software shows the recorded data for each 15 minute?	Yes	
6	Does the monitoring software show the energy production, power production, DC current and voltage inputs, AC current and Voltage outputs, P.F, real and reactive power output?	Yes	
7	Are the monitoring software shows the wind speed, ambient temperature, module temperature and Irradiance sensor data?	Yes	
8	Are there alarm management?	Yes	
9	Can the data be exported?	Yes	

10. Weather Station Checklist

	Inspection Point	Available or Not	Notes and Recommendations
1	Is the weather station mounted more than 1.5 meters off the ground and surrounding terrain or structures?	Available	
2	Is the weather station installed with secure mount using guy wires…etc.?	Available	
3	Is the weather station designed to withstand very harsh weather conditions?	Available	
4	Is weather station measure the POA irradiance?	Available	
5	Does the weather station measure module and ambient temperature?	Available	
6	Does the weather station measure global horizontal irradiance?	Available	Preferably inspection point
7	Does the weather station measure wind speed and direction?	Available	Preferably inspection point
8	Has the weather station data logger with communication ports like Modbus…etc.?	Available	
9	Can the data collected be transferred remotely and locally?	Available	
10	Can the data collected be viewed by the existing PV power stations' monitoring system?	Available	

11. DC Cables Checklist

No.	Inspection Point	Current Situation	Notes and Recommended Modifications
1	Electrical Design Inspection:		
1.1	Has the maximum open circuit voltage for string less than rated voltage?	Yes	where $V_{OC\text{-}max}$, string =867.1 V and V cable rated = 1500V
1.2	Have the maximum strings current less than cables rated current?	Yes	The worst case where using $4mm^2$ the maximum current could flow through the cable is 43.95A which is less than cable rated current 52A
1.3	Have the voltage Drop in DC cables less than 1%?	Yes	Maximum voltage drop are in inverter 4 string 3 is 0.49%
1.4	Have the power losses in DC cables less than 3%?	Yes	Maximum power losses are in inverter 4 string 3 is 0.49%
2	Wiring Method Inspection:		
2.1	Have DC cables fixed durable on structure?	No	There are many DC cables not tightened well
2.2	Are cables between tables lays inside appropriate trucking or conduit, if existing?	Yes	the DC conduits are oversized
2.3	Are DC cable conduit buried more than 50 cm underground?	Yes	Buried 50 cm under ground

No.	Inspection Point	Current Situation	Notes and Recommended Modifications
2.4	Are DC string cables identified by separate color coding red for positive and black for negative?	Yes	Cables are colored by red for positive and black for negative
2.5	Have the cables used armored cable or installed in earthed metal conduit or trucking?	Not required	This is for DC cables longer than 50 m
2.6	Are plug connectors between DC cables as less as possible?	Yes	This is to reduce the loose connections and the voltage drop that caused by transfer resistance of plug connector, which is less than 5 milliohms [3]
2.7	Have the wiring of DC cables method mitigate induced voltage surges?	No	
2.8	Have the DC cables identified by separate color coding, marking tape or tagging at points of termination, connection, and splices?	No	
2.9	Have the AC and DC conductors grouped together by cable ties and at intervals not to exceed 6 ft. where occupied in the same junction box or raceway?	Not required	

No.	Inspection Point	Current Situation	Notes and Recommended Modifications
2.10	Have conduit entries and ends closed by isolating material like Polyurethane foam?	Yes	
3	Cables Standards Inspection Points:		
3.1	IEC/EN 61034 "Low smoke emission"	Yes	
3.2	IEC/EN 603332-1-2 "flame redundant"	Yes	
3.3	EN 50267-2-1 "Halogen free"	Yes	
3.4	EN 50267-2-2 "Low corrosive of gases"	Yes	
3.5	NFX 70-100-1-2 "Low toxicity of gases"	Yes	

12. AC Cables Checklist

No.	Inspection Point	Current Situation	Notes and Recommended Modifications
1	Electrical Design Inspection		
1.1	Have the cable voltage rating 0.6/1kV?	Yes	
1.2	Have the maximum current less than cables rated current?	No	All inverter cables have maximum current less than cables rated current, but the main AC cable is undersized
1.3	Have the voltage drop in AC cables less than 3%?	Yes	
1.4	Have the power losses in AC cables less than 3%?	No	The percentage power losses for each of inverter 4, 9 and 10 are 3.03%, 3.37% and 3.01% respectively, which exceeds the acceptable limit.
2	Wiring Method Inspection:		
2.1	Have AC cables fixed durable on structure?	Yes	
2.2	Are AC cable conduits buried more than 100 cm underground?	Yes	
2.3	Are AC cable inserted in suitable conduit size according to NEC requirements?	Yes	
2.4	Have not any cable buried directly?	No	Main AC cable has been directly buried
2.5	Are the distance between manholes less than 6m according to local standards?	Yes	
2.6	Are AC cables identified by color-coding?	Yes	

No.	Inspection Point	Current Situation	Notes and Recommended Modifications
2.7	Have the cables used armored cable or installed in earthed metal conduit or trucking for cable length more than 50m?	Not required	We have separate grounding wire beside each AC cable.
2.8	Are the joints (if exciting) installed properly?	No	There is a joint on AC inverter's 7 cable located inside manhole number 9, which is used simply stuck. It should be joined by suitable heated joint.
2.9	Is the maximum joint number in the same cable?	Yes	
2.10	Have the AC cables identified by separate color coding, marking tape or tagging at points of termination, connection, and splices?	No	
2.11	Have the AC and DC conductors grouped together by cable ties and at intervals not to exceed 6 ft. where occupied in the same junction box or raceway?	Not required	
2.12	Have conduit entries and ends closed by isolating material like Polyurethane foam?	No	There are many locations not closed
2.13	Have mechanical resistance from compression, tension, bending and shear loads?	Unknown	It is not checked

No.	Inspection Point	Current Situation	Notes and Recommended Modifications
2.14	Have Ultraviolet (UV) radiation, weather resistance and ozone resistance when cables are laid outdoor s without protection; heat and cold resistance (laying temperatures: 70°C on roofs, 55°C in lofts)?	Yes	According to the data sheet
2.15	Is a minimum warranty period of two years?	No	
3	Cables Standards Inspection Points:		
3.1	IEC 60364	Unknown	
3.2	IEC 60227	Yes	
3.3	IEC 60502 (Part 1 & 2)	Yes	

13. Metering System Checklist

	Inspection Point	Current Situation	Notes and Recommended Modifications
A	Meter		
A.1	The environmental resistance information signs was fixed on the meter's electrical panel written "Meter Panel "with following information: its CT ratio and date of installing date. Another sheet contains empty table for future rehabilitation that can write date of meter replacement, meter serial number and CT ratio"	Not Available	
A.2	Are there Bidirectional meter?	Yes	The main purpose of this meter: discovering electricity theft
A.3	Are there galvanized enclosure?	Yes	
A.4	Are there Lock?	No	There is no suitable place for the lock
A.5	Is the Meter accuracy 0.5 for active energy?	Yes	
A.6	Is the meter configured?	Yes	all settings like CT ,VT ratio and connection entered right
A.7	Is the meter compatible with installed CT?	Yes	

	Inspection Point	Current Situation	Notes and Recommended Modifications
A.8	Are the voltage and current with in meter range?	Yes	
A.9	Are there suitable circuit breaker before and after the meter?	Not Available	This is for direct connected meters, we have here meter with CT's
A.10	Are the meter cables have appropriate size?	No	Some cables are under sized as denoted by red circles in Figure (5.30). The meter installation guide recommends 6mm^2 cable size for each meter power supply cable and current ports
A.11	Are suitable protections installed in the meter power supply input?	No	250 mA fuses or circuit breaker should be installed on L_R and L_S as denoted by red circles in Figure (5.30)
A.12	Is meter power supply taken from the main busbar?	No	The meter power supply have taken electricity from inverter 12 now; so when this inverter disabled, metering system disabled also. The modification is connecting the meter power supply to the main busbar, as

	Inspection Point	Current Situation	Notes and Recommended Modifications
			denoted by red circles in Figure (5.30)
A.13	Is the metering system connected on MV or LV grid?	On LV grid	This connection because TDECO owns this PV station, else it should be connected to the MV with appropriate CT’s and VT’s that takes TR losses in to consideration.
B	Current Transformer		
B.1	Are the CT's have suitable current and voltage ratings?	Yes	
B.2	Are the CT's have suitable dimension?	Yes	the dimension suitable with main AC cable size
B.3	Are the CT's accuracy class 0.5?	Yes	
B.4	Are the secondary S2 port in CT's connected to the ground?	No	These ports have been connected to the neutral. Grounding the secondary terminals of current transformers is necessary; therefore it provides a reference towards earth in case of transformer failure, and prevents dangers for persons or risks of damage for the device

	Inspection Point	Current Situation	Notes and Recommended Modifications
			installed in the switchboard. As denoted by red circles in Figure (5.30)
B.5	Are the CT's cables have appropriate size?	No	as mentioned in meter installation guide that should be $6mm^2$ As denoted by red circles in Figure (5.30)

14. Transformer Check List

	Inspection Point	Available or Not	Notes and Recommendations
1	Has PV power station transformer suitable power rating?	Yes	Transformer capacity has 400kVA with load factor 0.875
2	Has PV power station transformer 33/0.4kV voltage rating?	Yes	
3	Has PV power station transformer 50Hz frequency?		
4	Has PV power station transformer DNY11 winding configuration?	Yes	
5	Has PV power station transformer dielectric class oil impressed with free breathing?	Yes	This condition is preferable
6	Has PV power station transformer copper windings HV/LV?	Yes	
7	Is PV power station transformer suitable for outdoor installation?	Yes	
8	Has PV power station transformer conservator tank?	Yes	
9	Has PV power station transformer ventilation Oil Nature Air Nature (ONAN)?		
10	Has PV power station transformer off load tap changer?	Yes	
11	Has PV power station transformer drain valves?	Yes	
12	Has PV power station transformer filled with low viscosity mineral insulation oil?	Yes	
13	Has transformer station 33 kV Drop-out Fuse Switch, 3-phase with fuse holder for drop out fuses with 10A fuses for each phase?	Yes	
14	Has transformer station 36 kV surge arrestor with Arm for surge arrestors (K160/3)?	Yes	

	Inspection Point	Available or Not	Notes and Recommendations
15	Has transformer station 33 kV Isolator switch with side arm (K1555)?	Yes	
	Is it comply with the following standards:		
16	BS EN 50464-1	Yes	
17	BS EN 50464-2	Yes	
18	BS EN 50464-3	Yes	
19	BS EN 50464-4	Yes	
20	IEC 60296	Yes	

15. Safety Labeling and Identification Checklist

	Inspection Point	Available or Not	Notes and Recommendations
A	PV plant site:		
A.1	It should be enclosed by fence.	Available	
A.2	The fence and doors should be connected to grounding manholes	Not Available	
A.3	Warning signs with yellow triangular stating "Electrical Danger" were fixed on fence every 5-10meter	Not Available	
A.4	Warning signs with yellow triangular stating "Electrical Danger" were fixed on structure each 5-10meter	Available	
A.5	Name Plate for project name, installer and emergency number were fixed in the project instance	Available but there is note	Installer and emergency number not mentioned
A.6	Single line diagram for whole PV station	Available	
A.7	Board for Emergency shutdown instruction	Available	
A.8	Board for general information about regular cleaning	Available	
A.9	Dual supply warning labels fitted at point of interconnection	Not Available	
A.10	Are all electrical equipment marked with the manufacturer's identification and applicable specifications and ratings?	Available	
A.11	Are fire extinguishers available on site?	Not Available	

	Inspection Point	Available or Not	Notes and Recommendations
B	Cables:		
B.1	DC cables were labelled 'PV array cable- live during daylight' every 5-10 m	Not Available	
B.2	Number of string and inverter were labelled each DC cable at the beginning, the end, each cable joint and every 5-10 meter	Not Available	
B.3	Number of inverter and distribution board were labelled for each AC cable at the beginning, the end, each cable joint and every 5-10 meter	Not Available	
B.4	Warning tape above all cables were buried underground	Available	
C	Distribution Boards:		
C.1	Two caution signs on ABB enclosure stating the first is "Warning Dual supply, isolate both normal supply from MDB and solar supplies from DC isolator switch at the bottom of ABB enclosure and all string fuses before working on this electrical board", and the second is “active parts inside the boxes are fed from a PV array and may still be live after isolation from the PV inverter and public supply”	Not Available	According to [18]
C.2	Single line diagram for electrical connection inside ABB enclosure	Available	

	Inspection Point	Available or Not	Notes and Recommendations
C.3	Wiring diagram for the modules were connected in each inverter	Available	
C.4	Labels for inverters' enclosure numbers	Available	
C.5	Single line diagram for electrical connection inside MDB	Available	
C.6	Clear labels for each protection device inside MDB mainly on the main AC circuit breaker.	Available	
C.7	labels for each protection device inside ABB enclosure	Not Available	We can't install it because ABB enclosures have narrow spacing
D	Printed signs general requirements:		
D.1	The label must resist the environment for 25 to 40 years	Not Available	We haven't any guarantee from the press
D.2	Is plastic or metallic engraved signs	Plastic	Metallic engraved sign would be best
D.3	If it is plastic used, it should not be placed in direct sunlight	Available	Some signs fixed inside MDB and others under the PV modules
D.4	Are all signs and labels suitably affixed and durable?	Yes	
E	Inverters:		
E.1	Labels for inverter numbers	Available	
E.2	Labels for Inverter protection settings	Not Available	

	Inspection Point	Available or Not	Notes and Recommendations
E.3	Ground fault protection label stating "Warning Electric Shock Hazard, if a ground fault is indicated normally grounded conductors maybe ungrounded and energized "	Not Available	According to [17]

جامعة النجاح الوطنية
كلية الدراسات العليا

نظام طاقة خلايا شمسية مربوطة مع شبكة كهرباء طوباس: فحوصات ميدانية، تقييم والتحسين الأمثل.

إعداد
إشراق جرار

اشراف
أ.د. مروان محمود

قدمت هذه الاطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة وترشيد الإستهلاك بكلية الدراسات العليا في جامعة النجاح الوطنية، نابلس–فلسطين.
2018

نظام طاقة خلايا شمسية مربوطة مع شبكة كهرباء طوباس:

فحوصات ميدانية، تقييم والتحسين الأمثل.

إعداد

إشراق جرار

إشراف

أ.د. مروان محمود

الملخص

أصبحت الخلايا الشمسية المربوطة على الشبكة الكهربائية أفضل خيار في مجالات الطاقة المتجددة. 4771 كيلو واط خلايا شمسية مربوطة مع شبكة شركة كهرباء طوباس. تركز هذه الرسالة على محطة خلايا شمسية بقدرة 350 كيلو واط تم تمويلها من الحكومة التشيكية، وتعتبر هذه المحطة من أكبر محطات الطاقة الشمسية في طوباس. موقع المحطة يستقبل متوسط إشعاع شمسي جيد، حيث بلغ متوسط الإشعاع الشمسي السنوي لعام 2016 على السطح المستوي والسطح المائل 5.13 كيلو واط ساعة / متر مربع–يوم و5.925 كيلو واط ساعة / متر مربع – يوم على التوالي، وكان معدل درجات الحرارة لتلك السنة حوالي 20.5 درجة مئوية.

هذه الرسالة تقدم التقييم الفني لتركيب المحطة الشمسية بقدرة 350 كيلو واط مع اعتبار المواصفات المحلية والدولية، وتم عرض التوصيات الفنية بخصوص تركيب المحطة. تم تقييم أداء المحطة أيضاً، والتي ناقشت نوعين من أنواع الفاقد في الطاقة وهما: الفاقد غير المسيطر عليه مثل تعطل العواكس وانقطاعات في شبكة الكهرباء، والفاقد الناتج من معدات الطاقة الشمسية مثل الخلايا الشمسية وكوابل التيار الثابت والعواكس وكوابل التيار المتردد والعداد. تم احتساب الكفاءة الكلية للمحطة وهي 11.94%. كما تم احتساب مؤشرات لتقييم أداء المحطة مثل نسبة أداء المحطة الشهري الفعلي والمتوقع والسنوي الفعلي والمتوقع حيث كانت نسبة الأداء السنوي الفعلي للمحطة 75.6%. الإنتاج السنوي الفعلي المحدد لكل كيلو واط 1640 كيلوواط ساعة / كيلو واط خلايا شمسية بينما يبلغ الإنتاج السنوي المتوقع المحدد لكل كيلو واط 1740 كيلوواط ساعة / كيلو واط

خلايا شمسية. لقد تم احتساب معامل سعة المحطة الفعلي والمتوقع وهو 18.7% و19.81% على التوالي حيث أن هاتين القيمتين ضمن المجال المعروف عالمياً (12%–24%). إنتاج الطاقة الكهربائية من المحطة الفعلي لعام 2016 هو 574039 كيلو واط ساعة، بينما كان الإنتاج المتوقع 609029 كيلو واط ساعة.

تهدف هذه الدراسة ايضاً إلى فحص أثر الإشعاع الشمسي والحرارة والغبار وعدد متعقبات الطاقة لصفوف الخلايا الشمسية على إنتاج الكهرباء من مشروع الخلايا الشمسية، كما تهدف أيضا الى دراسة التحسين الأمثل لكل من كوابل التيار الثابت والمحولات.

لقد تم أيضا إجراء تقييم اقتصادي للمحطة بدلالة التكلفة للمحطة على طيلة عمر المشروع وتكلفة إنتاج الطاقة. وأظهرت النتائج أن المحطة الممنوحة تحقق جدوى اقتصادية بينما تعتبر غير مجدية اقتصاديا في حالة تمويل كامل المحطة من قبل شركة كهرباء طوباس وذلك بسبب سعر الأرض وتكلفة تجهيز الموقع.

إضافة لذلك، هذه المحطة الشمسية تدعم البيئة في فلسطين بشكل إيجابي حيث أنها تقلل إنتاج 577.97 طن من ثاني أكسيد الكربون سنوياً.