An-Najah National University

Faculty of Graduated Study

Techno-Economic Assessment of the Electric Grid –Connected PV Power Plant at Arab American University / Jenin

By

Ahlam Hasan Abu Zahew

Supervisor

Prof. Marwan Mahmoud

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This Thesis was Defended Successfully on 10/ 6/ 2018 and approved by:

Defense Committee Members		**Signature**
1. Prif. Marwan Mahmoud	**/ Supervisor**	**...…….……**
2. Dr. Osam Al Omari	**/ External Examiner**	**…..…………**
3. Dr. Mohammed Al Sayed	**/ Internal Examiner**	**…...…………**

Dedication

I would like to dedicate this work for the only capital of Palestine

To the heart of Palestine

Jerusalem

Acknowledgment

Prof. Dr. Marwan Mahmoud, I would like to thank you from all my heart for all your advices, help, encouragement, efforts, love and patience. You are the one that I would thank the most. Without you I wouldn't be here in the way that I am in.

The thankful is continued to all peoples those who help me by hands and by wards: my family, my friends, my colleagues, my university AAUJ and all the stuff in the EIT department thank you. Special thanks for Mr. Salah Jabareen for his assistant during this project.

الإقرار

أنا الموقع أدناه، مقدم الرسالة التي تحمل العنوان:

Techno-Economic Assessment of the Electric Grid –Connected PV Power Plant at Arab American University / Jenin

أقر بأن ما شملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تم الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، وأي جزء منها لم يقدم من قبل لنيل أي درجه أو لقب علمي لدى أي مؤسسة تعليمية أو بحثية أخرى

Declaration

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

Student's name: **اسم الطالب:**

Signature: **التوقيع:**

Date: **التاريخ:**

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Techno-Economic Assessment and Evaluation of the Electric Grid –Connected PV Power Plant at AAUJ-Jenin

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Abstract

The performance of 70 kW_p grid-connected PV system in Arab American University have been analyzed. The performance Parameters considered under this study are the final PV system yield, performance ratio and capacity factor. The economical assessment was also analyzed including cash flow, payback period, net present value and the unit energy cost. The annual system outputs were 100 MWh and 95 MWh in 2015 and 2016 respectively. May 2015 and 2016 had the highest output energy with approximately 12 MWh in both years. The PV final yield varies between 180 kWh/kW_p in May and 47 kWh/kW_p in January, with annual final yield of 1428 kWh/kW_p and 1367 kWh/kW_p for 2015 and 2016 respectively. With respect to performance ratio(PR) the system had an annual PR of 80% in 2015 and 76.8% in 2016. The monthly PR varied between 52% in Jan and 99% in March in 2015 and (34% in Sep and 99% in Nov) in 2016. On the other hand, from the economic perspective the system seems to be economically acceptable with a 7 years payback period, a positive net present value mounting to 31612.7$ and an internal rate of return of 13% which is greater than the 8% interest rate used in the economic evaluation.

Chapter One
Introduction

1. Introduction

Global energy demand rate has been increased by 199% between 1973 and 2009 [1]. This increase synchronized with a wide spread in renewable energy sources all around the world as a solution of the rapid depletion of fossil fuel energy sources and critical environmental issues (CO_2, NO_x, SO_x emissions and other environmental serious problems).

Among all types of renewable energy sources (RES), solar energy has the greatest potential in Palestine. According to political, economic, environmental, geographical, social and infrastructure conditions in Palestine; small and large-scale PV systems can highly meet the energy demand growing in Palestine [2].

The annual rate of PV system growth between 2005 and 2016 was 47%. Figure 1.1 shows the cumulative amount of on grid PV systems all around the world. Between 1991 and 1994, more than 2250 grid connected rooftop PV systems were installed in Germany, within 1000-rooftop PV program [3]. Since then, rooftop PV systems faced a great acceptance all around the word.

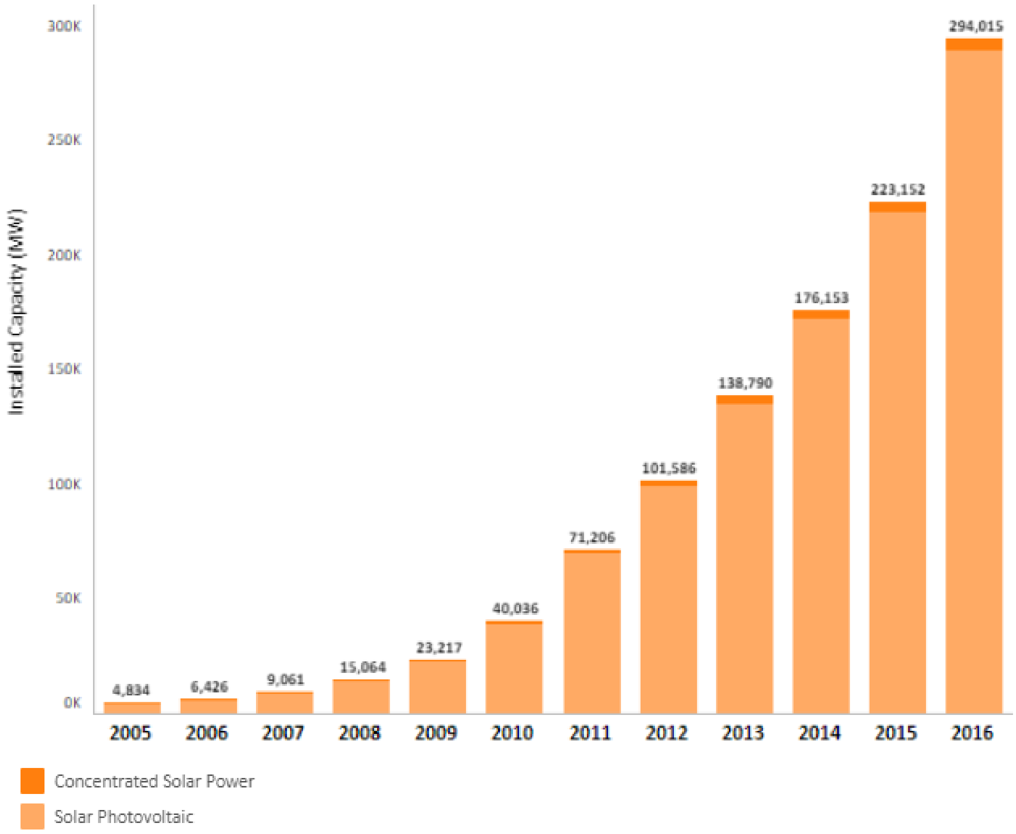

Figure 1-1: The peak power of installed grid connected PV systems in the world [4].

In 2012, the Palestinian energy authority (PEA) started its initiative towards more RE utilization. Its goal was to cover 10% of electricity needed in Palestine by RES by 2020; where 25MW of it should be covered by PV systems. 1000 house roofs were covered by PV systems with 5kWp each according to PEA[5,6]. Many other PV rooftop, street light, standalone systems and large PV power plant were installed in Palestine-west bank as well.

Yarza, Tana, Almekhel, Msafer Yata, Atof … and other Palestinian villages were provided by PV systems [7].

1.1 Objectives

The main aims of this thesis are to study the performance of the PV system located at the rooftop of Engineering and Information Technology (EIT) faculty at Arab American University Jenin (AAUJ) and to evaluate it according to the estimated measuring results. The following activities were performed to achieve the main aims:

1. Studying the specifications and characteristics of the electric grid supplying the EIT campus in AAUJ.

2. Measure, analyze and evaluate the performance of the 70 kW_p PV power plant established at AAUJ.

3. Applying special software simulation packages in the evaluation process.

4. Determining the economic feasibility of the current PV power plant.

5. Make recommendation for improving the efficiency and thereby the feasibility of the current PV power plant.

1.2 Thesis Structure

Chapter Two: Photovoltaic Technology

This chapter starts by a brief description of PV theory, concept and the parameters affecting the PV output energy. In addition, it discusses the energy current situation in Palestine and the solar power potential which can give a clear vision for the utilization of PV systems in the future.

Chapter Three: Configuration of the Electric Network and the PV Power Plant of AAUJ

This chapter discusses the electrical network of the EIT project, starting its connection with the grid. The entire connections between the PV modules, inverters and all protection devices are also discussed.

The second part of this chapter discusses the system site with respect to shadowing, tilt and azimuth angles of the system.

Chapter Four: Monitoring and Evaluation of the PV System

In this chapter the performance of the PV system is evaluated by using the optimal measured data. Output energy, coverage percentage, final yield, peak sun hour, performance ratio, capacity factor and daily PV production are discussed.

Chapter Five: Economic Analysis

The financial feasibility of the project is discussed in this chapter. Cash flow, pay pack period, net present value, IRR and unit energy cost are studied and discussed.

Chapter Six: Conclusions and Recommendations

This chapter presents the conclusions and recommendations which are based on the implemented research and the trained results.

Chapter two
Photovoltaic Technology

2. Photovoltaic Technology

2.1 Introduction

Photovoltaic effect is a physical phenomenon where the energy carried by optical electromagnetic radiation is converted into electric one. When sun light falls on semiconductors material a photon with an energy equal to or greater than energy gab between valance and conduction band are absorbed which break a bond and an electron become free to roam through the lattices. This electron leaves a hole behind him. The movements of electrons and holes in opposite directions generates electrical current in the semiconductor. This current can flow in an external circuit. And so, the energy absorbed from the sun light will be converted in to electrical energy [8].

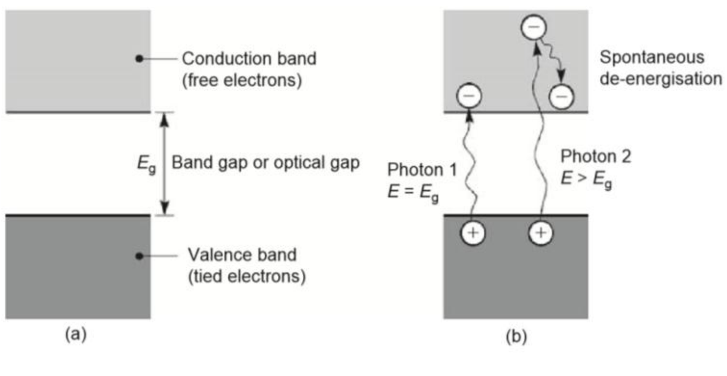

Figure 2-1: Energy diagram of a semiconductor: (a) in darkness; (b) under illumination [8].

Figure 2.1 shows atypical solar cell that consists of a semiconductor material, having a certain energy gab Eg and a certain thickness W, doped by either N-type material (material with 5 electrons in its last orbit) or P-type material (material with 3 electrons in its last orbit). Electron in the valance band can absorbe the energy from the photon with energy equal to or greater than Eg each photon can create one electron-hole pair whatever the energy of the photon is [8].

Solar cell is therefore usually consisting of two wafers of silicon doped ‘P-type ‘on one side and ‘N-type ‘on the other. Where a depletion region appears from the tendency of the excess electrons from N region to try to pass to region P to which they are attracted by the excess holes and vice versa. Figure 2.2 represent a schematic representation of a PN junction [8].

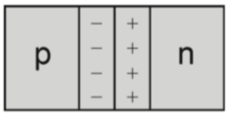

Figure 2-2: Schematic representation of a PN junction [8].

2.2 Current Voltage Characteristic

Photo diode term is used to designate a PV cell where the PN junction represents the core of a PV cell. Figure 2.3 shows the current – voltage characteristic of a silicon PV cell in darkness and under illumination.

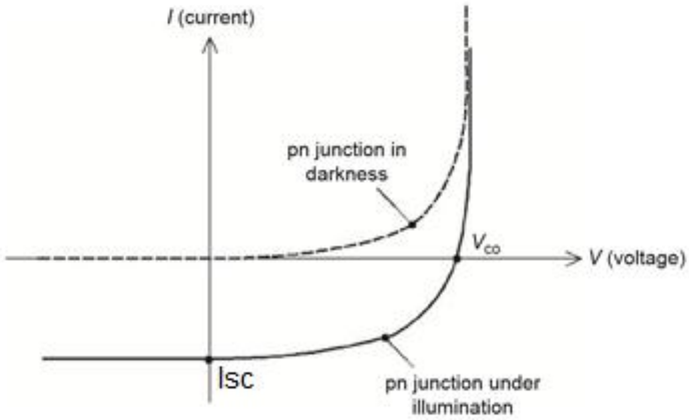

Figure 2-3: Current–voltage characteristics of a silicone diode in darkness and under illumination [8].

The dashed line represents the darkness curve which is similar to the diode IV curve where the solid line represents the IV curve under the illumination, where the diode produces a photo current that depends on the quantity of incident light. I_{sc} (short circuit current) represent the constant generation current by light. V_{oc} on the contrary is the open circuit voltage illumination at zero output current.

The equivalent circuit of a PV cell is drawn up in the Figure below.

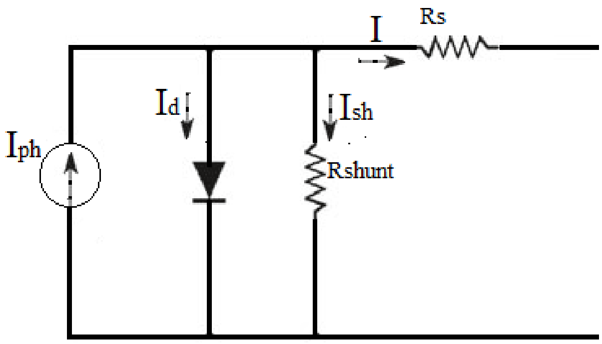

Figure 2-4: The equivalent circuit of a PV cell [8].

If we consider the PV cell as a silicon diode in order to determine its current curve then, the current will be as shown in equation (2.1) [8].

$$I = I_{ph} - I_d - I_{sh} \tag{2.1}$$

$$I = I_{ph} - I_o[(e^{q(\frac{(Vd * A)}{kT})}) - 1] - (\frac{V + R_s I}{R_{sh}})$$

Where,

I_d : diode current

I_{ph}: photon current

I_{sh}: shunt current

V_d: diode voltage

R_s: series resistant

A: identity factor usually A between (1-2)

R_{sh}: shunt resistant

k = 1.38 * 10^{-23}J (Boltzmann constant)

q = 1.602 * 10^{-19} C (electron charge)

T = absolute temperature in K

The series resistor is very small and the shunt resistor is very large then we can neglect the value of the shunt current.

This term ($e^{q(V_d A/kT)}$) >> 1 and so, we can consider the value of I to be

$$I = I_{ph} - I_o\,(e^{q\frac{V_d A}{kT}}) \tag{2.3}$$

and the open circuit voltage (I = zero) is

$$Voc = \left(\frac{kT}{qA}\right) ln\left(\frac{I_{ph}}{Io}\right) \tag{2.4}$$

Figure 2.5 shows the current- voltage characteristic curve of a PV cell. The dashed line curve represents the power (IV products), the system may operate at other point of power (I and V values) such as power at point 2. The value of P differs according to the amount of illumination and temperature as defined later. The broken lines curves represent the theoretical curves of constant power. [8]

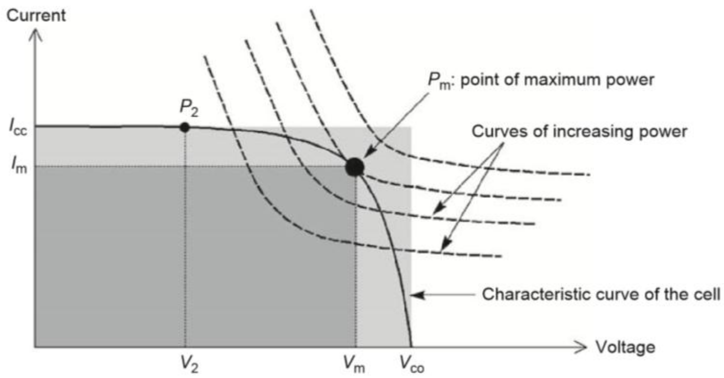

Figure 2-5: Maximum power on a current–voltage characteristic of a PV cell [8].

The square shape drawn from P_m point is less than that produced by (I_{sc} and V_{oc}) products, the ratio of these two squares can be represented as the fill factor (FF)

$$FF = \frac{P_{peak}}{I_{sc} \times V_{oc}} \tag{2.5}$$

The ratio of the maximum(peak) power produced by a PV cell/ module and the input solar energy represent the efficiency (η):

$$\eta = \frac{P_{peak}}{E \times A} \tag{2.6}$$

Where,

A: surface area of the cell / module

E: the solar radiation intensity [W/m^2]

Usually η is tabulated at standard conditions (E=1000 W/m^2, AM =1.5, T=25C^o).

2.3 PV, Module and Array

A PV module is a set of PV cells connected in series, to increase the voltage output. A combination of modules forms a PV array as shown in the Figure below.

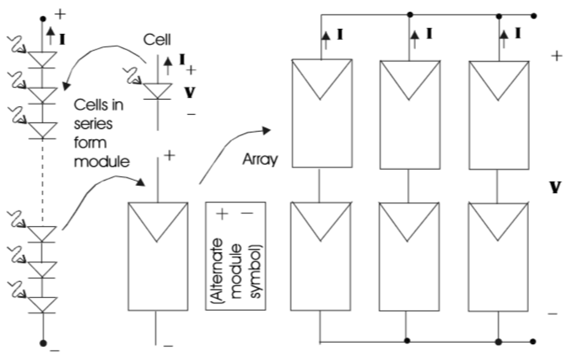

Figure 2-6: PV, Module and Array [8].

2.4 Effect of Illumination on PV Power Production

Figure 2.7 shows the “IV curve of a monocrystalline cell under various solar radiation. This Figure shows the obvious relation between output power and radiation. The PV power production increases as incident radiation intensity increases. The current relation with radiation incident is also evident, the current increases linearly with the increase of incident radiation while the voltage increases little and nonlinearly.

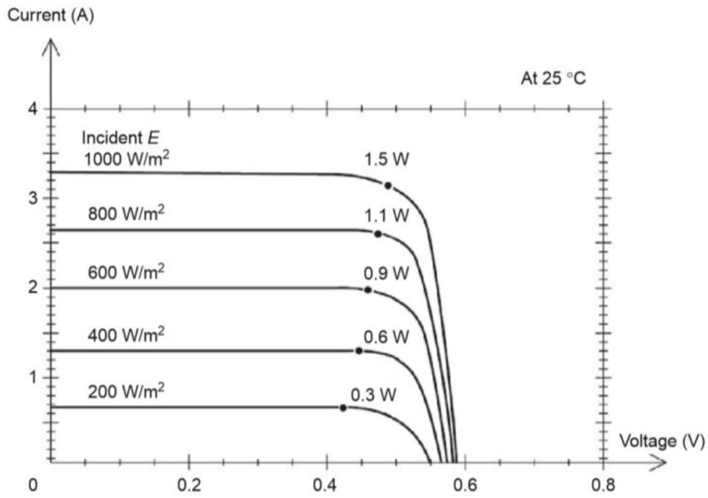

Figure 2-7: I/V Curves of a monocrystalline cell under various radiation intensities.

2.5 Types of PV Systems

The electrical output of a PV module depends on its dimension, technology, and the received solar radiation. There are two major types of PV systems.

Standalone type:

In this type of installation, energy is used directly from collecting modules. Such applications only function during sun light period and do not work at darkness. And so, an electrical energy storage is needed to store all the excess energy generated by the system, to be used at zero production periods. Or it may be converted to hydraulic energy by pumping water to a high storage water tank during sun light hour. To be used for generation of electricity at darkness period. [8]

Grid connected type:

This type of installation does not need any storage unit, since it is connected via a DC/AC inverter with the utility grid. The excess energy generated by the PV will be injected to the grid and any shortage in the energy fed to the load will be covered from the grid, according to utility tariff [8].

2.6 Components of PV Grid Connected System

This system consists of solar modules, inverters, switching devices, metering, grounding and other protection devices which discussed here after.

2.6.1 PV Modules

The main part of any PV system is the PV modules. These modules are connected together in series to form a string. Strings are connected in parallel to form an array.

2.6.2 Grid Inverter

Grid inverter is used in order to convert direct current and voltage generated by the PV array in to alternating current and voltage at a frequency and voltage equivalent and in phase to that of the electrical grid. The input power to the inverter is the fluctuating power produced by the PV system. Most inverters connected to the grid incorporate maximum power point tracking system(MPPT). MPPT automatically adjust the system voltage so that the PV array operates at its maximum power point. Moreover, the inverter should be able to detect an islanding situation and take appropriate measures to protect persons and equipment's. [9,10]

2.6.3 Protection Equipment

In order to have a high quality and efficiency of electrical energy production the construction of complex systems was increased. This leads to increase the requirements for safety and availability since the failure of a machine or larger system parts can cause a significant cost.

2.6.4 Fuses

IEEE refers to ‘Fuse’ as a device that opens a circuit with fusible part, which is heated and severed by current flowing through it. In PV system a fuse link is used on each string in order to protect the conductors and modules from overcurrent faults and help to minimise any safety hazards [9].

2.6.5 Circuit Breakers

Is an electrical switch that operate automatically (Open or Closed) in order to protect the electrical circuit or system from the reverse current that means a current flow backwards through the system when the output voltage is higher than that at the input [9].

2.6.6 Lightning Protection

One of the most spectacular meteorological phenomena is lightning, that is generated by the interaction of clouds elements. Lightning can reach a power of several hundred giga watts and it is considering to be very dangerous, it can kill, injure and damage people, building and equipment installed in exposed areas or even miles away from the point where the lightning strikes. Therefore, they should be protected by an external air terminal that attracts the lightning arc and discharge it in the ground [9].

2.6.8 The Surge Protection Device (SPD)

It is connected in parallel on the power supply circuit of the loads that it has to protect. This is the most commonly used and most efficient type of overvoltage protection. Figure 2.8 expose the SPD connection principle [9].

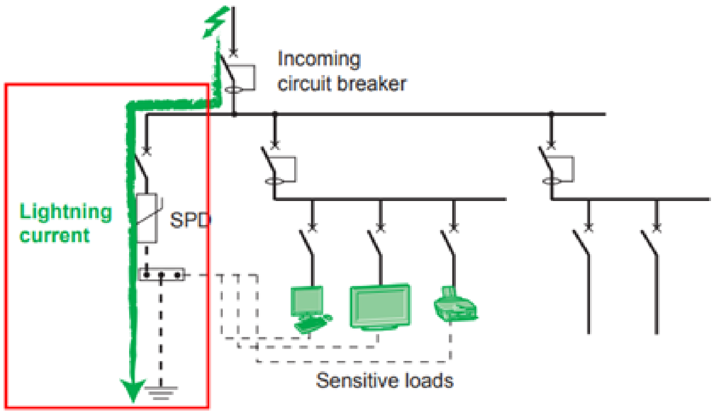

Figure 2-8: SPD connection principle.

2.6.9 Grounding

Grounding equipment's provides a low- resistance path for surge current from lightning strikes or equipment's fault; in order to protect the system, stabilize voltage and provides a common reference point.

All system components including equipment boxes appliances frame and PV mounting equipment should be grounded to protect human from leakage current from conductors to the frame of equipment [9].

2.6.10 Meter and Instrumentation

Two main type of meters are used in PV system

- Utility kilowatt-hour meter
- System kilowatt-hour meter

Utility kWh meter

Energy delivered to or from the grid were measured using a kWh- meter. Usually a utility installs a bidirectional meter with a digital display on the customer side, this meter displays the cumulative total value of energy fed to or from the grid [9].

System meter

Although it is possible for the system to operate without a system meter; it is an essential device to measure and display system performance and status.

Typically, system meter measures voltage, current, frequency, output energy and power in small time intervals. And it is mainly connected by SCADA system that allow remote observing of the system [9].

2.7 Current Situation of Solar Energy in Palestine

2.7.1 Introduction

Energy is the modern criterion of development in any society, where technological and industrial improvement for welfare life go a hand by hand with higher energy consumption. In the time where daily energy consumption mainly met by conventional source of energy {coal, oil and natural gas}, the consumption rate increased by 199% between 1973 and 2009 worldwide [1]. Therefore, enormous efforts had made by the governments to develop and utilize alternative sources of energy in order to meet their growing rate of energy consumption, protect the environment from greenhouse gases result from conventional sources combustion and to achieve sustainability and independently in the long term. Palestine (west bank and Gaza strip) with an area of 6020km^2 divided between west bank (5666km^2) and Gaza strip (365km^2) is surrounded mainly by Israel. Small portion of Gaza is bounded by Mediterranean [1]. In Palestine 100% of fossil fuels and 89% of electricity supply comes from Israel. Detailed of energy imported, exported and produced is tabulated in Table 2.1. This makes Palestinian be faced with an energy dependence crisis. Table 2.2 shows a percentage of number of hours of electricity services in both west bank and Gaza strip and at Palestine in general. On the other hand, renewable energy sources in Palestine constitute about 27% of total energy consumption in the form of solar energy (43% mainly for water heating by household solar heater), biomass such as wood 51% olive cake 6% that also used for heating [5].

Table 2-1: Energy balance of Palestinian territories in GWh, 2010[5].

Energy flows	Energy Products						Total
	Petroleum derivatives	Solar Energy	Electricity	LPG	Olive Cake	Wood and coal	
Primary Production	-	1340.5	-	-	190	1582.5	3113
Imports	6652.8	-	4158.8	1598.3	-	37.5	12447.5
Exports	-	-	-	-	-	-43	-43
Total Energy Supply	6652.8	1340.5	4158.8	1598.3	190	1576.9	15517.5

Table 2-2: Household percentage according to number of hours of electricity service, January 2011[5].

Region	Percentage for number of hours of electricity service:			Total
	Less than 16 h	17 – 23h	24 h	
Palestinian Territory	34.7	0.0	65.3	100
West Bank	0.5	0.0	99.5	100
Gaza Strip	100	0.0	0.0	100

2.7.2 Palestinian Solar Energy Potential

Palestine with a daily average solar radiation of 5.4kWh/m^2 and about 3000 hours of sunshine per year has a great solar energy potential. Although, the average solar radiation varies between 2.63kWh/m^2 per day in December and 8.4kWh/m^2 per day in June it still encourages the utilization of solar in many applications [5].

In the time where Palestine is considered to be one of the leading countries worldwide in the usage of solar water heater for domestic application approximately 67% of houses use, it still needs more utilization of solar energy PV systems [5].

Studies showed that a PV power plant (polycrystalline silicon with an efficiency of 11%) with an area of $8km^2$ in the area of Jordan valley, where solar radiation ranging between (5.4-6 kWh/m2) per day annually, can generate 1GW of electricity. This plant could cover 2.7% of the valley land that had a low population density. Such field can cover 27% of the current Palestinian electricity needs. On the other hand, 2.7% of the current Palestinian electricity needs could be covered by using only 10 % of the Palestinian roof top areas [average $150m^2$ each house]. It is worth mentioned hear that Palestine energy consumption considered to be one of the lowest in the region while it has the highest price for energy in the region. [1]

The Palestinian energy authority has prepared a strategy to raise the RE contribution in energy sector where we look for clean and secure electricity supply. The goal of this strategy is to achieve 10% of total power requirement by Palestine from renewable energy by 2020. The target identified as the following: 45MW form ground and rooftop PVs, 20MW from concentrated solar power plants, 21 MW biogas and 44 MW from wind. [5]

The Palestinian distribution of annual total irradiation map shown in Figure 2.9 shows that Palestine has an average annual sum of global horizontal irradiation between 2000 and 2200 kWh/m^2, according to this reading

Palestine has a great potential for solar energy generation. Moreover, according to the map of annual energy generation potential of c-Si PV system shown in Figure 2.10, PV has an annual energy potential between 1400 and 1600 kWh/kW. This potential can extremely solve the energy crisis in the region [10].

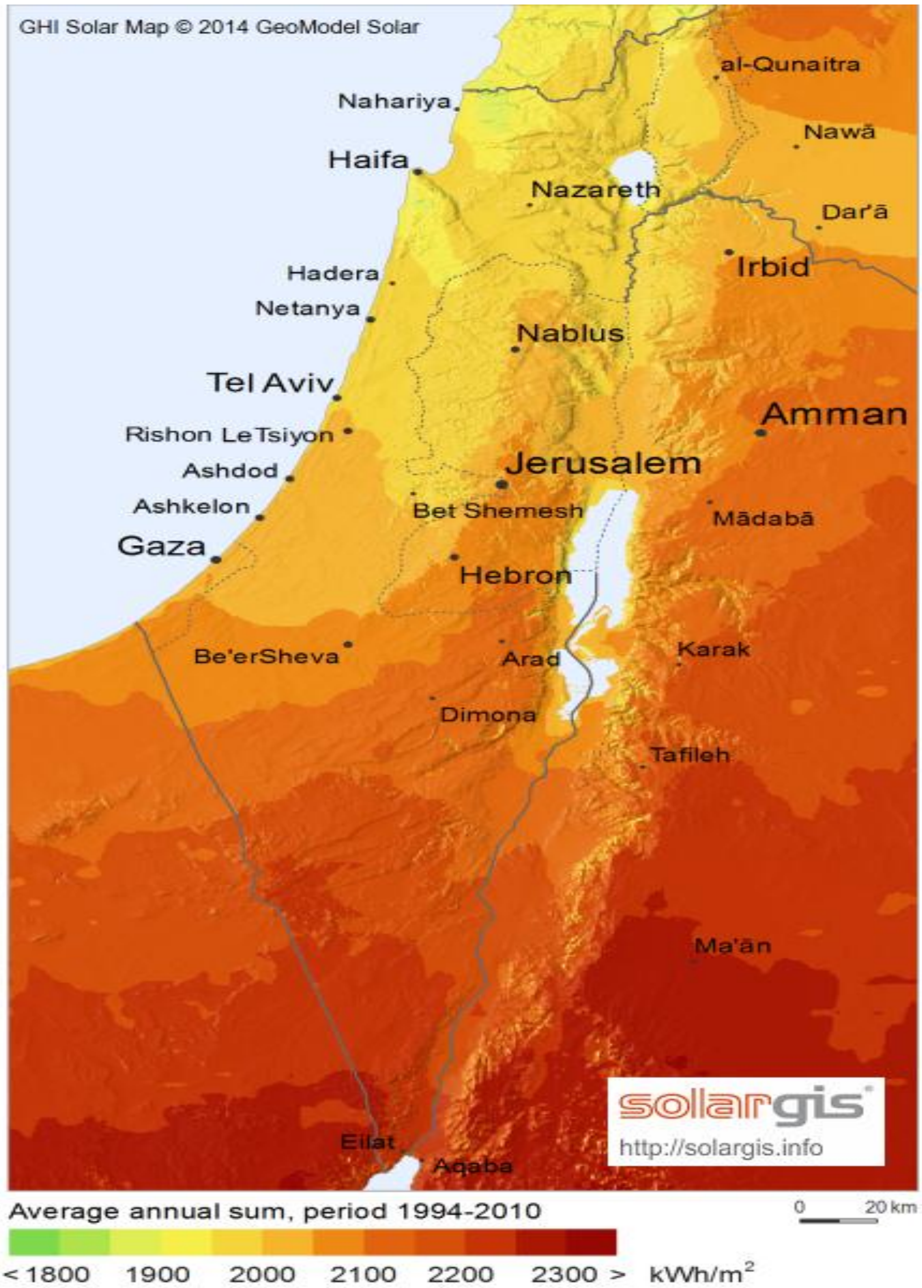

Figure 2-9: Average annual sum of global horizontal irradiation in Palestine [11].

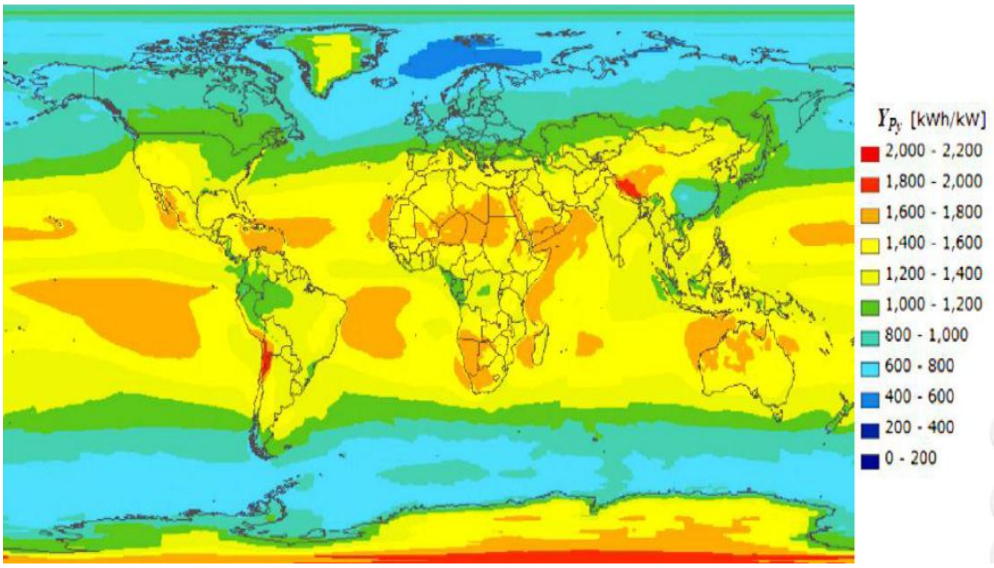

Figure 2-10: Global potential map of PV energy generation (kWh/kW) by c-Si PV module [11]

2.7.3 Temperature Effects

PV power generation systems represent a promising technology for energy generation in Palestine. However, operation conditions extremely affect its output power. Temperature operates a critical role in the PV systems. It affects PV system output power as well as operation efficiency. Climate in Palestine vary widely, between costal area – which is mild during winter with average temperature 15C^{o} and hot during summer with an average temperature 24C^{o}- and Jordan valley climate that is warm in winter hot and dry at summer.

In a typical PV system between 6 and 20 % of the incident radiation converted in to electricity and that’s according to the module efficiency while the remaining part converted into heat which significantly increase the temperature of the PV module and reduce it efficiency.

In order to examine the temperature effect on the electrical efficiency of a PV module output. The expected output power of a PV Cell/Module can be found according to the following equation [12]:

$$P_{max} = I_{mpp} \times V_{mpp} = FF \times I_{sc} \times V_{oc} \tag{2.7}$$

Where:

P_{max}: maximum output power

FF : Fill factor

I_{mpp}, V_{mpp}: the maximum output current and voltage respectively

$$\eta_c = \eta_{ref}[1 - \beta_{ref}\,(Tc - T_{ref}\,)] \tag{2.8}$$

Where:

η_c : Cell / module efficiency

Ref: reference value, at reference conditions

β : Temperature coefficient K^{-1}

β: Material property coefficients.

T_C: cell/module operating temperature (K)

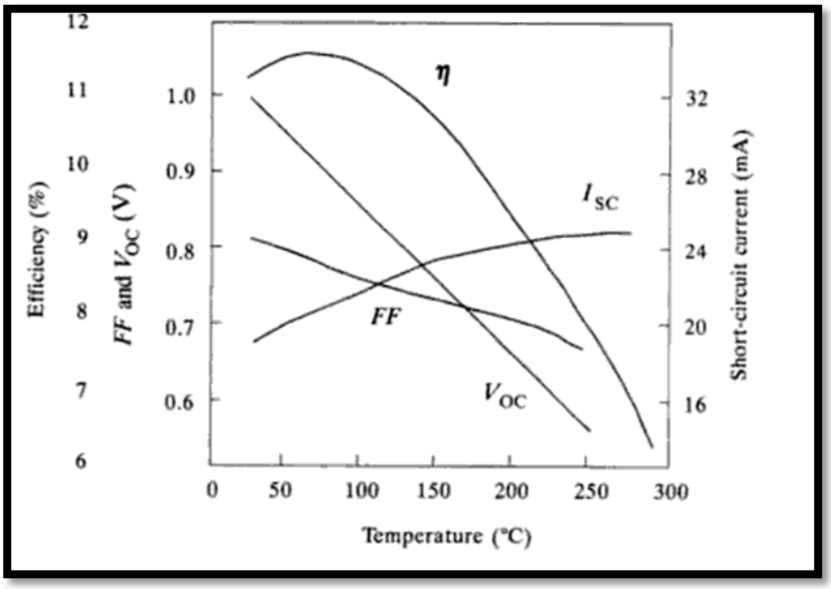

Figure 2-11: Variation of operation parameters with cell temperature [8].

This relation shows the linear relation between Cell/module efficiency and its temperature, that will describe the reduction in output energy in the months with higher temperature later on this study. Figure 2.11 summarize the operation parameter (I,V, η and fill factor) variation with temperature. Despite the fact that I_{sc} increases slightly with the temperature the excessive reduction in V_{oc} reduce the fill factor and the efficiency as its clear in the Figure 2.11.[8]

2.7.4 Grid Connected PV systems Tariff Instructions in Palestine

According to the Palestinian Energy authority instructions for the grid connected PV systems, Palestinians could utilize the sun power by PV on and off grid systems. For grid connected PV systems, when the production is greater than consumption; 75% of the excess energy is transferred to the next months. It is worth mentioning here that excess energy transfers for only one year (from the 1st April to 31th March) if it is not consumed by the load in the next months. On the other hand, when the load consumption is greater than the PV system output energy; the load would consume the remaining needed energy from the grid and they have to pay distributors according to the utility tariff per kWh after subtracted the amount of excess energy from previous months as defined in the following equation. [13]

$$\Delta E = E_c - E_P$$

$$Dist\_dues = (\Delta E - C) \times f \quad (2.8)$$

Where:

E_c : electrical energy consumption

E_p : electrical energy Production

$Dist\_dues$: distributors dues

C : 75% of the excess energy produced by the PV system on the previous months

f: tariff value per kWh

The calculation of the electricity generated by the PV system in Palestine can be done using two types of power metering systems: net metering and feed in tariff. Bidirectional power meter is used in the net metering systems where the energy inflow, outflow and net energy are measured using the same meter device. And so, the system priced according to equation 2.8. On the other hand, in the feed in tariff system; two separate metering devices are used, one for the inflow energy and one for the outflow energy. This means that the electricity consumed and the generated one are priced separately. [14]

Chapter Three

The Configuration of the Electrical Network and the pv Power Plant of AAUJ

3. The Configuration of the Electrical Network and the PV Power Plant of AAUJ

In order to understand the power flow, through the system network; the electrical network of the university will be discussed in the following section.

3.1 AAUJ Electrical Network

AAUJ which consists of 11 independent building is feed by electricity through eight transformers with a rated power as defined in table 3-1. from TDECO. The university has eight diesel generators (DG) as well. These generators act in the case of grid fault.

Table 3-1: AAUJ transformers power rating.

Transformer	**Rated Power (kVA)**
الامريكية 1	400
الامريكية 2	400
الجامعة/ الغربي	400
الجامعة / الطبية المساندة	630
الجامعة /كلية العلوم	630
الجامعة / استاد AS	630
الجامعة /استاد	630
القبول والتسجيل	630

The 70 kWp-PV system is connected with 600 kVA diesel generator and 630 kVA utility transformer in the same bus bar that feeds three buildings of the university as shown in Figure 3.1. The loads are fed by these three sources. Any excess power generated by the PV is transferred to the utility grid.

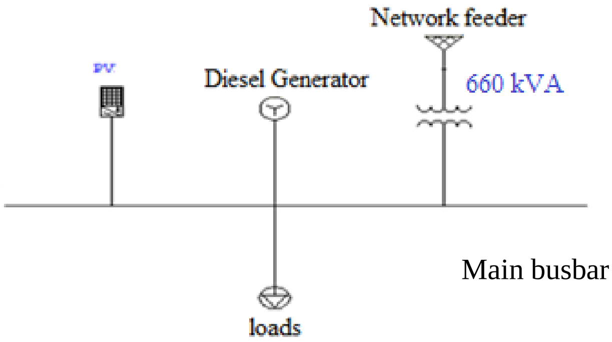

Figure 3-1: EIT Cumpos electrical network Feeder.

The nominal power installed capacity of the PV system at the STC is 70 kWp. The PV system consists of 234 PV modules type Hanwha each of 300W. These modules are divided into three groups, first group consists of 62 modules divided in three strings two with 20 modules in series each and the third consists of 22 modules in series. The remaining two groups consist of 86 modules each; divided on four strings two with 22 modules in series each and two strings with 21 modules in series. These groups are connected to (20, 27.6 and 27.6 kVA) inverters respectively. Figure 3-2 shows the entire connection of the 20 KVA and 27.6kVA transformers.

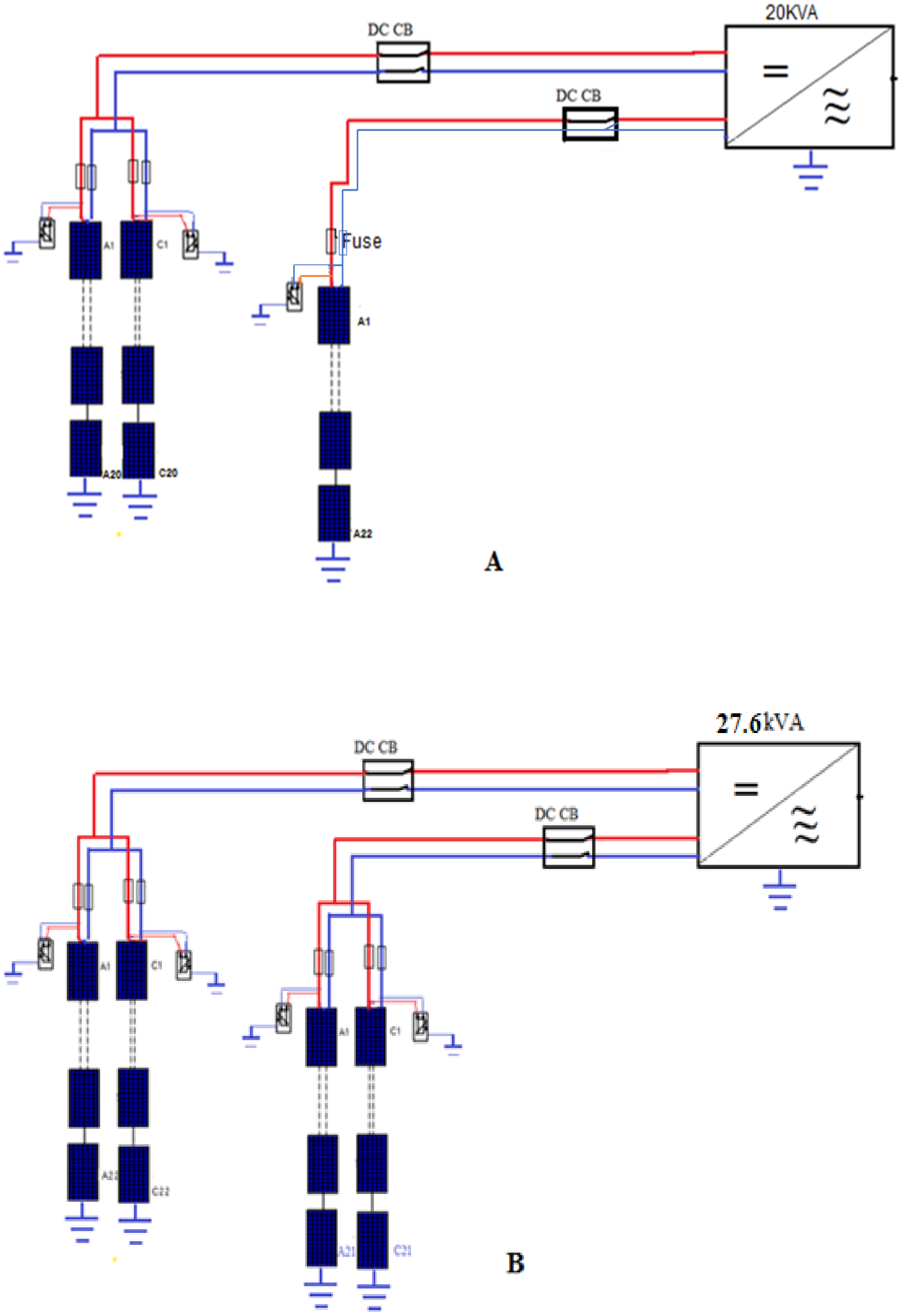

Figure 3-2: A-The entier connection of the 20kVA transformer. B - The entier connection of the 27.6kVA transformer of the AAUJ PV system.

The single line diagram of the PV system is drawn in Figure 3-3. All the PV system components used in the system are defined in the following sections with their specific values and characteristics.

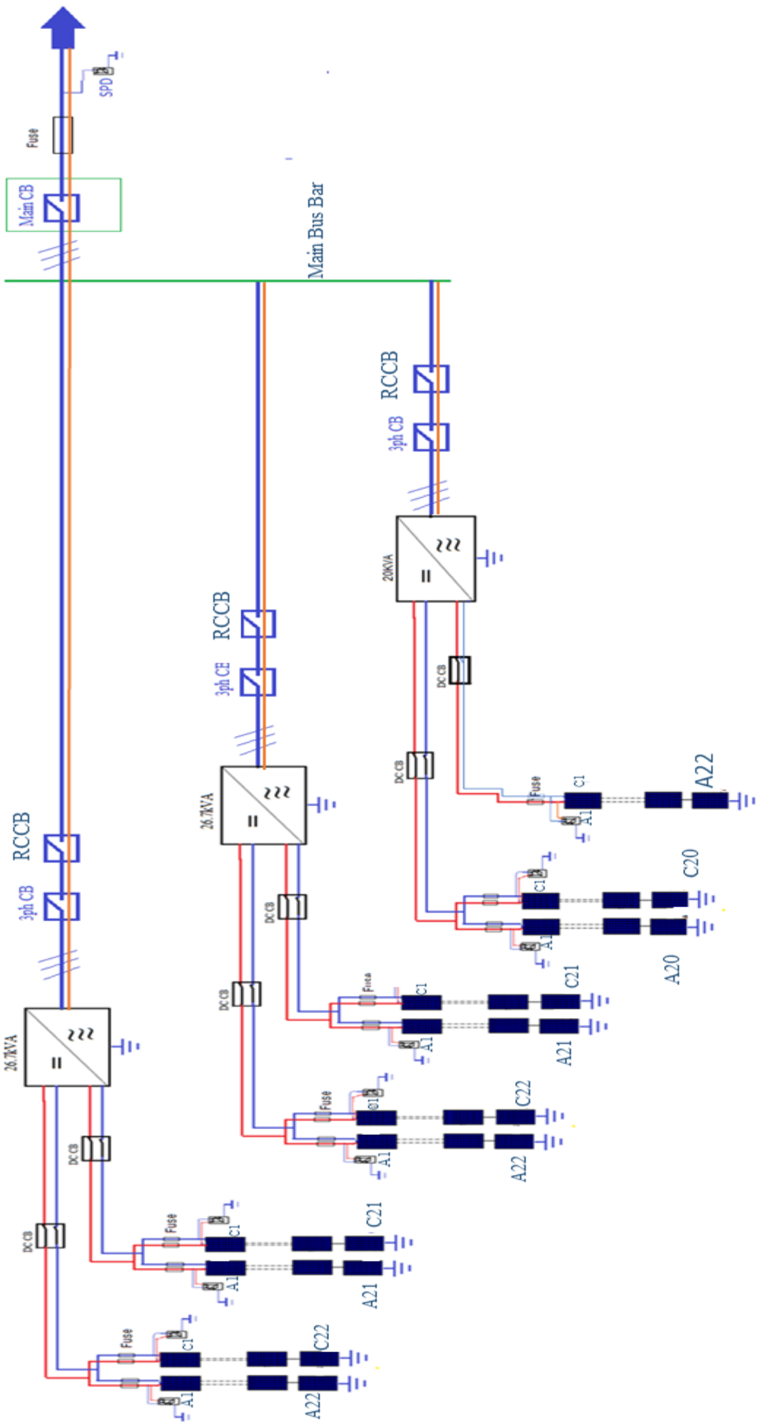

Figure 3-3: single line diagram of the 70 kWp in AAUJ.

3.2 PV System Components

The system components will be discussed in the following sections, appendix A presents all the equipment data sheets.

3.2.1 PV Module

300 W peak poly-crystalline PV modules were used in the system. Table 3.2 shows the electrical and mechanical characteristic of the PV module. Three bypass diodes are used in each PV module in order to reduce the losses by bypassing the current in the case of shadowing. Figure 3.4 shows the utilized 300W Hanwha PV module front view.

Table 3.2: Electrical and mechanical Characteristics of Hanwha module.

Electrical Characteristics at Standard Test Conditions (STC)	
Power class	300 W
Maximum Power (P_{max})	300 W
Open Circuit Voltage (V_{OC})	44.9V
Short Circuit Current (I_{SC})	8.78A
Voltage at Maximum Power (V_{mpp})	36.1V
Current at Maximum Power (I_{mpp})	8.32A
Module Efficiency (%)	15.5%
Mechanical characteristic	
Dimensions	1956mm ×988mm ×45 mm
Weight	27±0.5kg
Frame	Aluminum-alloy
Front	4mm tempered glass with anti-reflective coating
Cell Size	156 mm × 156 mm (6in ×6in)
Number of Cells	(Pieces) 72 (6 × 12)
Output Cables Solar cable	4 mm2; length: 1200 mm

Figure 3-4: Hanwha Module Front View.

3.2.2 DC Surge Protection Device (SPD)

Two ABB surge protection devices were connected in parallel with each string in all inverters. One of them is connected to the positive side and the other one to the negative side. This device has a nominal discharge current of 20 k A and the maximum discharge current is 40kA. In addition, its rated DC voltage is 440 V and its nominal AC voltage is 400/690 V. Figure 3.5 shows the SPD connected to inverter 3.

Figure 3-5: The SPD connected to inverter 3 in AAUJ PV system.

3.2.3 DC Fuses

Figure 3-6 shows the ABB fuses that are connected in series with each string in all inverters. Two fuses one with positive led and one for negative led were used for each string. 32 A is the nominal current with 690/750 DC operation voltage.

Figure 3-6: Fuses connected with inverter 3 in AAUJ PV system**.**

3.2.4 DC Circuit Breaker

Figure 3-7 shows the 25 A and 800 Volt DC circuit breaker that connect the PV output for each maximum power point (MPP) with the inverter input. However, Circuit breaker is used for selectively switch strings even under load in the event of fault or for maintenance purposes, for fire protection and personal safety reasons. Furthermore, selective isolation of the strings in the event of inadequate system performance.

Figure 3-7: DC circuit breaker of two PV strings.

3.2.5 Grid Inverter

Three ABB inverters were used in this project each of three phases. Two inverters with 27.6kVA and 20 kVA are used. Inverters have two independent MPPT ports. With an operating voltage between (252 V – 950V) and rated voltage of 620 V. The data sheets of the inverters are represented in appendix A. Figure 3.8 below shows the inverters used in this system. Reviewing the interior connection of the system shown in Figure 3-2. Maximum number of PV module connected in series for each inverter input was 22. Then the maximum open circuit voltage for each inverter input equals to:

$$\text{Maximum open circuit voltage for each inverter input} = \text{N} \times \text{V}$$

Where,

N: Number of modules

V: open circuit voltage per PV module

Maximum open circuit voltage for each inverter input = 22 × 44.9 = 988V,

is less than the absolute maximum voltage that the inverter can handle.

On the other hand, two PV strings are in parallel which means that the maximum short circuit current that may inter the MPPT input is:

$$\text{Maximum short circuit current for each inverter input} = \mathrm{N} \times \mathrm{I}$$

Where,

N: Number of modules

I: short circuit current per PV module

Maximum short circuit current for each inverter input = 2×8.78 = 17.56A, which is less than the 25 A, the maximum current that the MPPT input can handle.

Figure 3-8: ABB and AURORA inverters front view.

3.2.6 AC Circuit Breaker

Three AC circuit breakers are connected with the three inverters AC outputs. 63A and 40A are the nominal currents for the 27.6 k VA and 20kVA inverters respectively. Figure 3-9 shows the AC CB used in this system.

Figure 3-9: AC CB.

3.2.7 Residual Current Circuit Breaker (RCCB)

Three RCCB with a rated current of 40 A, rated voltage of 230/400 V and a residual rated current of 30mA were used in this system to connect the AC output of the inverters with the utility meter system. Figure 3-10 shows the RCCB used in this project.

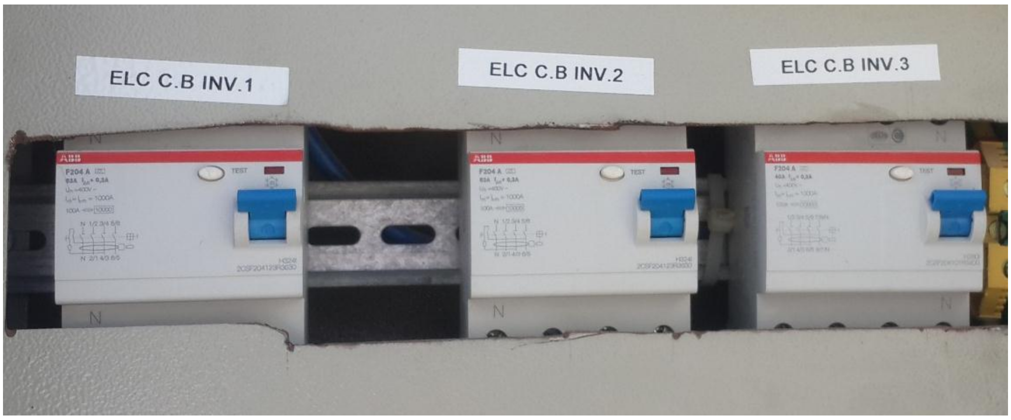

Figure 3-10: Residual Current Circuit Breaker.

3.2.8 AC Surge Protection Device

Another SPD is connected in parallel with the AC output of the three inverters. It has a 20kA nominal current with a maximum current of 40 kA. 440 V, 1900 V are the nominal and maximum voltages respectively. Figure 3-11 shows the AC SPD used in this project.

Figure 3-11: AC Surge Protection Devices.

3.2.9 AC Fuses

Figure 3-12 shows the ABB fuses connected in series with inverters output. 128A, 690V are the nominal current and voltage of these fuses. Figure 3.12 shows the AC fuses used in this project.

Figure 3-12: AC Fuses.

3.2.10 Main Circuit Breaker

An AC circuit breaker with a nominal current of 125A is used as a main CB to connect or disconnect the system from the grid. Figure 3-13 shows the main AC CB used in this project. Figure 3-14 shows the main distribution panel.

Figure 3-13: Main CB.

Figure 3-14: AC main distribution panel.

3.2.11 Lightning Protection

Figure 3-15 shows the 40kA/1000V lightning air terminal protection for AAUJ system.

Figure 3-15: lightning air terminal.

3.2.12 Grounding

25 mm^2 copper wire was used as main earthing cable while 10 mm^2 one was used for sub earthing cables in the system. Figure 3-16 shows the earthing wire and equipment used in this system.

Figure 3-16: AAUJ project earthing box

3.2.13 Meter and instrumentation

Utility kWh meter

Figure 3-17 shows the Schneider meter device used in the system.

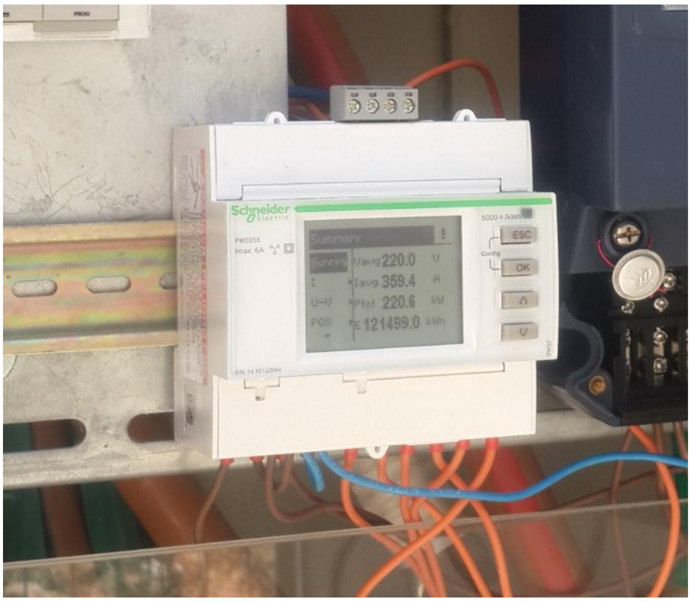

Figure 3-17: AAUJ PV project utility Schneider meter**.**

System meter

Typically, system meter measure voltage, current, frequency, output energy and power on small time intervals. And it is mainly connected by SCADA systems that allow remote observing for the system. Figure 3-18 shows the kWh system meter used in the PV system.

Figure 3-18: AAUJ PV project system meter.

3.3 Evaluation of the PV System Site

As mentioned in previous section of this study, Palestine is considered to have a high solar energy potential. However unsuitable site location will cause excessive losses in energy production. Free shading area with an ability for the PV module to be well oriented and accommodated are the critical rules for any site selection criteria. Shading, tilt and azimuth angle for the system under the study will be discussed in the following sections.

3.3.1 Shading

Shading has a great effect on PV energy production, however small shading even that caused by a single branch of leafless tree or that from a hanging wire may adversely affect energy production by the module. This is because shading one cell essentially turn off all the cell in series with it.

Shading from building itself (hanging wire, lighting, ...etc.), tree, other building and module strings on the system should be carefully avoided during design and planning stages. The required distance between modules strings in the same PV system can be calculated using equation (3.2). Figure 3.19 shows array shading distance parameters. [15]

$$d = w * [\sin(\beta)\tan(23.5° + l) + \cos(\beta)] \quad (3.2)$$

Where

$\beta =$ tilt angle of the PV array

$L =$ latitude

$w =$ width of the array

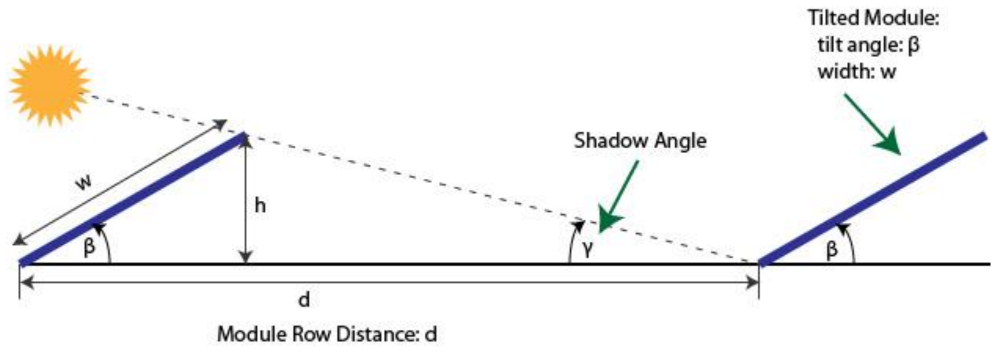

Figure 3-19: shadowing Distance parameters[16]

By considering the system under this study with a tilt angle $\beta = 18.6°$ and a width $w = 3.9m$ the minimum distance d that guarantees no shading from the PV module during the peak hours is $d = 5.46m$

The mounted arrays have a spaced distance of $d = 7m$ which is good compared to the minimum distance which is 5.46m. Moreover, the system site is shading free from tree, buildings, hanging wire or towers. Figure 3-20 shows the PV system front view.

Figure 3-20: AAUJ PV system Front View

3.3.2 Tilt and Azimuth Angle

A tilt angle between the latitude of the location (l) and (l -15) will maximize the output with losses in total output energy below 5% [9].

Palestine locates in the north hemisphere in the 32 latitude that requires a module azimuth angle toward south and a tilt angle between (17^o – 32^o) for maximum output energy. Figure 3-21 shows a tilt and azimuth angle representation. System under the study is mounted towards south with a tilt angle of 18.6^o which guarantee maximum total output energy throughout the year with losses below 5%.

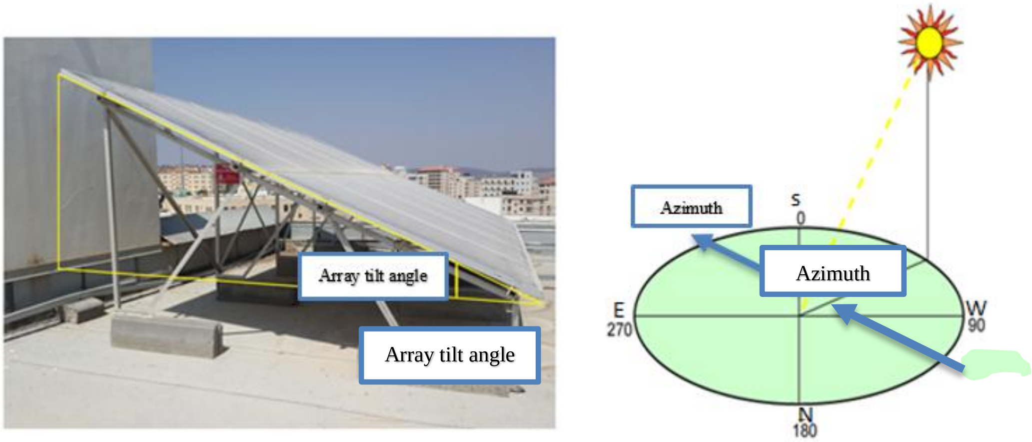

Figure 3-21: Tilt and azimuth angle representation [17].

Chapter Four

Monitoring and Operation of the pv System Located at AAUJ

4. Monitoring and Evaluation of the AAUJ PV System

4.1 Introduction

Accurate evaluation of PV system performance is very essential for development of PV industry, for components manufacturers, for researchers, system developer and for defining the quality of existing project [8]. The main goal of this study is to define the performance of a grid connected PV system mounted on the top roof of EIT campus in AAUJ during two years of continuous operation. In order to determine the PV system performance; total annual and monthly production, monthly and yearly coverage percentages, final yield and performance ratio will be studied in the following sections. These parameters define the overall system performance with respect to the energy production, solar sources and overall effect of system losses. The results will be compared with other similar systems and with the expected performance determined using PVSYST simulation.

4.2 Metrological Data on the Site of AAUJ Project

Figure 4.1 shows the monthly daily average solar radiation in kWh/m^2.day in the project site. The annual sum of global horizontal solar irradiance amounts to 1961 kWh/m^2 (5.4 kWh/m^2.day) [19]

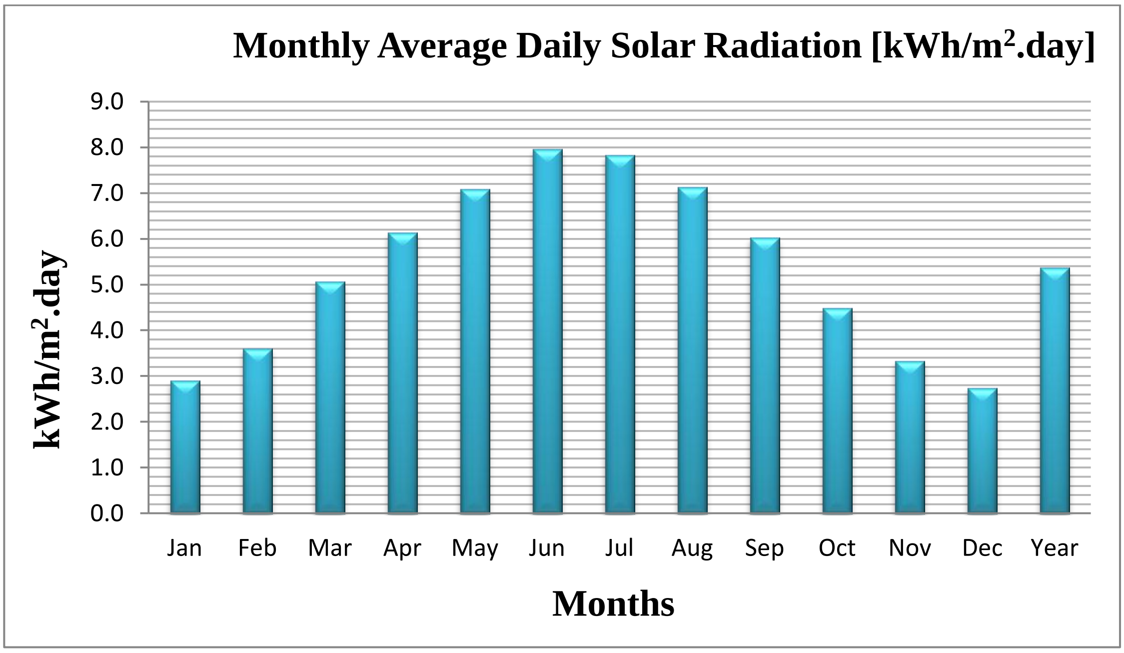

Figure 4-1: Monthly average daily solar radiation in the site of AAUJ.

This data was gathered by a Solar Atlas Mediterranean which is for global horizontal data for the southern and eastern Mediterranean region. Data for this part were gathered by Earth observation satellite and based on existing ground measurements tools in the region. The data were averaged for 20 years (1991-2010). Figure 4.2 shows the monthly average ambient temperature with the monthly average sunshine hours. These curves give a clear description for the monthly solar energy production. Although, Jun, July, August and September had a larger value of sunshine hours it has a lower value of production than other months during the year and that refers to the effect of temperature. It is evident from the graph that these months have a higher value of temperature and since the PV module efficiency inversely proportional to the ambient temperature; the output energy was lowered in these months [19].

May, has the advantage of both high sunshine hours and moderate temperature with respect to all other months and so, it has the highest output energy during the year.

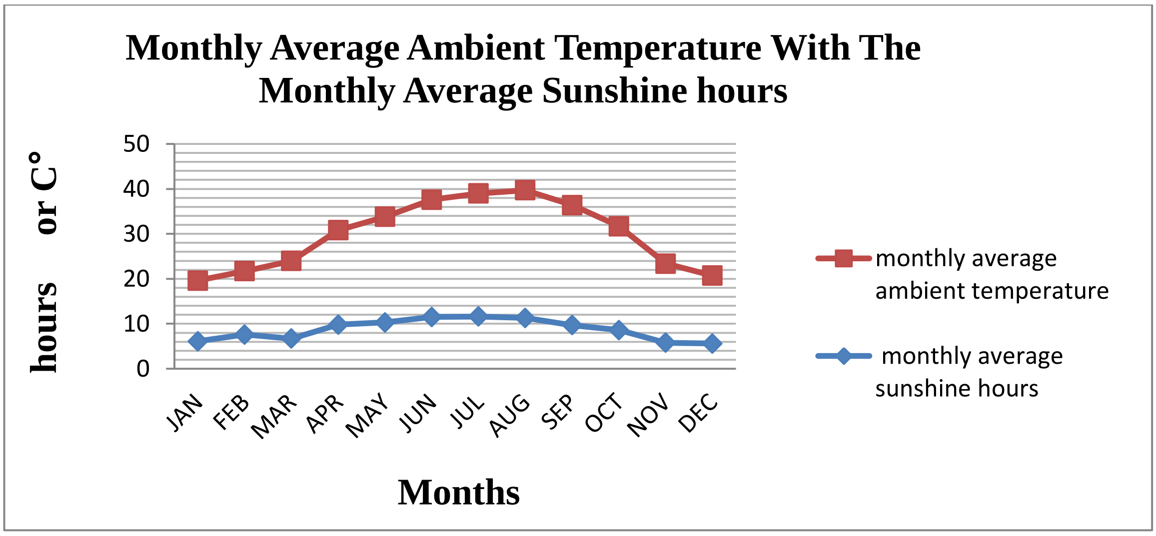

Figure 4-2: The monthly average ambient temperature with the monthly average sunshine hours [18].

4.3 Output Energy

The energy produced by the solar PV system depends on some factors that include solar PV array size, amount of irradiance, total efficiency of the system which implicitly includes system losses. The losses include shading, temperature, inverter efficiency, voltage drop, orientation and tilt angle of the modules. PV system production data from Jan 2015 to Dec 2016 were used in this performance evaluation. PV modules output power and energy were used along with irradiation data taken from Solar-Med-Atlas web site. The total energy produced by the PV system in 2015 and 2016 were about 100MWh and 95MWh respectively. Table 4-1 tabulates the monthly energy output of the system in 2015 and 2016. It is clear that May,2015 with 12825 kWh has the highest value of production. May, 2016 with 12589 kWh was the highest as well and that may refer to many reasons such as

- Sky clearness from clouds and dust.
- Optimal temperature.

Table 4-1: Monthly energy production of the 70kWp-PV system at AAUJ during 2015 and 2016.

Energy [kwh]		
Months	**2015**	**2016**
Jan	3,290.9	3,290.9
Feb	4,564.8	5,618.3
March	11,114.4	8,433.1
April	11,055.1	12,124.4
May	12,825.3	12,588.9
June	11,211.4	12,115.8
July	10,117.7	10,805.2
Aug	8,581.6	8,447.7
Sep	7,621.7	4,316.9
Oct	8,258.3	4,710.2
Nov	6,123.4	7,667.4
Dec	5,220.4	5,629.0

4.4 Coverage Percentage

Coverage percentage is the load percentage that the PV system can cover per month or year. It is the total energy produced per month or year over the total energy consumed by the load for the same period. Table 4.2 shows the monthly load consumption in 2015 and 2016. The total load consumption was 454.4MWh in 2015 and 402.2 MWh in 2016. The annual coverage percentage can be found by the following equation:

$$\text{Annual Coverage percentage} = \frac{A_P}{A_C} \qquad (4.1)$$

Where,

A_P: Annual PV production

A_C: Annual load consumption

With 100 MWh and 95 MWh PV production in 2015 and 2016 respectively, the coverage in 2015 and 2016 were as follows:

- Annual coverage percentage (2015) = $100\ \text{MWh}/\ 454.4\text{MWh} = 22\%$
- Annual coverage percentage (2016) = $95\ \text{MWh}/\ 402.2\text{MWh} = 23.6\%$.

Table 4-2: Monthly load consumption

Month	Consumption [kwh]	
	2015	**2016**
Jan	54084	43627
Feb	30159	27837
March	31598	29344
April	38501	32851
May	40427	35060
June	30652	23165
July	38047	30266
Aug	44836	42701
Sep	36794	29907
Oct	39560	42778
Nov	35548	30787
Dec	34188	33928

The PV monthly load coverage percentage is illustrated in Figure 4.3. The coverage percentage varies between (6-36.5) % in 2015 and (7.5-52.3) % in 2016. PV production was approximately similar in both years. However, energy consumed in 2016 was lower than that consumed in 2015 at about 20%.

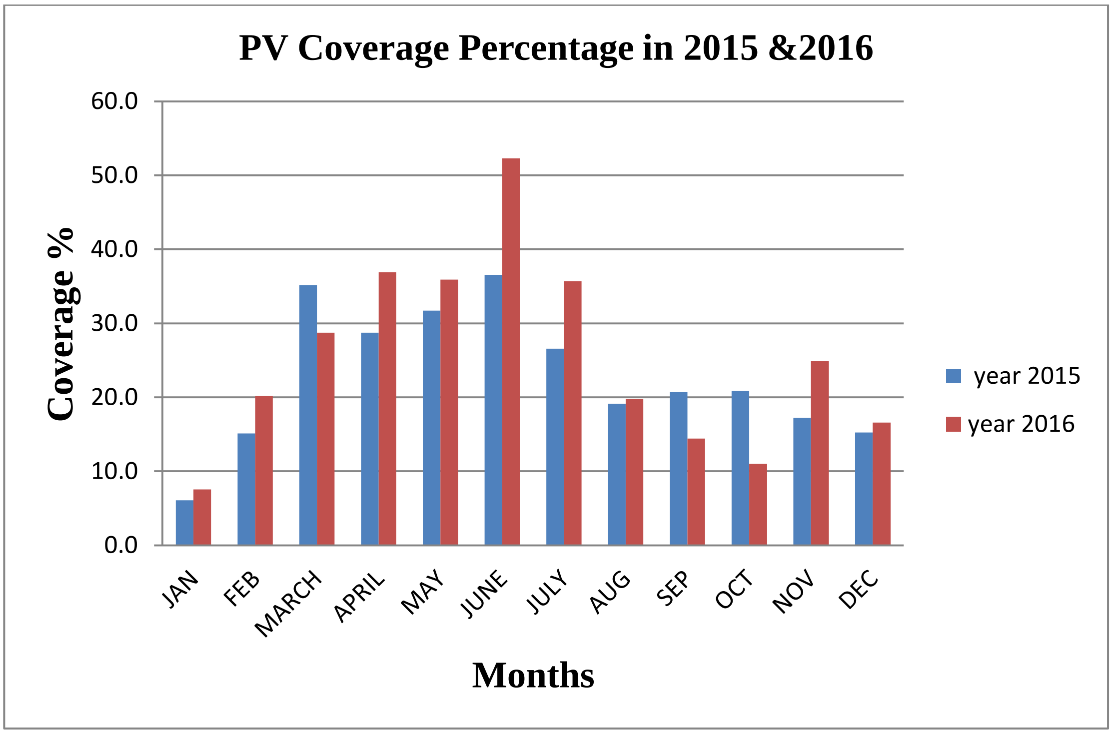

Figure 4-3: PV Monthly coverage percentage of the 70kWp-PV system at AAUJ

4.5 Performance Parameters

In order to determine the overall system performance, solar radiation and effect of system losses; Final Yield, PSH, Performance Ratio and Capacity Factor will be investigated.

4.5.1 Final yield (Y_F)

One of the most important parameters to define the technical performance of a PV system is the final yield which is the annual, monthly or daily net AC energy produced by the PV system to the peak power of the PV system at STC (cell temperature of 25°C and an irradiance of 1000 W/m^2 with an air mass 1.5). It represents the number of hours that the PV system would need to provide the same energy if it operates at its peak power. Y_F

normalize the energy produced with respect to the system capacity. And so, it is a suitable parameter to compare PV systems with different capacities.

$$Y_F = \frac{E\ (kWh)}{P_{Peak}\ (kW)} \tag{4.2}$$

The monthly final yield of the system varies between 180 kWh/kW$_P$ in May and 47 kWh/kW$_P$ in January. The system had an annual final yield of about 1428kWh/kW$_P$. It is clear that the YF is proportional to the energy output. Figure 4.4 shows the daily average final yield that can be found as following:

The PV energy produced is 11.11 MWh in March 2015, with 70kWp power of the system, the daily final yield is obtained as follows:

$$Y_{F(day)} = \frac{(11.11 \times 10^{\wedge 3}\ kWh)}{(31day \times 70\ kW_p)} = 5.11\ kWh/kW_p.day$$

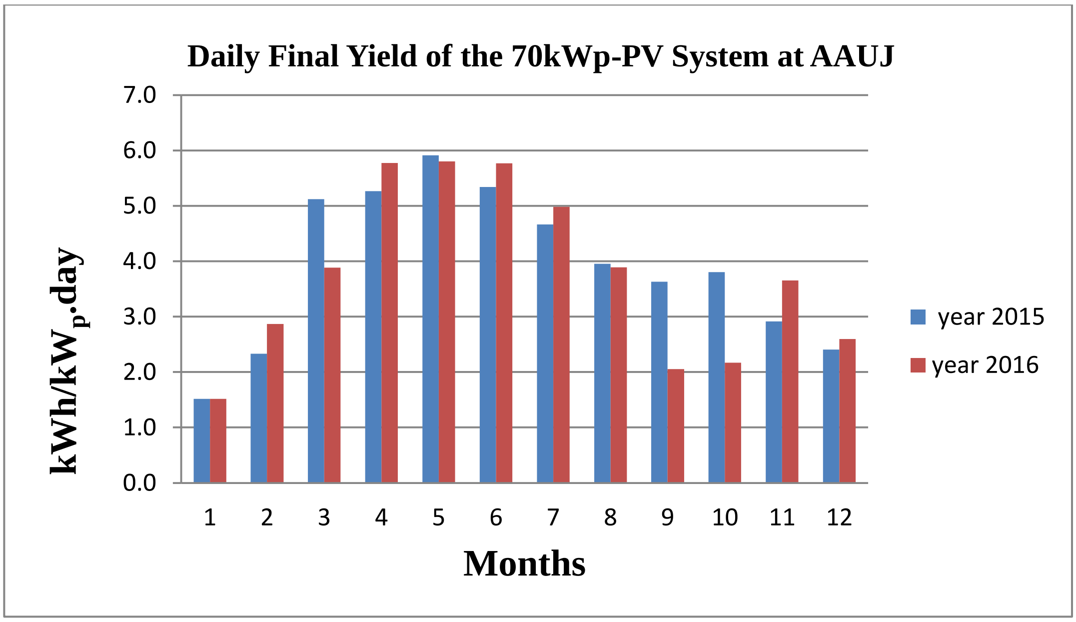

Figure 4-4: Daily final yield of the 70kWp-PV system at AAUJ.

Table 4.3 summarizes the values of annual and average monthly final yield with the solar radiation for some PV projects around the world.

Table 4-3: PV systems final yield values around the world [19,20,21].

Solar radiation (kWh/m^2.year)	**Average monthly final yield (kWh/kW_p)**	**Annual final yield(kWh/kW_p)**
2244.7	146.73	1760.76
2000	88.8	1065.6
1596	92	1105
1346.85	90.5	1086

Reviewing the data in Table 4.3 it is evident that the final yield increases with the increase of solar radiation. Comparing the project under this study with these systems, the AAUJ project has an annual final yield equals to 1428kWh/kW_p while the solar radiation in the site is about 1961 kWh/m^2. which means that the system has good performance comparing to other similar systems.

4.5.2 Peak Sun Hours (PSH)

PSH is the global irradiance in the earth (kWh/m^2) divided by the reference irradiance G_o (kW/m^2).

$$PSH = \frac{Es}{Go} \tag{4.3}$$

Where,

E_s: is the irradiance in the plane (kWh/m^2).

G_o: reference irradiance ($1000W/m^2$).

Figure 4.5 shows the monthly daily peak sun hours at the AAUJ site. For example, PSH for March is obtained as follows:

$$\text{PSH} = \frac{157\ \text{kWh/m2}}{31 \times 1\text{kW/m2}} = 5.1\ \text{hours} — \text{day}$$

The average daily peak sun hours around the year can be calculated as the sum of daily average for each month divided by 12:

$$\text{PSH} = \frac{2.9 + 3.6 + 5.1 + 6.1 + 7.1 + 8 + 7.8 + 7.1 + 6 + 4.5 + 3.3 + 2.7}{12}$$

$$= \mathbf{5.36\ hours}$$

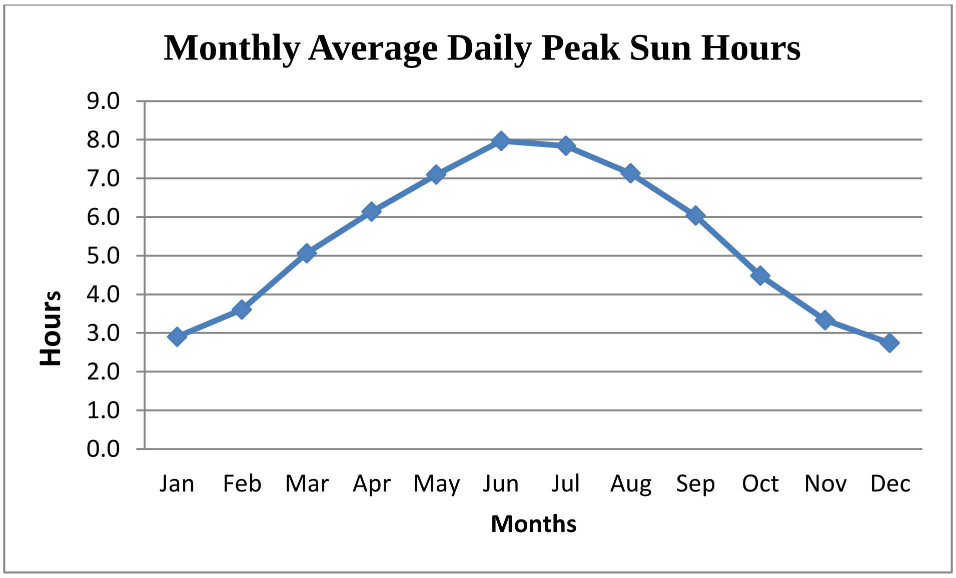

Figure 4-5: Monthly average daily peak sun hours at the site of AAUJ

4.5.3 Performance Ratio (P_R)

P_R represents the total losses in the system when converting from solar energy input to electrical AC output energy; due to inverter inefficiency, wiring, mismatch, PV module temperature, components faults and incomplete use of irradiation due to reflection, soiling and snow. P_R is the ratio of the actual output energy to the expected one.

$$P_R = \frac{A_E}{E_E} \tag{4.4}$$

Where,

A_E: actual output energy kWh

E_E: expected output energy kWh

In order to calculate the expected output energy of a PV system the following equation is used:

$$E_E = G \times A \times \eta \tag{4.5}$$

Where,

G: solar radiation kWh/m^2

A: PV system area (452.2m^2)

η : PV module efficiency (15.5% for this project)

For example, the expected output energy in May 2015when the solar radiation is 220 kWh/m^2 is

$$EE = 220 \times 452.2 \times 0.155 = 15420 \text{ kWh}$$

Then, the PR in May 2015 where the actual output energy is 12825 kWh is

$$PR = \frac{12825}{15420} \times 100\% = 83.1\%$$

Figure 4.6 shows the monthly PR of the system in 2015 and 2016. Performance ratios of 70% and above are considered to be good. Usually, the PR values are greater in winter than in summer months due to reduction in ambient temperature and thereby the module losses.

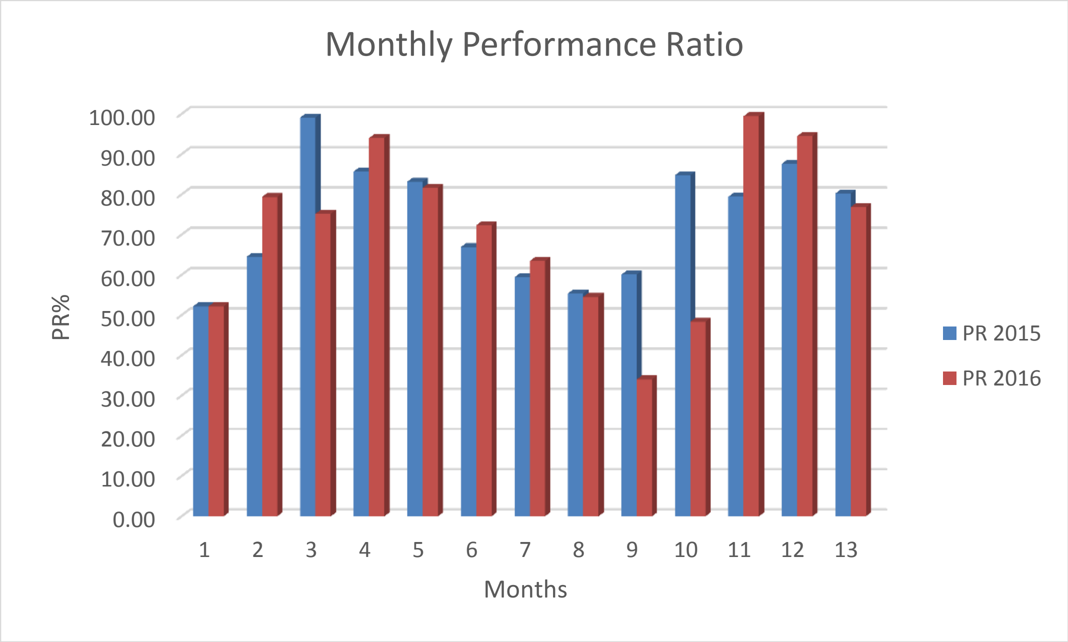

Figure 4-6: Performance ratio for 2015 and 2016 of the 70kWp-PV system at AAUJ.

The values of *PR* for the system under this study fall within (52% in Jan and 99% in March) in 2015, with a 80% annual value and within (34% in Sep and 99% in Nov) in 2016, with a 76.8% annual average. This readings indicate a very good performance for the system when compairing it with general PR for systems that fall within (0.6 to 0.8). It also indicates that there were a small amount of energy losses during the total process.

4.5.6 Daily PV production

Reviewing the daily energy production for each month during 2015 and 2016, effects of temperature, solar radiation, sunshine hours and clouds shading can be clearly noticed.

Inspecting the daily energy production for May, June, July and August we find approximately close daily production values. Figure 4.8 displays the daily production in June. Data taken from SCADA system connected to the system, the closeness of the daily energy values during the whole month are recognizable. This issue refers to approximately similar values of solar radiation and ambient temperature as well as to sky clearness.

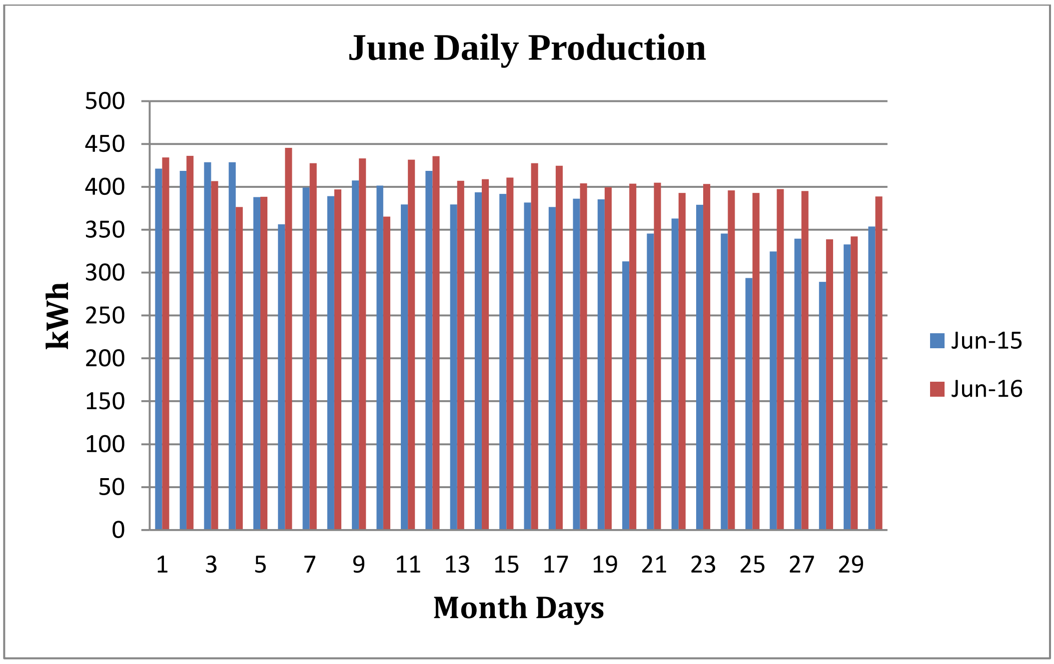

Figure 4-7: June daily production of the 70kWp-PV system at AAUJ in 2015 and 2016.

During winter, autumn and spring seasons, the sky is covered with clouds during period of these seasons which affect the energy production resulting in a fluctuation in the daily production. This issue is demonstrated in Figure 4.9 where the energy production during December varies between zero kWh/day and 300 kWh/day.

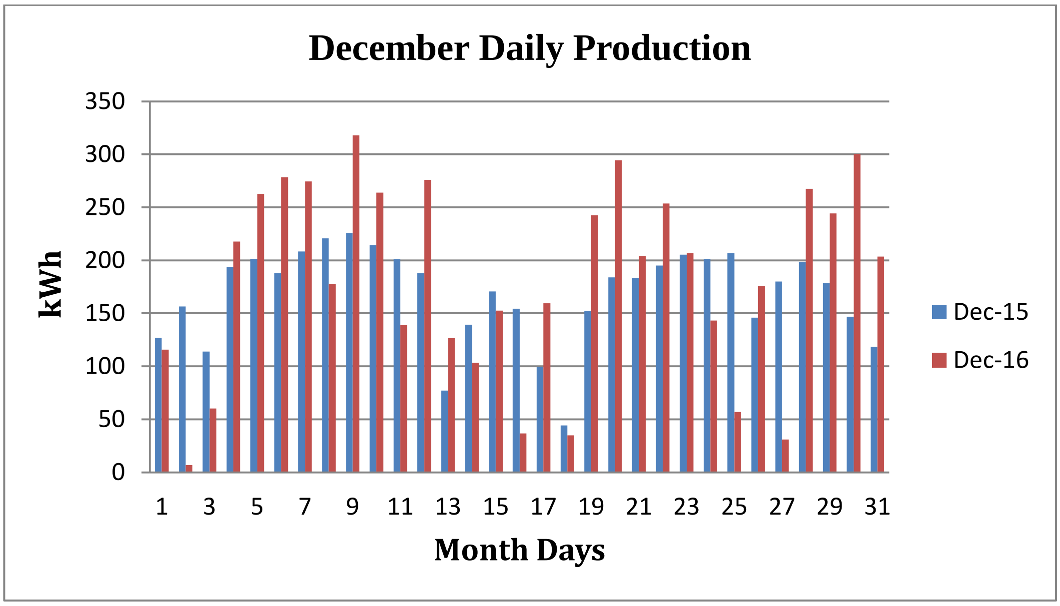

Figure 4-8: December daily production of the 70kWp-PV system at AAUJ.

4.6 Maximum and Minimum Day Production

Figure 4.10 illustrates the energy production on 6th November 2015 where the total energy produced amounts to 20.6kWh/day which is the minimum amount in this year. The corresponding minimum energy produced on 2nd December 2016 amounts to 4.9kWh/day.

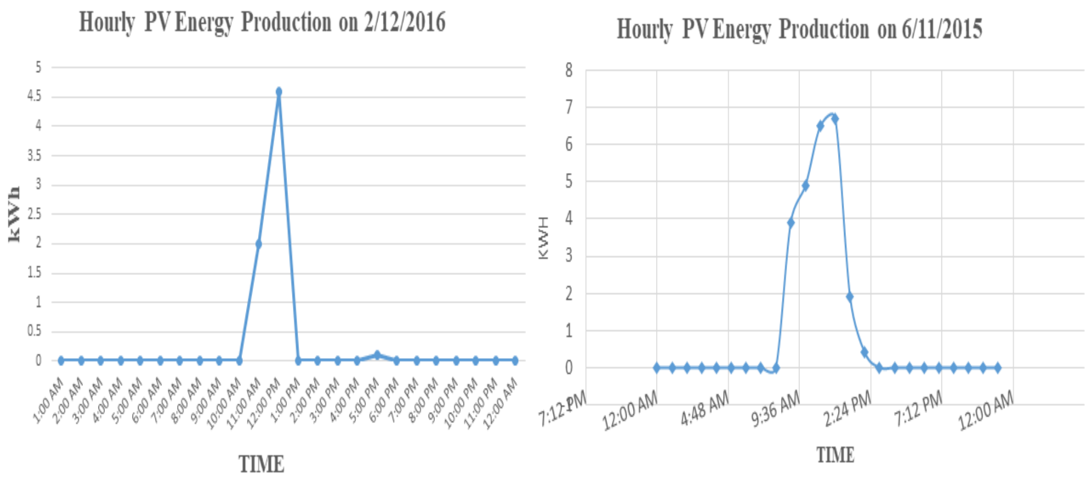

Figure 4-9: 6th of November 2015 and 2nd of December hourly average energy production of the 70kWp-PV system at AAUJ

On 18th April 2016 and 25th April 2015 with 380 and 409 kWh respectively the highest daily production in 2016 and 2015 were recorded. Figure 4.11 Shows the energy production curve for 25th of April 2015. Sine wave shape describe the solar radiation on this day. That means a sky free from clouds.

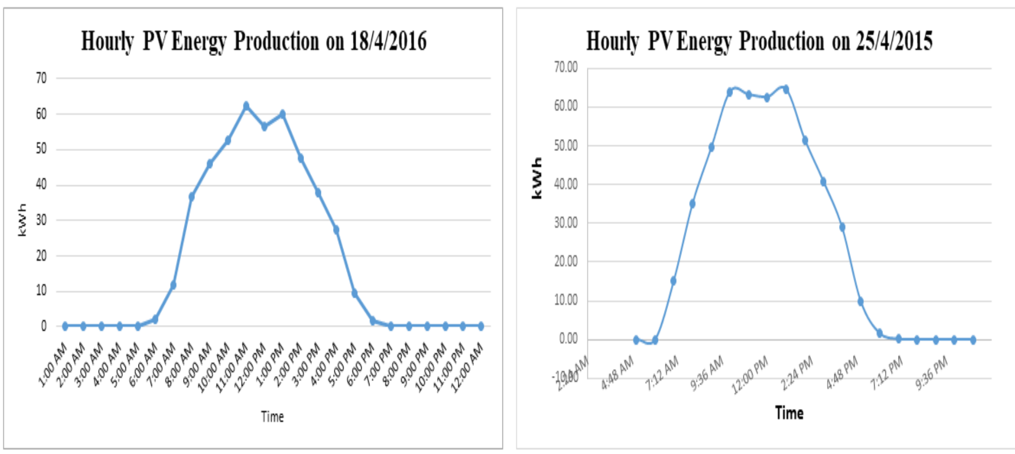

Figure 4-10: 25th April 2015 and 18th April 2016 daily production of the 70kWp-PV system at AAUJ

4.7 Environmental Effects of the 70kWp-PV System at AAUJ

Global warming is one of the major environmental issues which sounded the alarm around the world. Most industrialized countries have addressed CO_2 and other greenhouse gases emission reduction on their political agenda. While the conventional methods of energy generation seem to be one of the most harmful procedures on climate, air, water, land and wildlife; renewable techniques provide an environmental and social problems solution in addition to sustainable developments for human activities. Photovoltaic energy conversion has high expectations for their abilities on CO_2 emission reductions (absence of any air emissions and waste production during their life working).

The environmental and social-economic benefits of PV systems can be concluded in the following points:

- Greenhouse gases (mainly CO_2 and NO_x) emission reduction
- Electrical grid transmission line reduction
- Save water resources from toxic waste
- Increase the national energy independency
- Provides job opportunities
- Security of energy supply

For the system under study and in order to estimate its environmental effects the, CO_2 emission saving in tons was calculated and shown in Figure 4.12. According to *Tsoutsos et al* [20] each kWh generated by PV can save between (0.6 - 1) kg of CO_2 emission. In this study an average value of 0.8 $kgCO_2/kWh$ will be considered.

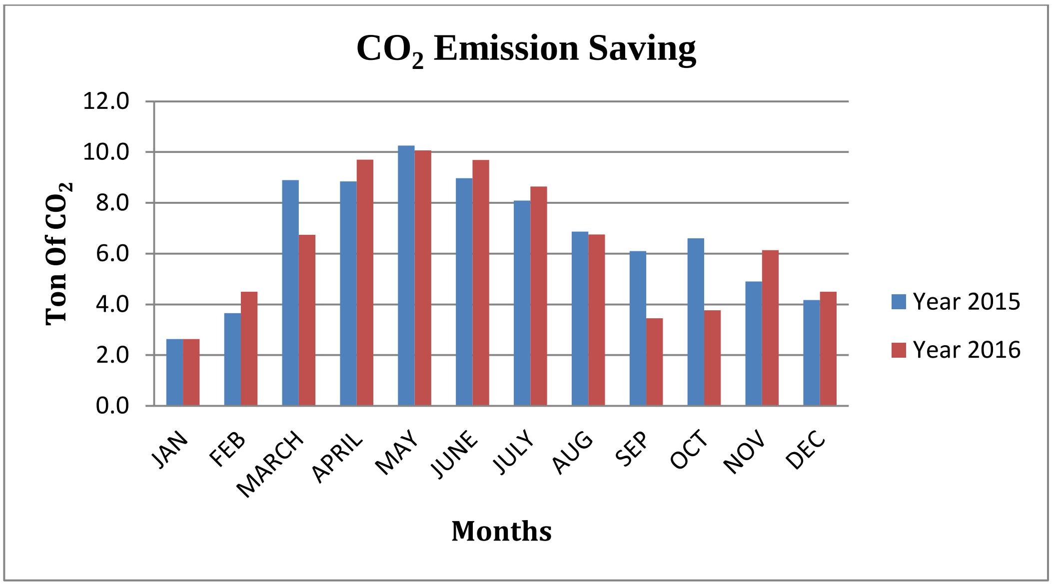

Figure 4-11: CO2 emission saving in tons by the 70kWp-PV system at AAUJ.

It is clear that the CO_2 emission saving by the 70 kWp-PV system of AAUJ varies between 2 and 10 tons per month. The annual savings of CO_2 emission were 80 tons and 76.6 tons in 2015 and 2016 respectively.

Chapter Five
Economic Analysis

5. Economic Analysis

5.1 Introduction

Within various RES technologies PV technology has a special attention due to its potential and abundant worldwide and the fact that it can't be monopolized by few countries.

In this chapter, economic analysis of the project will be implemented. It's cash flow diagram, net present value, payback period, unit energy cost and internal rate of return (IRR) will carefully be discussed.

5.2 Fixed and Running Cost

The 70kWp PV system under this study was constructed by PALPOWER Company. This project was funded completely by the institution "Future for Palestine". From the AAUJ university perspective this project is feasible anyhow since there is no initial cost. To perform an economical study for the project, PALPOWER has provided us by the total initial investment cost which was 95200$.

In order to complete this economic study these assumptions were made.

- All the annual energy production is assumed to be consumed by the load, since the amount of energy feed to the grid was little (1584kWh) after two years of operation.

- The interest rate i or what is so called "the weighted average cost of capital" is assumed to be 8%
- The average annual energy produced by the system is 97.7MWh.
- The annual energy production of the system is assumed to decrease by 0.8%.
- The construction cost for each 1kWh is considered to be 0.54 NIS/ kWh (0.153$/kWh).[21]
- Annual operation and maintenance cost is assumed to be 1% of the initial investment (952$).
- Replacement cost for the inverters (13200$), payed one time during the life time of the project.
- The salvage value at the end of the project life time is assumed to be 3.5% of the initial cost (3332$).
- The project life time is assumed to be 20 years.

5.3 Cash Flow

Cash flows: are the amounts of money estimated for future projects or observed for business activity that have taken place. Often Cash flow calculated for a specific time period. Annual one is the most common one. [22]

Cash inflows (R) are the revenues, incomes, and savings generated by project and business activity. Usually a plus sign is used to indicate a cash inflow. For this project the price of the energy produced by the system was considered to be the cash inflow $(0.153\$ * \mathit{annual\ energy\ production\ kWh})$ .Salvage value at the end of this project life time was given a positive value, as well.

Cash outflows (D) are the disbursements, initial costs, expenses, and taxes caused by projects and business activity. Usually a negative sign is used to indicate a cash outflow. For this project the cost of operation and maintenance for the PV system were considered to be the cash outflow (1% of the initial investment) in addition to the initial investment cost. Figure 5.1 shows the cash flow diagram during the life time of the project. [22]

$$\text{Net cash flow} = \text{cash inflows} - \text{cash outflows NCF} = \text{R} - \text{D} \qquad (5.1)$$

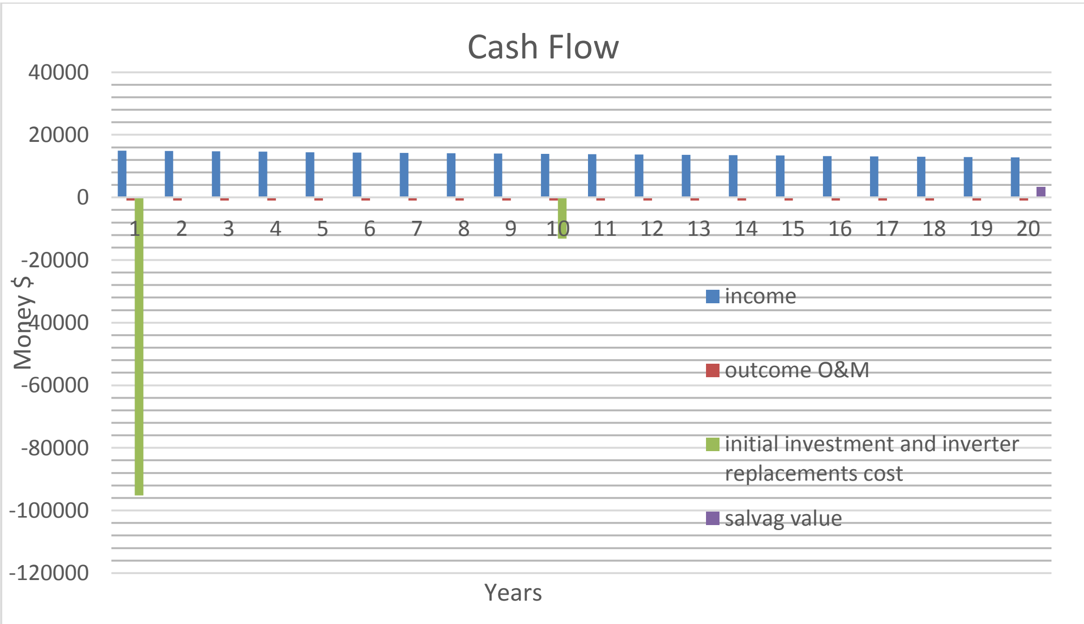

Figure 5-1: Cash flow

5.4 Payback Period

Payback period, is one of the earlier methods in projects financial analysis. It is an easy way to define the period of time that the project needs in order to recover its initial investment. Usually it was found by dividing the initial cash investment by the annual cash flow. As the period is small as the project is accepted economically. [22]

Despite the payback method is considered to be the least accurate technique, it still gives a good indication of the project profitability.

Due to the varying in the annual cash because of the degradation in the PV system efficiency, the payback period can be found by drawing accumulative diagram of the cash flow. As shown in Figure 5.2, when the cumulative value equal zero that means that the project covers all its initial expenditures and it start gaining. From the Figure 5.2 it is evident that after **seven** years the system covers its expenses and start gaining. The reduction in the revenues at the 10^{th} year refers to the inverter replacement cost.

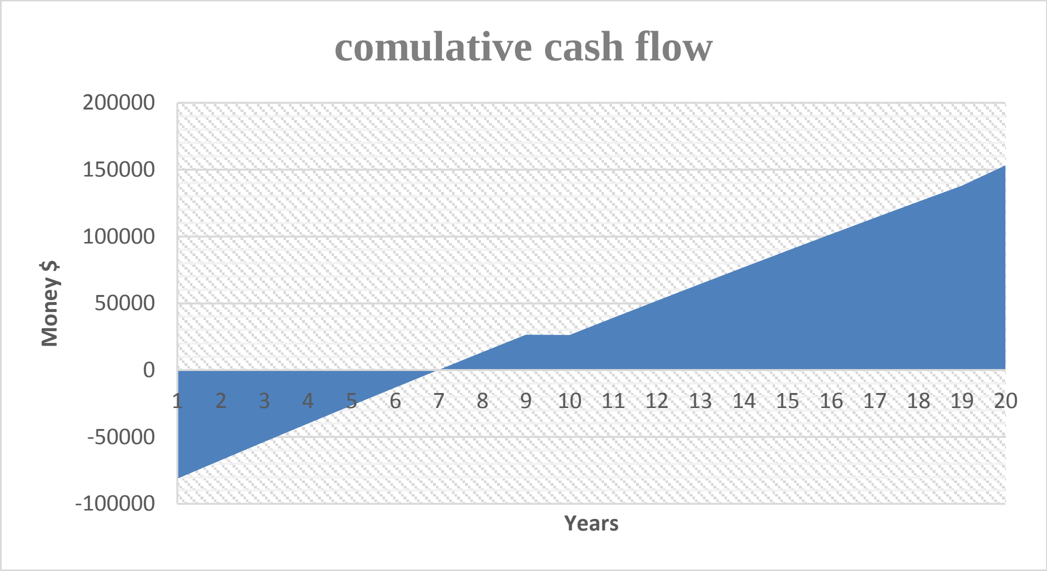

Figure 5-2: Cumulative cash flow

5.5 Net Present Value (NPV)

This is one of the popular technique to determine whether the project is financially viable or not. The net present value is the difference between the present value of the cash inflow and the present value of the cash outflow.

NPV could be positive, negative or zero. When NPV is positive or zero i.e: the inflow is greater than or equal to the cash outflow; the project is considered to be acceptable, while it is not financially acceptable when NPV is negative i.e: cash outflow is greater than cash inflow. [23]

The NPV in this study will be calculated according to the following equation. [22]

$$\mathrm{NPV}\ \mathrm{C} + \mathrm{C}_{\mathrm{O\&M}} \times (\mathrm{P/A}, \mathrm{i}, \mathrm{n}) + \mathrm{C_s} \times (\mathrm{P/F}, \mathrm{i}, \mathrm{n}) + \mathrm{outcomeY_1} \times (\mathrm{P/F}, \mathrm{i}, 1) + \mathrm{outcomeY_2} \times (\mathrm{P/F}, \mathrm{i}, 2) + \ldots\ \mathrm{C_{IR}} \times (\mathrm{P/F}, \mathrm{i}, 10) + \cdots + \mathrm{outcomeY_{20}} \times (\mathrm{P/F}, \mathrm{i}, 20) \tag{5.3}$$

Where,

C: the initial investment

C_S: salvage value

n: number of years (20)

C_{IR} : Inverters Replacement Cost.

i: interest rate

$C_{O\&M}$: operation and maintenance cost

(P/A,i,n) and (P/F,i ,n) are the compound interest factors

Using C=-95200 \$, C_s=3332\$, $C_{IR=}$-13200 \$ $C_{O\&M}$ = -952 \$,

(P/A, 8%, 20) =9.8181, (P/F, 8%, 20) =0.2145, (P/F, 8% ,10) = 0.4632 and compound interest factors (P/F, 8%, n) from n=1 to 20 as defined in appendix B. In order to calculate the expected annual output energy for the project life time, the average of the total annual output energy of 2015 and 2016 was used with an annual degradation factor of 0.8%.

$$NPV = -95200 + -952 \times (9.8181) + 3332 \times (0.2145) + 14948 \times (0.959) + 14828 \times (0.8573) + \cdots - 13200 \times 0.4632 + \cdots + 12832 \times (0.2145)$$

The total NPV = 31612.66 \$

The NPV is positive and it means the project is financially acceptable (cash inflow is greater than cash out flow)

5.6 Unit Energy Cost (UEC)

UEC represent the generation average cost per kWh. This method considers all the costs including the initial cost, operation and maintenance cost and any other expenditures during the project life time. This method is very useful to compare between different types of energy generation methods that assists policymakers, researchers and others to guide discussions and decision making. Equation below is used to find the UEC. [24]

$$UEC = \frac{C_{tot}}{E_{tot}} \tag{5.4}$$

Where,

C_{tot}: the PV system expenditures including the capital cost, operation and maintenance cost and replacement cost during the project life time.

E_{tot}: the energy output (kWh) generated by the system during its life time,

$$C_{tot} = \text{initiat cost} + \text{O\&Mcost} \times \text{project life time} - \text{salvage value} + \text{inverters replacements cost}$$

$$C_{tot} = 95200 + 952 \times 20 - 3332 + 13200 = 124108\$$$

$$\mathrm{E_{tot}} = 1910 \text{ MWh},$$

According to the calculated data in appendix C that takes the depreciation factor in account.

$$\text{UEC} = \frac{124108}{1910000} = 0.065\ \$/\text{kWh}$$

5.7 Internal Rate of Return IRR

Internal rate of return IRR: it is the rate of interest that exactly repay the initial investment with its interest payment over the life of the project. IRR can be found as the value of i that achieve the following condition. [25]

$$c - \sum_{1}^{n} \frac{Ct}{(1+i)^{t}} = 0 \tag{5.7}$$

Where,

t: number of the year

C_t: net cash flow at year t

C: initial investment

A MATLAB program is used to find the value of IRR and that refer to the variation of the net cash flow over the project life time, the value of IRR= 13.3% which is greater than the minimum interest rate (i=8%) that we used for this project and this gives a good indication about the profitability of the project since IRR must be greater than i to be financially acceptable. The complete MATLAB code is provided in appendix D.

Chapter Six
Conclusions and Recommendations

6. Conclusions and Recommendations

6.1 Conclusions

After two years of continuous operation and based on measured data and data analyzed, it was evident that the 70 kW_p PV system located at the rooftop of EIT campus of AAUJ had worked efficiently. The following points summarize the output results.

- The system had an average final yield of 3.9 kWh/kW_p-day which amounts to more than 5.8 kWh/kW_p-day in some months. This can be considered as an acceptable result.

- Considering the general performance ratio that varies between 55% and 99% it can be realized that the system performance is good.

- The monthly average capacity factor that reach to 24% is a good indicator to the energy production in the system, it is also summarize the overall efficiency of the system.

- The project monthly output energy in the two years of operation describe the relation between the output energy or system efficiency with the ambient temperature where the output energy and system efficiency decrease as ambient temperature increase.

- The world today looks for green energy sources. AAUJ PV project with more than one ton of CO_2 emission saving per kW_p per year; shows a good environmental energy source option.

- With seven years payback period of the project, Positive NPV and an IRR of 13% the PV system is economically a feasible solution for the lack of energy. Moreover, it may encourage investors to invest in this field as well.

6.2 Recommendations

- Palestine has a high solar energy potential and lacks for all kinds of conventional energy resources. The obtained positive results in this study encourage to increase the use of PV system.

- Installing measuring systems for solar radiation, wind speed and ambient temperature in different areas of Palestine is highly recommend.

- Raise the awareness on the economic and environmental profitability of the use of renewable energy sources to increase the spread of PV systems in Palestinian society.

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Appendixes

Appendix A-1

HSL 72 | Poly

Hanwha Solar

Five Key Features

1 Guaranteed quality: 12 year product warranty, 25 year linear performance warranty *

2 Predictable output: Positive power sorting of 0 to + 5 W

3 Innovative solution: Anti-reflective coating for high sunlight absorption

4 Robust design: certified to withstand up to 4000 Pa wind load and up to 7000 Pa snow load**

5 Anti-PID : Modules are qualified to withstand PID(Potential Induced Degradation)***

* Please refer to Hanwha Solar Product Warranty for details
** Please refer to Hanwha Solar Module Installation Guide
*** PID test conditions : module charged -1000V with Al-foil covered surface, 25 ˚C, 168h

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

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

HSL 72 | Poly

Electrical Characteristics

Electrical Characteristics at Standard Test Conditions (STC)

Power Class	290 W	295 W	300 W	305 W	310 W	315 W
Maximum Power (P_{max})	290 W	295 W	300 W	305 W	310 W	315 W
Open Circuit Voltage (V_{oc})	44.5 V	44.8 V	44.9 V	45.1 V	45.2 V	45.3 V
Short Circuit Current (I_{sc})	8.69 A	8.75 A	8.78 A	8.85 A	8.91 A	8.97 A
Voltage at Maximum Power (V_{mpp})	35.4 V	35.8 V	36.1 V	36.3 V	36.6 V	36.9 V
Current at Maximum Power (I_{mpp})	8.20 A	8.26 A	8.32 A	8.42 A	8.48 A	8.55 A
Module Efficiency (%)	15.0 %	15.3 %	15.5 %	15.8 %	16.0 %	16.3 %

P_{max}, V_{oc}, I_{sc}, V_{mpp} and I_{mpp} tested at Standard Testing Conditions (STC) defined as irradiance of 1000W/m² at AM 1.5 solar spectrum and a temperature of 25±2°C. Module power class have positive power sorting: 0 to +5W. Measurement tolerance: +/- 3% (P_{max})

Electrical Characteristics at Normal Operating Cell Temperature (NOCT)

Power Class	290 W	295 W	300 W	305 W	310 W	315 W
Maximum Power (P_{max})	212 W	216 W	220 W	223 W	227 W	233 W
Open Circuit Voltage (V_{oc})	41.5 V	41.7 V	41.8 V	42.0 V	42.2 V	42.3 V
Short Circuit Current (I_{sc})	7.03 A	7.08 A	7.10 A	7.18 A	7.25 A	7.28 A
Voltage at Maximum Power (V_{mpp})	32.1 V	32.5 V	32.7 V	32.9 V	33.2 V	33.9 V
Current at Maximum Power (I_{mpp})	6.61 A	6.65 A	6.73 A	6.78 A	6.84 A	6.88 A
Module Efficiency (%)	13.7 %	14.0 %	14.2 %	14.4 %	14.7 %	15.1 %

P_{max}, V_{oc}, I_{sc}, V_{mpp} and I_{mpp} tested at Normal Operating Cell Temperature (NOCT) defined as irradiance of 800W/m²; 20°C; Wind speed 1m/s. Measurement tolerance: +/- 3% (P_{max})

Temperature Characteristics

Normal Operating Cell Temperature (NOCT)	45°C + / - 3°C
Temperature Coefficients of P	- 0.43 % / °C
Temperature Coefficients of V	- 0.31 % / °C
Temperature Coefficients of I	+ 0.05 % / °C

Maximum Ratings

Maximum System Voltage	1000 V (IEC)
Series Fuse Rating	15 A
Maximum Reverse Current	Series fuse rating multiplied by 1.35

Mechanical Characteristics

Dimensions	1956mm x988mm x45 mm
Weight	27±0.5kg
Frame	Aluminum-alloy
Front	4mm tempered glass with anti reflective coating
Encapsulant	EVA
Back Cover	Composite sheet
Cell Technology	Polycrystalline
Cell Size	156 mm x 156 mm (6in x6in)
Number of Cells (Pieces)	72 (6 x 12)
Junction Box	Protection class IP 67; with 3 bypass diodes (or 3 pairs,2 each)
Output Cables	Solar cable: 4 mm²; length: 1200 mm
Connector	Amphenol H4

System Design

Operating Temperature	- 40 °C to 85 °C
Hail Safety Impact Velocity	25 mm at 23 m/s
Fire Safety Classification (IEC 61730)	Class C
Static Load Wind / Snow	4000Pa/7000Pa

Packaging and Storage

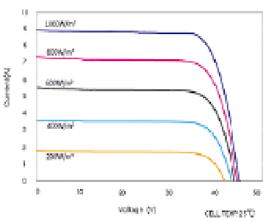
Storage Temperature	- 40 °C to 85 °C
Packaging Configuration	22 pieces per pallet
Loading Capacity (40 ft. HQ Container)	484 pieces

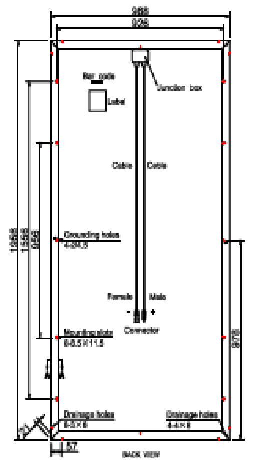
Nomenclature:

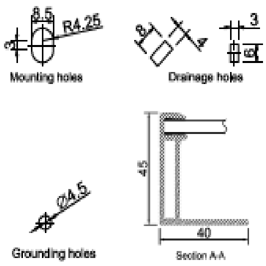
Full product name:
HSL72P6-PB-1-xxx
xxx represents the power class

Performance at Low Irradiance:

The typical efficiency at 200 W/m² in relation to 1000 W/m², (25°C, AM 1.5) is at least 96 % of STC efficiency.







Appendix A-2

OVR PV 40 1000 C

Products → Low Voltage Products and Systems → Modular DIN Rail Products → Surge Protective Devices SPDs → Surge Protective Devices SPDs Accessories

General Information

Extended Product Type:	OVR PV 40 1000 C
Product ID:	2CTB803950R0100
EAN:	3660308516565
Catalog Description:	OVR PV 40 1000 C Surge Protective Device
Long Description:	395001

Ordering

Minimum Order Quantity:	1 piece
Customs Tariff Number:	85363090

Popular Downloads

Data Sheet, Technical Information:	-
Instructions and Manuals:	-

Dimensions

Product Net Width:	17.6 mm
Product Net Depth:	55.6 mm
Product Net Height:	57 mm
Product Net Weight:	50 g
Width in Number of Modular Spacings:	1

Technical

Number of Protected Poles:	1
Arrester Class:	II
Product Main Type:	T2
Standards:	EN 50539-11
Version:	Plug-in
Discharge Current:	Nominal 20 kA Maximum 40 kA
Maximum Continuous Operating Voltage (U_c):	(L-PE) 1100 V (L-L) 1100 V (L-N) - V (N-PE) - V
Voltage Rating DC:	1000 V

Short Circuit Withstand Icc:	10 kA
Product Name:	Surge Protective Device
Suitable For:	To protect the systems against the transient overvoltage (lightning)

Certificates and Declarations (Document Number)

Declaration:	2CTC432042G1701
Declaration of Conformity - CE:	2CTC436004G1701
Instructions and Manuals:	-

Container Information

Package Level 1 Units:	1 piece
Package Level 1 Width:	117 mm
Package Level 1 Length:	25 mm
Package Level 1 Height:	82 mm
Package Level 1 Gross Weight:	65 g
Package Level 1 EAN:	3660308516565

Classifications

Object Classification Code:	141DGA
ETIM 4:	EC000941 - Surge protection device for power supply systems
ETIM 5:	EC000941 - Surge protection device for power supply systems
ETIM 6:	EC000941 - Surge protection device for power supply systems

Appendix A-3

CYLINDRICAL FUSE HOLDERS

PMX MODULAR FUSE HOLDERS

	POLES	MODULES	REFERENCE WITHOUT INDICATOR	REFERENCE WITH INDICATOR	I_n (A)	U (V)	PACKING Uni./BOX
22x58	I	2	485301	485308	100*	690	6/48
	N	2	485302	–	100*	690	6/48
	I+N	4	485303	485309	100*	690	3/24
	2	4	485304	485310	100*	690	3/24
	3	6	485305	485311	100*	690	2/16
	3+N	8	485306	485312	100*	690	1/8
	4	8	485307	485313	100*	690	1/8
22x58 24VDC	1	2	–	485314	100*	24	6/48
	1+N	4	–	485315	100*	24	3/24
	2	4	–	485316	100*	24	3/24

* ACCEPT 125A FUSE-LINKS

485308

PHOTOVOLTAIC FUSE HOLDERS

PMX FUSE HOLDERS FOR PHOTOVOLTAIC APPLICATIONS

The first feature that PV Modular fuse holders offers, is the 1000V DC or 1100V DC rated voltages. They have been developed to offer a compact, safety and economic protection solution in photovoltaic installations where due to the increase of the power and technologic evolution, no-load voltages above 800V DC can be achieved. Modular fuse holders for 10x38 & 14x51 gPV fuses according IEC/EN 60269 standard. Compact design, with reduced distances. Manufactured with a high quality materials: Silver plated copper contacts and plastic materials with high temperature resistance and selfextinguishable. All the materials are according to the European Directive RoHS (Restriction of the use of certain hazardous substances in electrical material). UL certification (File E359201).

1000V DC 10x38	POLES	MODULES	REFERENCE	DESCRIPTION	I_n (A)	U (V DC)	PACKING Uni./BOX
WITHOUT INDICATOR	1	1	485150	SINGLE-POLE	32	1000	12/192
	2	2	485151	TWO-POLES	32	1000	6/96
WITH INDICATOR	1	1	485152	SINGLE-POLE	32	1000	12/192
	2	2	485153	TWO-POLES	32	1000	6/96

485152

Appendix A-4

S802PV-S25

General Information

Extended Product Type:	S802PV-S25
Product ID:	2CCP842001R1259
EAN:	7612271210977
Catalog Description:	S802PV-S25-R High Performance Circuit Breaker
Long Description:	The S802PV-S25 is a 2-pole High Performance Circuit breaker for photovoltaics (DC) with B-characteristic, with cage terminal and a rated current of 25 A. It is a current limiting device with a maximum breaking capacity of 5kA at 800V. It can be used for voltages up to 800V DC. It has two different tripping mechanisms, the thermal tripping mechanism for overload protection and the electromechanic tripping mechanism for short circuit protection. The S802PV-S25 complies with IEC/EN 60947-2 and allows the use for industrial applications. It has numerous of approvals, therefore it can be used worldwide. The extensive range of accessory makes the use of S802PV-S25 more comfortable. Due to the fast arc extinction of S802PV-S25 your application will be secured.

Categories

Products » Low Voltage Products and Systems » Modular DIN Rail Products » High Performance Circuit Breakers HPCBs

Ordering

Minimum Order Quantity:	1 piece
Customs Tariff Number:	85362020
EAN:	7612271210977

Dimensions

Product Net Depth:	82.5 mm
Product Net Height:	95 mm
Product Net Weight:	0.49 kg
Product Net Width:	54 mm

Container Information

Package Level 1 Width:	105 mm
Package Level 1 Length:	60 mm
Package Level 1 Height:	99 mm
Package Level 1 Gross Weight:	0.51 kg
Package Level 1 EAN:	7612271210977
Package Level 1 Units:	1 piece

Environmental

Ambient Air Temperature:	Operation -25 ... +60 °C Storage -40 ... +70 °C
Resistance to Shock acc. to IEC 60068-2-27:	5 g 30 ms
Resistance to Vibrations acc. to IEC 60068-2-6:	2 - 13.2 Hz / 1mm 13.2 - 100Hz / 0.7g with load 100% x le
Environmental Conditions:	Damp Heat Cyclic acc. to IEC 60068-2-30 12+12 cycle Damp Heat Cyclic acc. to IEC 60068-2-30 55°C @ 90-96% Damp Heat Cyclic acc. to IEC 60068-2-30 25°C @ 90-100% Dry Heat Test B acc. to IEC 60068-2-2 16 hour @ 55 °C Dry Heat Test B acc. to IEC 60068-2-2 2 hour @ 70 °C
RoHS Status:	Following EU Directive 2002/95/EC August 18, 2005 and amendment

Technical

Number of Poles:	2
Tripping Characteristic:	B
Rated Current (I_n):	25
Rated Operational Voltage:	800 V DC
Power Loss:	at Rated Operating Conditions per Pole 4.3 W
Rated Insulation Voltage (U_i):	1500 V DC
Rated Ultimate Short-Circuit Breaking Capacity (I_{cu}):	(800 V DC) 5 kA
Rated Service Short-Circuit Breaking Capacity (I_{cs}):	(800 V DC) 5 kA
Overvoltage Category:	III

Pollution Degree:	2
Rated Impulse Withstand Voltage (U_{imp}):	8 kV
Housing Material:	Insulation group I, RAL 7035
Contact Position Indication:	ON / OFF / TRIP
Degree of Protection:	acc. to IEC 60529 IP20
Remarks:	Connection from top and bottom Connecting with CU only IP40 in enclosure with cover Cage terminal with captive screw
Terminal Type:	Screw Terminals
Connecting Capacity:	Flexible 1 ... 50 mm² Flexible Stranded 1 …70 mm²
Tightening Torque:	3.5 N·m
Recommended Screw Driver:	Pozidriv 2
Mounting on DIN Rail:	TH35-15 (35 x 15 mm Mounting Rail) acc. to IEC 60715 TH35-7.5 (35 x 7.5 mm Mounting Rail) acc. to IEC 60715
Mounting Position:	Any
Standards:	IEC/EN 60947-2

Certificates and Declarations (Document Number)

Instructions and Manuals:	2CCC413016M0010
Data Sheet, Technical Information:	2CCC413003C0203
Declaration of Conformity - CE:	2CCC413035D0601
RoHS Information:	2CCC413008D0204

Classifications

E-nummer:	2100003
ETIM 4:	EC000042 - Miniature circuit breaker (MCB)
ETIM 5:	EC000042 - Miniature circuit breaker (MCB)
ETIM 6:	EC000042 - Miniature circuit breaker (MCB)
Object Classification Code:	F

Appendix A-5

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	

Appendix A-6

F204 A-63/0,3-L

ABB

Products → Low Voltage Products and Systems → Modular DIN Rail Products → Residual Current Devices RCDs → Residual Current Devices RCDs

General Information

Extended Product Type:	F204 A-63/0,3-L
Product ID:	2CSF204123R3630
EAN:	8012542820901
Catalog Description:	F204 A-63/0,3-L Residual Current Circuit Breaker
Long Description:	The RCCBs F200 series assures protection to people and installations aga inst fault current to earth. A large offer for standard instantaneous and sele ctive AC and A types is completed with some configurations for special app lications. This product is suitable for installations where neutral on the left i s needed.

Ordering

Minimum Order Quantity:	1 piece
Customs Tariff Number:	85363030

Popular Downloads

Data Sheet, Technical Information:	2CSC400002D0209
Instructions and Manuals:	2CSF423001D6406

Dimensions

Product Net Width:	0.070 m
Product Net Height:	0.085 m
Product Net Depth:	0.069 m
Product Net Weight:	0.360 kg

Technical

Standards:	IEC/EN 61008
Operating Characteristic:	Instantaneous
Type of Residual Current:	A type
Rated Residual Current:	300 mA
Rated Current (I_n):	63 A
Number of Poles:	4
Position of Neutral Terminals:	Left
Power Loss:	at Rated Operating Conditions per Pole 4.4 W
Rated Voltage (U_r):	230/400 V

Environmental

Ambient Air Temperature:	Operation -25 ... +55 °C Storage -40 ... +70 °C
RoHS Status:	Following EU Directive 2011/65/EU

Certificates and Declarations (Document Number)

Declaration of Conformity - CE:	9AKK106713A5602
Environmental Information:	S-P-00081
Instructions and Manuals:	2CSF423001D6406

Container Information

Package Level 1 Units:	1 piece
Package Level 1 Width:	0.082 m
Package Level 1 Height:	0.078 m
Package Level 1 Length:	0.096 m
Package Level 1 Gross Weight:	0.403 kg
Package Level 1 EAN:	8012542820901

Classifications

Object Classification Code:	Q
E-nummer:	2160168
ETIM 4:	EC000003 - Residual current circuit breaker (RCCB)
ETIM 5:	EC000003 - Residual current circuit breaker (RCCB)
ETIM 6:	EC000003 - Residual current circuit breaker (RCCB)

Appendix A-7

XT1C 160 TMD 63-630 3p F F

Products → Low Voltage Products and Systems → Circuit Breakers → Moulded Case Circuit Breakers → Tmax XT

General Information

Extended Product Type:	XT1C 160 TMD 63-630 3p F F
Product ID:	1SDA067395R1
EAN:	8015644012199
Catalog Description:	XT1C 160 TMD 63-630 3p F F
Long Description:	C.BREAKER TMAX XT1C 160 FIXED THREE-POLE WITH FRONT TERMI NALS AND THERMOMAGNETIC RELEASE TMD R 63-630 A

Ordering

EAN:	8015644012199
Minimum Order Quantity:	1 piece
Customs Tariff Number:	85362090

Dimensions

Product Net Width:	76.2 mm
Product Net Height:	130 mm
Product Net Depth:	70 mm
Product Net Weight:	1.1 kg

Container Information

Package Level 1 Units:	1 piece
Package Level 1 Width:	128 mm
Package Level 1 Height:	135 mm
Package Level 1 Length:	143 mm
Package Level 1 Gross Weight:	1.1 kg
Package Level 1 EAN:	8015644012199

Additional Information

Circuit Breaker Type to be Associated:	Power distribution
Electrical Durability:	120 cycles per hour 8000 cycle
Mechanical Durability:	Nr. Operations 240 cycles per hour Nr. Operations 25000 cycle
Number of Poles:	3
Opening Time:	CB with SOR 15 ms CB with UVR 15 ms

Power Loss:	at Rated Operating Conditions per Pole 4.3 W
Product Main Type:	SACE Tmax XT
Product Name:	Moulded Case Circuit Breaker
Product Type:	CB
Rated Current (I_n):	63 A
Rated Frequency (f):	50 / 60 Hz
Rated Voltage (U_r):	690 V
Rated Impulse Withstand Voltage (U_{imp}):	8 kV
Rated Insulation Voltage (U_i):	800 V
Rated Operational Voltage:	690 V AC 500 V DC
Rated Service Short-Circuit Breaking Capacity (I_{cs}):	(220 V AC) 40 kA (220 V AC) 40 kA (380 V AC) 25 kA (415 V AC) 25 kA (440 V AC) 12,5 kA (500 V AC) 9 kA (690 V AC) 4 kA
Rated Ultimate Short-Circuit Breaking Capacity (I_{cu}):	(220 V AC) 40 kA (230 V AC) 40 kA (380 V AC) 25 kA (415 V AC) 25 kA (440 V AC) 25 kA (500 V AC) 18 kA (690 V AC) 4 kA (250 V DC) 2 Poles in Series 25 kA (500 V DC) 3 Poles in Series 25 kA
Rated Uninterrupted Current (I_u):	160 A
Release Type:	TM
Standards:	IEC
Sub-type:	XT1
Terminal Connection Type:	Fixed Circuit-Breakers Front
Version:	F

Certificates and Declarations (Document Number)

Data Sheet, Technical Information:	1SDC210033D0204
Declaration of Conformity - CE:	9AKK106713A5532
Environmental Information:	1SDL000190R0001
GL Certificate:	1SDL000163R0103
Instructions and Manuals:	1SDH000719R0001

Classifications

ETIM 4:	EC000228 - Power circuit-breaker for trafo/generator/installation prot.
ETIM 5:	EC000228 - Power circuit-breaker for trafo/generator/installation prot.
ETIM 6:	EC000228 - Power circuit-breaker for trafo/generator/installation prot.
Object Classification Code:	Q
UNSPSC:	39120000

Appendix A-8

XT1C 160 TMD 125-1250 3p F F

Products » Low Voltage Products and Systems » Circuit Breakers » Moulded Case Circuit Breakers » Tmax XT

General Information

Extended Product Type:	XT1C 160 TMD 125-1250 3p F F
Product ID:	1SDA067398R1
EAN:	8015644012922
Catalog Description:	XT1C 160 TMD 125-1250 3p F F
Long Description:	C.BREAKER TMAX XT1C 160 FIXED THREE-POLE WITH FRONT TERMI NALS AND THERMOMAGNETIC RELEASE TMD R 125-1250 A

Ordering

EAN:	8015644012922
Minimum Order Quantity:	1 piece
Customs Tariff Number:	85362090

Dimensions

Product Net Width:	76.2 mm
Product Net Height:	130 mm
Product Net Depth:	70 mm
Product Net Weight:	1.1 kg

Container Information

Package Level 1 Units:	1 piece
Package Level 1 Width:	128 mm
Package Level 1 Height:	135 mm
Package Level 1 Length:	143 mm
Package Level 1 Gross Weight:	1.1 kg
Package Level 1 EAN:	8015644012922

Additional Information

Circuit Breaker Type to be Associated:	Power distribution
Electrical Durability:	120 cycles per hour 8000 cycle
Mechanical Durability:	Nr. Operations 240 cycles per hour Nr. Operations 25000 cycle
Number of Poles:	3
Opening Time:	CB with SOR 15 ms CB with UVR 15 ms

Power Loss:	at Rated Operating Conditions per Pole 10.7 W
Product Main Type:	SACE Tmax XT
Product Name:	Moulded Case Circuit Breaker
Product Type:	CB
Rated Current (I_n):	125 A
Rated Frequency (f):	50 / 60 Hz
Rated Voltage (U_r):	690 V
Rated Impulse Withstand Voltage (U_{imp}):	8 kV
Rated Insulation Voltage (U_i):	800 V
Rated Operational Voltage:	690 V AC 500 V DC
Rated Service Short-Circuit Breaking Capacity (I_{cs}):	(220 V AC) 40 kA (220 V AC) 40 kA (380 V AC) 25 kA (415 V AC) 25 kA (440 V AC) 12,5 kA (500 V AC) 9 kA (690 V AC) 4 kA
Rated Ultimate Short-Circuit Breaking Capacity (I_{cu}):	(220 V AC) 40 kA (230 V AC) 40 kA (380 V AC) 25 kA (415 V AC) 25 kA (440 V AC) 25 kA (500 V AC) 18 kA (690 V AC) 4 kA (250 V DC) 2 Poles in Series 25 kA (500 V DC) 3 Poles in Series 25 kA
Rated Uninterrupted Current (I_u):	160 A
Release Type:	TM
Standards:	IEC
Sub-type:	XT1
Terminal Connection Type:	Fixed Circuit-Breakers Front
Version:	F

Certificates and Declarations (Document Number)

Data Sheet, Technical Information:	1SDC210033D0204
Declaration of Conformity - CE:	9AKK106713A5532
Environmental Information:	1SDL000190R0001
GL Certificate:	1SDL000163R0103
Instructions and Manuals:	1SDH000719R0001

LR Certificate:	1SDL000163R0100

Classifications

ETIM 4:	EC000228 - Power circuit-breaker for trafo/generator/installation prot.
ETIM 5:	EC000228 - Power circuit-breaker for trafo/generator/installation prot.
ETIM 6:	EC000228 - Power circuit-breaker for trafo/generator/installation prot.
Object Classification Code:	Q
UNSPSC:	39120000

Appendix B

Compound interest table

8%	Compound Interest Factors								8%
	Single Payment		Uniform Payment Series				Arithmetic Gradient		
	Compound Amount Factor Find *F* Given *P*	Present Worth Factor Find *P* Given *F*	Sinking Fund Factor Find *A* Given *F*	Capital Recovery Factor Find *A* Given *P*	Compound Amount Factor Find *F* Given *A*	Present Worth Factor Find *P* Given *A*	Gradient Uniform Series Find *A* Given *G*	Gradient Present Worth Find *P* Given *G*	
n	*F/P*	*P/F*	*A/F*	*A/P*	*F/A*	*P/A*	*A/G*	*P/G*	*n*
1	1.080	.9259	1.0000	1.0800	1.000	0.926	0	0	1
2	1.166	.8573	.4808	.5608	2.080	1.783	0.481	0.857	2
3	1.260	.7938	.3080	.3880	3.246	2.577	0.949	2.445	3
4	1.360	.7350	.2219	.3019	4.506	3.312	1.404	4.650	4
5	1.469	.6806	.1705	.2505	5.867	3.993	1.846	7.372	5
6	1.587	.6302	.1363	.2163	7.336	4.623	2.276	10.523	6
7	1.714	.5835	.1121	.1921	8.923	5.206	2.694	14.024	7
8	1.851	.5403	.0940	.1740	10.637	5.747	3.099	17.806	8
9	1.999	.5002	.0801	.1601	12.488	6.247	3.491	21.808	9
10	2.159	.4632	.0690	.1490	14.487	6.710	3.871	25.977	10
11	2.332	.4289	.0601	.1401	16.645	7.139	4.240	30.266	11
12	2.518	.3971	.0527	.1327	18.977	7.536	4.596	34.634	12
13	2.720	.3677	.0465	.1265	21.495	7.904	4.940	39.046	13
14	2.937	.3405	.0413	.1213	24.215	8.244	5.273	43.472	14
15	3.172	.3152	.0368	.1168	27.152	8.559	5.594	47.886	15
16	3.426	.2919	.0330	.1130	30.324	8.851	5.905	52.264	16
17	3.700	.2703	.0296	.1096	33.750	9.122	6.204	56.588	17
18	3.996	.2502	.0267	.1067	37.450	9.372	6.492	60.843	18
19	4.316	.2317	.0241	.1041	41.446	9.604	6.770	65.013	19
20	4.661	.2145	.0219	.1019	45.762	9.818	7.037	69.090	20
21	5.034	.1987	.0198	.0998	50.423	10.017	7.294	73.063	21
22	5.437	.1839	.0180	.0980	55.457	10.201	7.541	76.926	22
23	5.871	.1703	.0164	.0964	60.893	10.371	7.779	80.673	23
24	6.341	.1577	.0150	.0950	66.765	10.529	8.007	84.300	24
25	6.848	.1460	.0137	.0937	73.106	10.675	8.225	87.804	25
26	7.396	.1352	.0125	.0925	79.954	10.810	8.435	91.184	26
27	7.988	.1252	.0114	.0914	87.351	10.935	8.636	94.439	27
28	8.627	.1159	.0105	.0905	95.339	11.051	8.829	97.569	28
29	9.317	.1073	.00962	.0896	103.966	11.158	9.013	100.574	29
30	10.063	.0994	.00883	.0888	113.283	11.258	9.190	103.456	30
31	10.868	.0920	.00811	.0881	123.346	11.350	9.358	106.216	31
32	11.737	.0852	.00745	.0875	134.214	11.435	9.520	108.858	32
33	12.676	.0789	.00685	.0869	145.951	11.514	9.674	111.382	33
34	13.690	.0730	.00630	.0863	158.627	11.587	9.821	113.792	34
35	14.785	.0676	.00580	.0858	172.317	11.655	9.961	116.092	35
40	21.725	.0460	.00386	.0839	259.057	11.925	10.570	126.042	40
45	31.920	.0313	.00259	.0826	386.506	12.108	11.045	133.733	45
50	46.902	.0213	.00174	.0817	573.771	12.233	11.411	139.593	50
55	68.914	.0145	.00118	.0812	848.925	12.319	11.690	144.006	55
60	101.257	.00988	.00080	.0808	1 253.2	12.377	11.902	147.300	60
65	148.780	.00672	.00054	.0805	1 847.3	12.416	12.060	149.739	65
70	218.607	.00457	.00037	.0804	2 720.1	12.443	12.178	151.533	70
75	321.205	.00311	.00025	.0802	4 002.6	12.461	12.266	152.845	75
80	471.956	.00212	.00017	.0802	5 887.0	12.474	12.330	153.800	80
85	693.458	.00144	.00012	.0801	8 655.7	12.482	12.377	154.492	85
90	1 018.9	.00098	.00008	.0801	12 724.0	12.488	12.412	154.993	90
95	1 497.1	.00067	.00005	.0801	18 701.6	12.492	12.437	155.352	95
100	2 199.8	.00045	.00004	.0800	27 484.6	12.494	12.455	155.611	100

Appendix C

production [MWh]	Income
97.7	14,948.1
96.9	14,828.5
96.1	14,709.9
95.4	14,592.2
94.6	14,475.5
93.9	14,359.7
93.1	14,244.8
92.4	14,130.8
91.6	14,017.8
90.9	13,905.6
90.2	13,794.4
89.4	13,684.0
88.7	13,574.6
88.0	13,466.0
87.3	13,358.2
86.6	13,251.4
85.9	13,145.4
85.2	13,040.2
84.5	12,935.9
83.9	12,832.4

Appendix D

IRR MATLAB CODE

```
Ct=[13996.1,13876.5,13757.9,...
13640.2,13523.5,13407.7,13292.8,13178.8,13065.8,12953.6,12842.4,12732.
0,...
12622.6,12514.0,12406.2,12299.4,12193.4,12088.2,11983.9,11880.4]; %
cash in flow
i=0.13328;% IRR
s=0;
ss=0;
C=95200-3332;% initial investment
for j=1:20
    s=Ct(j)/(1+i)^j;
    ss=s+ss;
end
out= C-ss
```

جامعة النجاح الوطنية

كلية الدراسات العليا

التقييم الفني والاقتصادي لنظام الخلايا الشمسية المرتبط مع الشبكة الكهربائية في الجامعة العربية الأمريكية / جنين

إعداد

أحلام أبو زهو

إشراف

أ. د. مروان محمود

قدمت هذه الاطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة واستراتيجية الترشيد، بكلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2018

التقييم الفني والاقتصادي لنظام الخلايا الشمسية المرتبط مع الشبكة الكهربائية في الجامعة العربية الأمريكية / جنين

إعداد

أحلام أبو زهو

إشراف

أ. د. مروان محمود

الملخص

تقوم هذه الاطروحة بتحليل أداء النظام الشمسي المتصل بالشبكة الكهربائية بقدرة 70 كيلو واط في الجامعة العربية الأمريكية. حيث تم دراسة كل من العائد النهائي للنظام الشمسي ونسبة الأداء وعامل السعة. كما تم تحليل التقييم الاقتصادي بما في ذلك التدفق النقدي، وفترة الاسترداد، وصافي القيمة الحالية وتكلفة وحدة الطاقة. حيث بلغت مخرجات النظام السنوية 100 ميجا واط ساعة و95 ميجا واط ساعة في الاعوام 2015 و2016 على التوالي. كما تراوح معدل القيمة الإنتاجية الشهري للنظام الشمسي ما بين 180 كيلو واط ساعة لكل كيلو واط في مايو و47 كيلو واط ساعة لكل كيلوواط في يناير، مع معدل قدرة إنتاجية سنوي قدره 1428 كيلوواط ساعة لكل كيلوواط و1367 كيلو واط ساعة لكل كيلوواط في العامين 2015 و2016 على التوالي.

فيما يتعلق بنسبة الأداء (PR)، كان للنظام نسبة أداء سنوية تقدر ب 80٪ في عام 2015 و76.8٪ في عام 2016. فيما تراوحت نسبة الأداء الشهرية بين 52٪ في يناير و99٪ في مارس 2015 و34٪ في سبتمبر و99٪ في نوفمبر 2016. من ناحية أخرى، من المنظور الاقتصادي يبدو أن النظام مقبول من الناحية الاقتصادية مع فترة سداد مدتها 7 سنوات، وحسب المعادلات الاقتصادية فإن للمشروع صافي قيمة حالية (NPV) موجب يقدر ب 31612.7 دولار مع معدل عائد داخلي يصل الى 13٪ وهو أكبر من معدل الفائدة 8 ٪ المستخدمة خلال عملية التقييم الاقتصادي. أخيرا بلغت تكلفة الوحدة الواحدة من الطاقة 0.065 دولار امريكي لكل كيلو واط ساعة.