An-Najah National University

Faculty of Graduate Studies

Technical Impacts of Grid Tied PV on JDECO Network: Case Study (Jericho and Al-Jeep Feeders)

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Dedication

إلى والدي العزيزن، ، ، بكل الحب والاحترام أهديكم هذا العمل..

الى من احترقت ليلا ونهارا حتى تضيء لنا حياتنا ... والدتي الغالية .. اليك

الى زوجتي العزيزة أمل وابني الغالي ياسر اللذين تحملوني وتحملوا انشغالي عنهم بكل حب ...

الى اخواتي الرائعات اللواتي وقفن الى جانبي بكل الدعم والحب والاسناد والعمل .. ريم وأسماء ..

الى اخوتي بغربتهم ...اللذين دعموني وساندوني .. اشتقت لكم .. سامي وأسامه

الى روح خالي محمد الطاهرة وجدي العزيز رحمهم الله ...

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الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل عنوان:

Technical Impacts of Grid Tied PV on JDECO Network: Case Study (Jericho and Al-Jeep Feeders)

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Abbreviations

IEC	Israel Electric Corporation ltd
PEA	Palestinian Energy Authority
EU	Europe Union.
PV	Photovoltaic.
PNA	Palestinian National Authority
PA	Palestinian Authority.
SWH	Solar Water Heater
PSI	Palestinian Solar Initiative
GPP	Gaza Power Plant.
JDECO	Jerusalem District Electric Company
PPC	Palestinian Petroleum Commission
NEDCO	Northern Electricity Distribution Company.
HEPCO	Hebron Electric Power Company
SELCO	Southern Electric Company.
PERC	Palestinian Electricity Regulatory Council.
KW	Kilo Watt (1,000 Watt).
KWh	Kilo Watt Hour.
MW	Mega Watt (1,000,000 Watt).
MVA	Mega Volt Amper
WB&G	West Bank and Gaza
ISC	Short Circuit Current
KVAR	Kilo Volt Ampere Reactive
KWh	Kilo Watt Hour
MPPT	Maximum Power Point
NIS	New Israeli Shekel
NOCT	Normal Operating Cell Temperature
PV	Photovoltaic
VOC	Open Circuit Voltage
Wp	Watt peak
ACCC	Aluminum Conductor Composite Core
ACSR	Aluminum Conductor Steel Reinforced
GPP	Gaza Power Plant
LV	Low Voltage
MV	Medium Voltage
NEDCO	Northern Electricity Distribution Company
NIS	New Israeli Shekel
PF	Power Factor
PA	Palestinian Authority
PCBS	Palestinian Central Bureau of Statistics

SCADA	Supervisory Control and Data Acquisition
SELCO	Southern Electric Company
VAR	Voltage Automatic Regulator
USc	United States cent.
Km	Kilo meter.
mm	mille meter.
SPBP	Simple Pay Back Period.
NO	Number.
E	East.
N	North.
W	West.
S	South.
MWh	Mega Watt Hour
NSP	Network Service Provider
MPPT	Maximum Power Point Tracker
STC	Standard Test Condition
FIT	Federal Income Tax
IRR	Interest Rate of Return
GIS	Geographic Information System
GTI	Grid Tie Inverter

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Abstract

Using Power World Simulator, Low Voltage case study of Al-Jeep electrical distribution network was simulated and analyzed and PSI was projected on the network using 5 KW_p grid tied PV systems .Then, the capacity of PV systems were increased and doubled, and each PV penetration level of 25%, 50%, 75%, 100% on the grid were simulated and investigated by modeling the one line diagram. Moreover, the PV systems using the simulator and the technical impacts regarding the power supply quality were examined.

It was noted that as the penetration level of grid tied PV on the grid increased above 50% of the transformer load, the distribution transformer would suffer from very poor power factor values and reverse power flow was detected on the grid towards the source causing the grid to appear as a reactive power source only, which beside the law power factor value would lead to less efficient grid elements and equipment and to heating generation due to the reactive power flow which will decrease their life time. Although the lines losses decreased as the PV penetration level increased and voltage levels improved at 25% PV penetration level. However after 50% penetration level, over voltage on the grid appeared

beyond the acceptable range according to IEC and grid code, especially on the rural feeder with high impedance and low loads, a significant current swing occurred and exceeded 100 A at 80% penetration level.

On the M.V case study of Jericho network and Jericho Solar PV station, negligible technical impacts were noted on the current level of penetration which, the current capacity of the station, equals 300 KW_p

Different levels of PV penetration level on the M.V network where examined by raising the capacity of the solar station gradually. This was modeled using Power World Simulator and physical and real time data of Jericho network and Jericho solar station.

No evidence of over voltage values where investigated at any PV penetration levels, but also no significant improving on the voltage level were noted on poor values buses voltages. Power factor of source bus decreased significantly as the penetration of the grid tied PV station capacity increased. Negligible effect of the line losses improvement appeared at all the tested penetration levels. An important current swing occurred beyond 50% penetration level.

Regarding the M.V case, it’s recommended from the researcher point of view, as a result of this study, that it was more justified and preferable if the sight location of the solar station was shifted to a new position closer to the residential load (AL-Magtas station).this new geographical position was investigated using the simulator and better values resulted for voltage levels and losses.

On the low voltage case study, the recommendation is to minimize the negative technical impact of the distributed PV generators on the conventional grid:

- Using smart grid systems to monitor the grid performance hourly and control the energy exchange times to mitigate the negative impacts, and maximize the benefits.

- Limiting the PV penetration level on the grid to 40% by the regulator for more safety.

- Study a storage system on the grid to act as a buffering zone.
- Limiting the penetration level of the grid tied PV system on the network (Feeder) to equal the minimum load of the feeder due to the potential rising of the voltage assuming no tap changing in L.V/M.V transformer.

Chapter I

Introduction

Chapter I
Introduction

A Background

Palestine has a lack of its own generation or supplies. So, it depends on Israel’s electrical network from Israel Electric Court (IEC). There is one electrical generation station in Gaza, but this station couldn’t satisfy all demands of Gaza Strip, so it still depends on Israel’s electricity supply with Egyptian electrical supply.

Nowadays, fossil fuel is the main energy supplier of the worldwide economy, but the recognition of it as being a major cause of environmental problems, climate changes, smog, and other human health problems, beside the increasing energy demands, and the scenarios of oil depletion end up in the next centuries, which leads for all these reasons to look for alternative clean and renewable resources in power generation [1].

One of the most important renewable sources is the solar energy, as the sun is the largest energy source of life while at the same time it is the ultimate source of most of renewable energy sources. Solar energy can be used to generate electricity in a direct way with the use of photovoltaic, or by using solar thermal or concentrating solar power to heat a media or water and generate steam then electricity. See figure I.1.

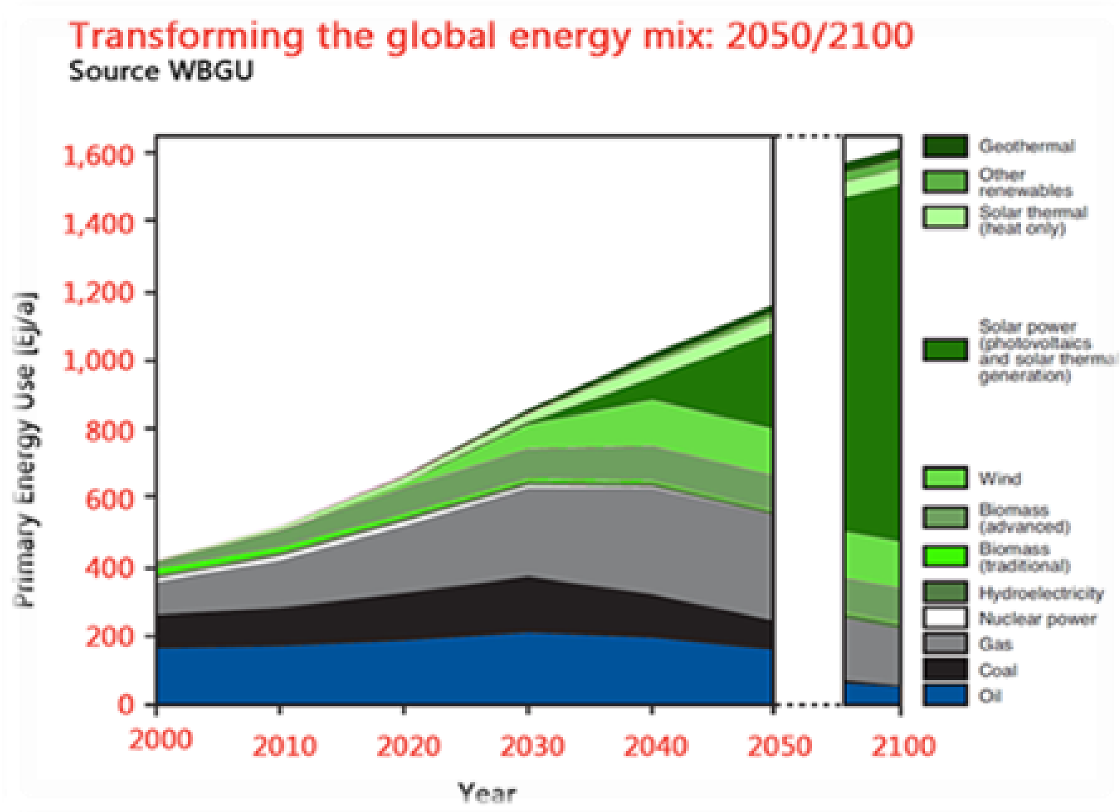

Figure (I.1): Transforming the Global Energy [1]

Palestine is located in a high solar power concentration area in the world, with an annually average irradiance of 5.4 kWh/m^2- day. This encouraged us to focus on utilizing the solar power as a source of electricity, to face our demand. Due to the lack of lands in Palestine because of the political situation and the occupation, on grid PV was the preferable clean source to choose for this study.

During the first decade of the 21^{st} century, the worldwide photovoltaic (PV) markets have experienced a tremendous expansion. The installed PV power increased from below 1000 MW to almost 8000 MW between the years 2000 and 2007. A majority of these systems are grid-connected and distributed, located at end-users in the very end of the electricity distribution grid. This expansion has been mainly due to generous subsidy schemes and incentives and laws, like feed in tariff and net metering from the governments, and the obligations that the countries and the governments were made, like 20-20 by EU [2].

Growing of PV for electricity generation is one of the highest in the field of the renewable energies and this technology is the future energy source. See figure (I.2) which show the growth of the installed capacity of the solar PV system in the world till 2011.

Total photovoltaic peak power capacity = 69,684 MWp in 2011. Germany is the world’s top PV installer, with a solar PV capacity as of December 2012 of more than 32.3 GW.

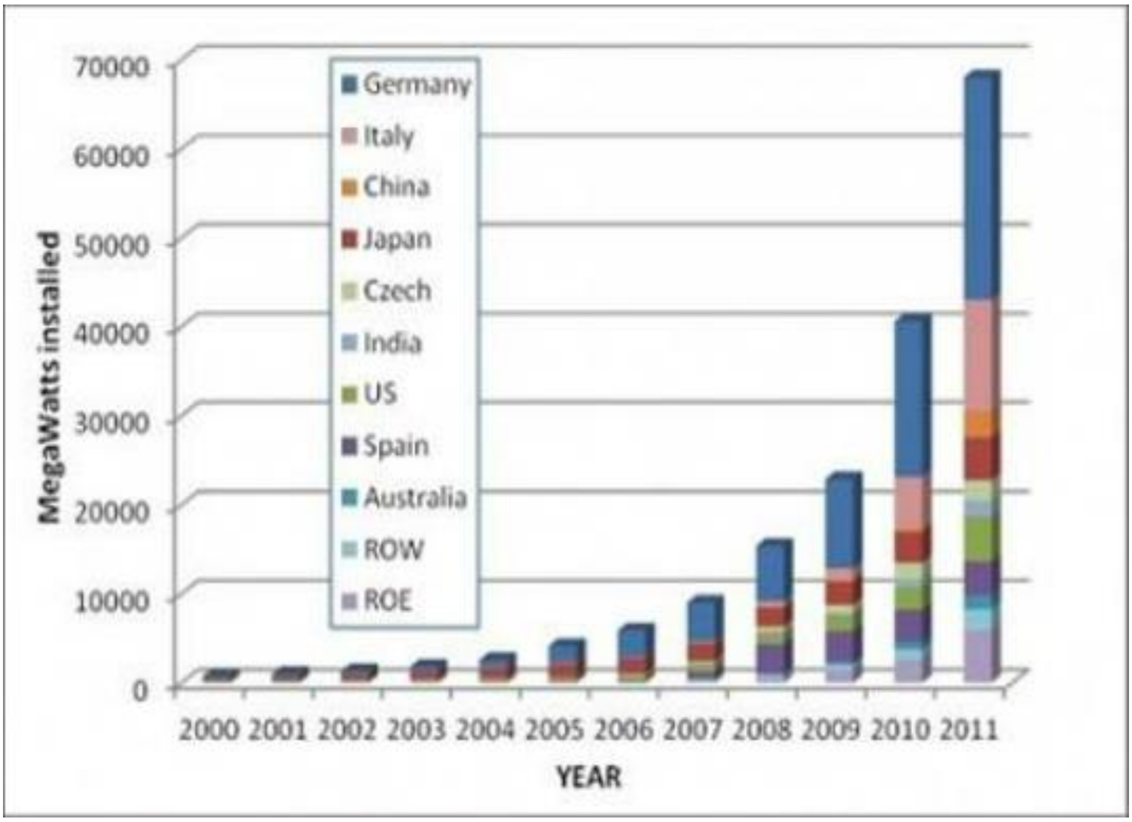

Figure (I.2): The Cumulative Installed Solar PV Capacity

The German new PV installations increased by about 7.6 GW in 2012 and solar PV provided 18 TWh of electricity in 2011, about 3% of total electricity.

Some market analysts expect this could reach 25% by 2050. Germany has a goal of producing 35% of electricity from renewable sources by 2020 and 100% by 2050.

With fast growing penetration of PV and other distributed power generation capacity, the impact of PV on the grid and vice versa is under discussion. Main concerns are the maximum tolerable level and the quality of the supply voltage. These concerns as well as the acceptable penetration limits have been verified by measurements in PV developments in several countries.

The technical requirements from both the utility power system grid side and the PV system side need to be satisfied to ensure the safety of the PV installer and the reliability of the utility grid. Clarifying the technical requirements for grid interconnection and solving the problems such as islanding detection, harmonic distortion requirements and electromagnetic interference are therefore very important issues for widespread application of PV systems. Grid interconnection of PV systems is accomplished through the inverter, which convert DC power generated from PV modules to AC power used for ordinary power supply to electrical equipment. Inverter system is therefore very important for grid tied PV systems.

The Palestinian National Authority (PNA) through the Palestinian Energy Authority (PEA) has a plane to construct electricity generation substations in the West Bank, these substations will decrease the dependence on IEC's electrical supply.

Palestine has high solar potential, so it's good to construct distributed On-Grid solar generation systems. The Palestinian people already use the solar energy in heating water using Solar Water Heaters (SWH) on rooftops of their households; they use it for drying the crops and for heat water for industrial needs.

PEA began to encourage distributed generation by the 1000 Rooftop project in the West Bank and PEA set rules on using the solar energy in electrical generation through the Palestinian Solar Initiative (PSI) to control the generation and to limit the problems referred to electricity generation by solar potential.

Since Palestine is a developing nation, its access to considerable amounts of energy is essential to achieve economic growth and development. While most of Palestine has access to electricity, there are many challenges facing Palestine, arising mainly from its energy dependence [3]. Its energy is not provided through domestic means but rather provided through Israel which controls the quantity and quality of energy imported [4].

Electricity is one of the major problems facing the Palestinian Authority, especially as the PA imports the majority of its needs, depending mainly on Israel (even though there is a power-generation plant in Gaza). Palestinians are still very dependent on importing electricity [5].

The main characteristics of energy sector in Palestine are:

- The total energy consumed in West Bank and Gaza is small compared to regional standards, and even smaller compared to international standards, which limits the scope for achieving economies of scale.
- Household sector accounts for most of energy demand (75%), because of the relatively little activity in manufacturing.
- Nearly all the electrical energy is purchased from Israel.
- West Bank and Gaza have different energy supply options.
- The electrical systems in the West Bank consist of numerous isolated distribution systems that are not integrated into a distribution network, and it has no generation capacity or transmission network [6].

The figure below (Figure I.3) shows the consumption of energy in 2003 by source of energy.

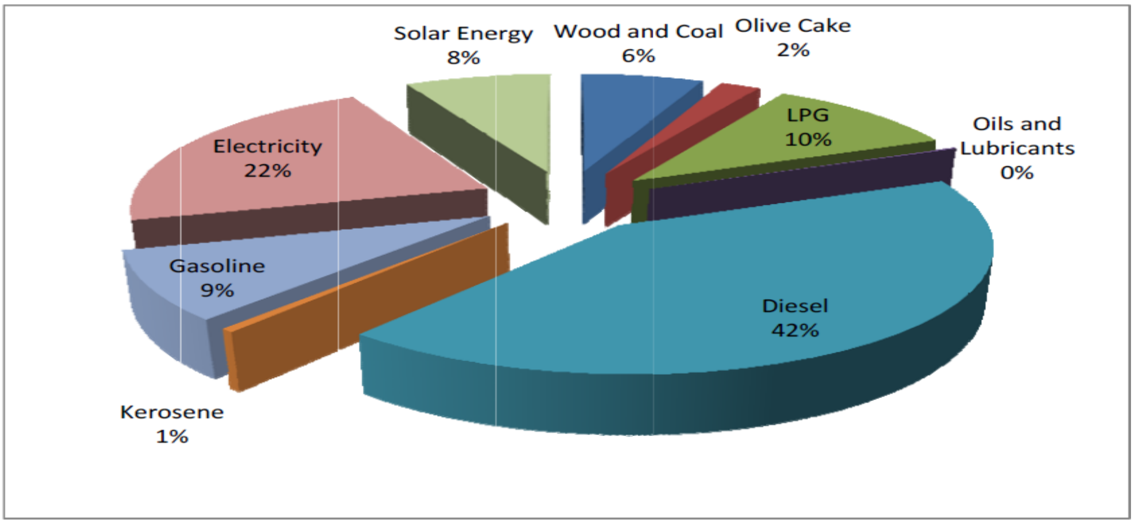

Figure (I.3): Consumption of Energy in 2003 by Source [7]

In 2006, the imports from electricity in Palestine reached 3,096,000 MWh while the production reached 345,000 MWh most of it from Gaza Power Plant [6].

The average monthly household electrical energy consumption in Palestine reached 259.6 kWh (233.6 kWh in the West Bank and 267.1 kWh in Gaza Strip) [8].

See this figure I.4 which shows the energy consumption in Palestine in 2006.

The total purchases of electric power in 2008 in the Palestinian territories were about 4,291,425 MWh, Where the purchases in the West Bank was about 2,799,990 MWH, including about 2,735,650 MWH from Israel and 64,340 MWh from Jordan. The total purchases in the Gaza Strip were 1,491,435 MWh, of which about 930,450 MWH from Israel, about 426,615 MWH from GPP and 134.370 MWH from Egypt. The imports of electricity to Palestine reached 3,864,810MWH while the production reached 426,615MWH from Gaza Power Plant. The quantity of electricity purchases in Gaza Strip was 1,491,435.0 MWH in 2008. The quantity of electricity purchases in West Bank was 2,799,989.6 MWH in 2008 [9].

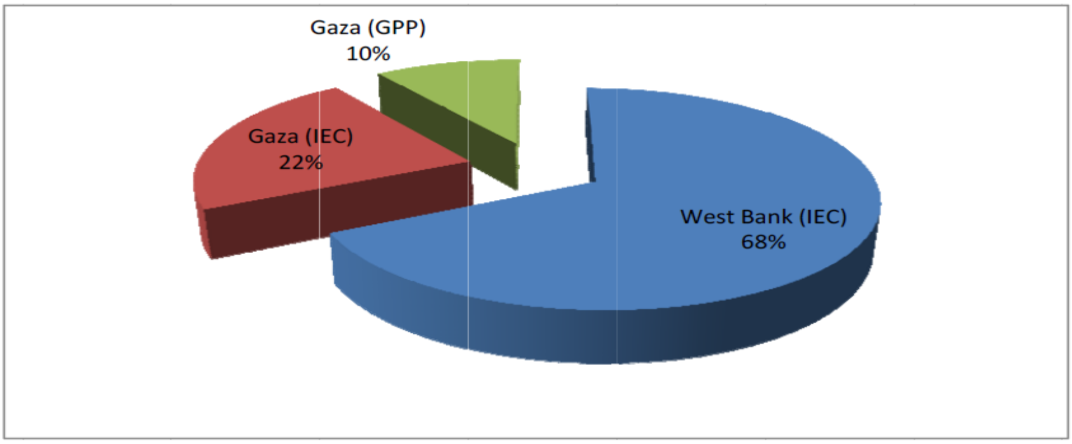

Figure (I.4): Electrical Energy Consumption in Palestine in 2006 [6]

The rate of household consumption of electricity in the Palestinian territories for families that used electricity through January 2011 has reached 266 kWh. In contrast, the average household electricity consumption was 254 KWh during the same period of 2010. This rate varies significantly between the Palestinian territories during the January 2011, as this rate has reached 314 kWh in the center of the West Bank, and did not Exceed 220 kWh in the northern West Bank [10].

In Palestine we are still at the first stage. In the past two years Palestinian Energy Authority (PEA) and the Palestinian Energy and Environment Research Center (PERC) were developing and reviewing renewable energy laws. Finally the Palestinian Solar Initiatives were endorsement by the cabinet (Council of Ministers) and because the legislative council has not been operating for many years as a consequence of the present political situation in Palestine to ratify the law. Legislation of great urgency was temporarily promulgated by the President in August, 2012.

The first On Grid PV project was launched this year in Jericho as a fund by the Japanese Government, with 300 KVA nominal power capacities.

The electricity network providers (utilities) are responsible for supplying every individual with a safe, reliable and economic power supply.

In several cases load increment leads to increased costs associated with distribution line upgrades and equipment failure. Of particular influence to these costs are the times of peak load. These are times when the maximum power is being consumed and they dictate the levels to which the electricity system needs to be maintained in order to meet the demand.

Recently, Network service provider has to look towards nontraditional strategies and search for alternatives and new sources in order to meet the increased loads and the emergence of various new technologies.

B Thesis Scope

The first scope of this Thesis is to have a good understanding of the impacts of the integration of PV systems into the electricity distribution network at the low voltage stage at different levels of penetrations of the

PV Grid-Tied systems. Additionally, there is a presentation about the Palestinian Solar Initiative PSI rules of installing distributed generation PV systems in the distribution of networks in Palestine.

The second scope of this Thesis is to study the medium voltage level PV generation system station. The study case of this Thesis was included in the medium voltage level system and takes a techno-economic study of the Jericho PV generation station in Jericho, West Bank.

The simulation of both low and medium voltage Grid-Tied PV systems is using the Power World Simulator Program.

This Thesis will begin with a summary of the energy situation which includes the electrical situation in the West Bank and Gaza in the near past, the present and the future plans for the generation and transmission developing in Palestine. Also, an interview about the distribution networks in West Bank.

The Thesis discusses the Photovoltaic PV systems concept and discusses the PV system's components and types, with giving examples to these systems in Palestine.

The Thesis discusses the Distributed Generation systems; concept, advantages, disadvantages and the properties of the distributed generation of the PV systems.

The Thesis takes a case study which is divided into two parts. The first part of the case study is a L.V PV generation of 5 KW penetrated into Al-Jeep L.V electrical distribution network. The second part of the case study is a M.V PV generation from Jericho solar station into Jericho M.V electrical distribution network.

The case study uses the Power World Simulator program in order to study and investigate the impacts of PV generation on the L.V and M.V electrical distribution networks. The simulation takes different penetration levels for both L.V and M.V analysis. In the part of M.V the simulation use physical and real time data from Jericho solar station and start the analysis at the current capacity of the station of 300 KW.

The results of this study case will be presented after the simulation using the Power World Simulator Program. Finally the Thesis will conclude with a summary and conclusion for the whole thesis, and there is more supported information in the Appendix of this Thesis.

Chapter One

Electrical Energy Situation in Palestine

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Electrical Energy Situation in Palestine

Introduction

The energy situation in Palestine is the worst situation compared to other countries in terms of its dependence on imported energy sources from outside. Palestine imports most of its needs in the field of energy and fuel from Israel. See table (1.1) which shows the quantity of imported and produced energy in Palestine from 2007 to 2011.

Table (1.1): Imported and Produced Energy in Palestine from 2007 – 2011 [11]

Source of Electricity	Year				
	2007	2008	2009	2010	2011
Imported electricity	3,188,272	3,864,810	3,982,940	4,158,848	4,621,686
Produced Electricity	417,065	426,615	500,661	473,321	569,332
Total	3,605,337	4,291,425	4,483,601	4,632,169	5,191,018

Palestine has to import 100% of Petroleum products from Israeli market and 88% of electricity from Israel electricity corporation ltd (IEC). West Bank and Gaza have different energy supply options. Most electricity demand (75%) is accounted for by the service and household sectors, since there is relatively little activity in manufacturing. Nearly all energy is provided by electricity and petroleum products, most of which has been purchased from Israel. By 2011 the electrical grid reaches 99% of Palestinian population. [12]

As the West Bank doesn't have any electrical generation plant, the electricity generation in Palestine is restricted in Gaza Power Plant (GPP), which is the only station to generate electricity in Palestine, which doesn't satisfy the whole electricity demand in Gaza. So the rest of Gaza electrical demand supported from Israel and Egypt. Table (1.2) shows the Quantity of Electricity Purchases (MWh) in Palestine by Source and Month, 2011.

There is no interconnection between West Bank and Gaza. So ,the electrical transmission and distribution are separated between the two territories. Gaza has an interconnection with Egypt to provide a part of electricity demand in Gaza network, so there is an interconnection between Jordan and West Bank to provide Jericho network.

The existing power supply in West Bank from IEC of 33 kV, 22 kV and 400 V is provided to the distribution utilities in West Bank and the direct consumers who are not controlled by the electrical utilities in West Bank. [13]

Table (1.2): Monthly Supplied Electricity in 2011 [11]

Month	Source				
	Israeli Electricity Company	Palestine Electric Company	Egypt	Jordan	Total
January	350,513	42,531	10,466	5,679	409,189
February	383,232	40,035	14,259	5,206	442,732
March	329,637	43,066	6,544	133	379,380
April	355,612	40,474	8,182	-	404,268
May	333,396	39,295	8,962	-	381,653
June	362,089	46,675	10,131	6,255	425,150
July	354,152	48,633	11,689	11,952	426,426
August	397,644	51,410	6,818	12,727	468,599
September	559,704	44,213	9,972	11,399	625,288
October	256,715	46,384	10,605	9,293	322,997
November	361,388	47,532	10,708	6,280	425,908
December	383,344	52,192	10,256	6,744	452,536
Total	4,427,426	542,440	118,592	75,668	5,191,018

There is no transmission of high voltage above 33 kV in West Bank, where the supplied power to the West Bank is restricted to the medium and low voltage distributed power.

The developing plane for electrical sector in Palestine includes building of two generation plants in West Bank, an interconnection with Jordan of 400 kV to provide 50% of West Bank demand throw Jericho and 9 substations 161/33 kV divided into three stages, the first stage include 4 substations in Jenin, Nablus, Ramallah and Hebron. The second stage includes two substations in Ramallah and Nablus. The third stage includes two substations, one between Tulkarem and Qalqilia and one between Hebron and Bethlehem. [14]

Renewable energy is the most promising source of future energy in Palestine, where Palestine has a high potential in solar energy, low wind potential and good biomass potential.

Palestinian energy authority (PEA) is interested in renewable energy and supports the development of renewable energy sector in Palestine throw the Jericho Photovoltaic (PV) generation station and the 1000 rooftop plant in West Bank. Moreover, the Palestinian solar initiative (PSI) aims to have 5 MW of renewable energy in the year 2015. [5]

1.1 Generation and Transmission Situation in Palestine

1.1.1 Present Generation and Transmission Situation

The West Bank depends almost entirely on IEC for electricity supply. It is mainly supplied by three 161/ 33 KV substations: one in the south in area C close to Hebron, a second in the north in the Ariel settlement (area C) close to Nablus, and a third in Atarot industrial area (area C) near Jerusalem. Electricity is supplied to the center of the West Bank via 33kV and 11kV distribution lines at several connection points with the IEC including, Ramallah, Jericho, Bethlehem and the eastern part of Jerusalem. [15]

The PA has agreed with Jordan to connect the Palestinian power grid to that of Jordan at Jericho through a 33kV line via King Abdullah Bridge. JDECO submitted a new request recently to upgrade the line to 132 kV, which is compatible with the voltage supplied by the Jordanian electricity company. JDECO will execute the work on the Palestinian side. The Jericho area will be disconnected from the Israeli power grid, and JDECO will manage a separate electricity supply system for the customers connected to the electricity supply from Jordan. The electrical supply in West Bank is shown in figure (1.1) and table (1.3). [16]

Figure (1.1): West Bank Electricity Supplies [13]

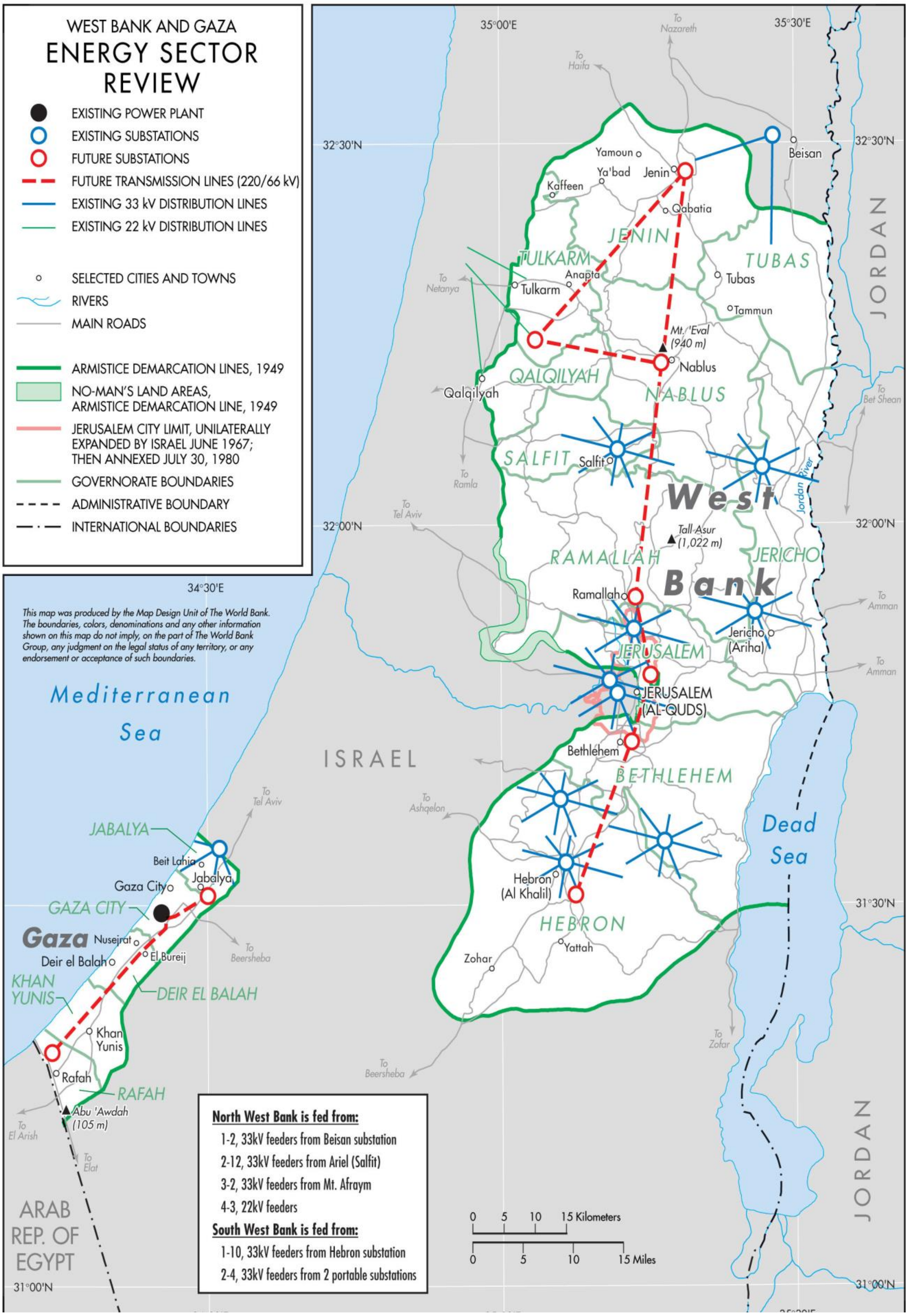

Figure (1.2): Electricity Supply System in West Bank and Gaza

Table (1.3): West Bank Supplies at 2009 [13]

Source of Supply	Amount
IEC	600MVA
Jordan	20 MVA
Total	620
Peak	500 MW (about 550 MVA)
No load shedding in West bank but there is a suppressed demand of more than 60 MVA	

Gaza receives electricity from IEC and from a gasoil (diesel) based power plant with electricity generating capacity of some 140MW located inside Gaza (GPP), which is the only major, power generating facility in West Bank and Gaza. Gaza also receives a small power supply from Egypt (17MW). GEDCO distributes electricity within Gaza. The electrical supply in Gaza is shown in figure (1.2) and table (1.4). [13]

Gaza is connected to the Israeli power grid at 11 points along the border from north to south, via 22 kilovolt transmission lines with total capacity of some 115MW [16]. The low distribution voltage of these feeders considerably constrains the ability of IEC to supply sufficient electricity for the potential demand for electricity in Gaza.

GPP began operating in 2002 to provide electricity to the Gaza Strip, especially in and around Gaza City, where about half of the residents of the Strip live. Its maximum manufacturing capacity, which at the outset was 140 MW, was restricted in practice by the limited capacity of the relay network. In June 2006, the power plant manufactured 90 MW and another 120 MW was provided to the Gaza Strip by the Israel Electric Corporation, in exchange for payment by the PA. [16]

GPP produces electricity at high prices compared to the price of electricity purchased from Israel. This is mainly because of the high price of gasoil used for the plant. Moreover, the maximum capacity of the plant has been restricted to about 90MW by the available transmission capacity from the plant to the Gaza power network.

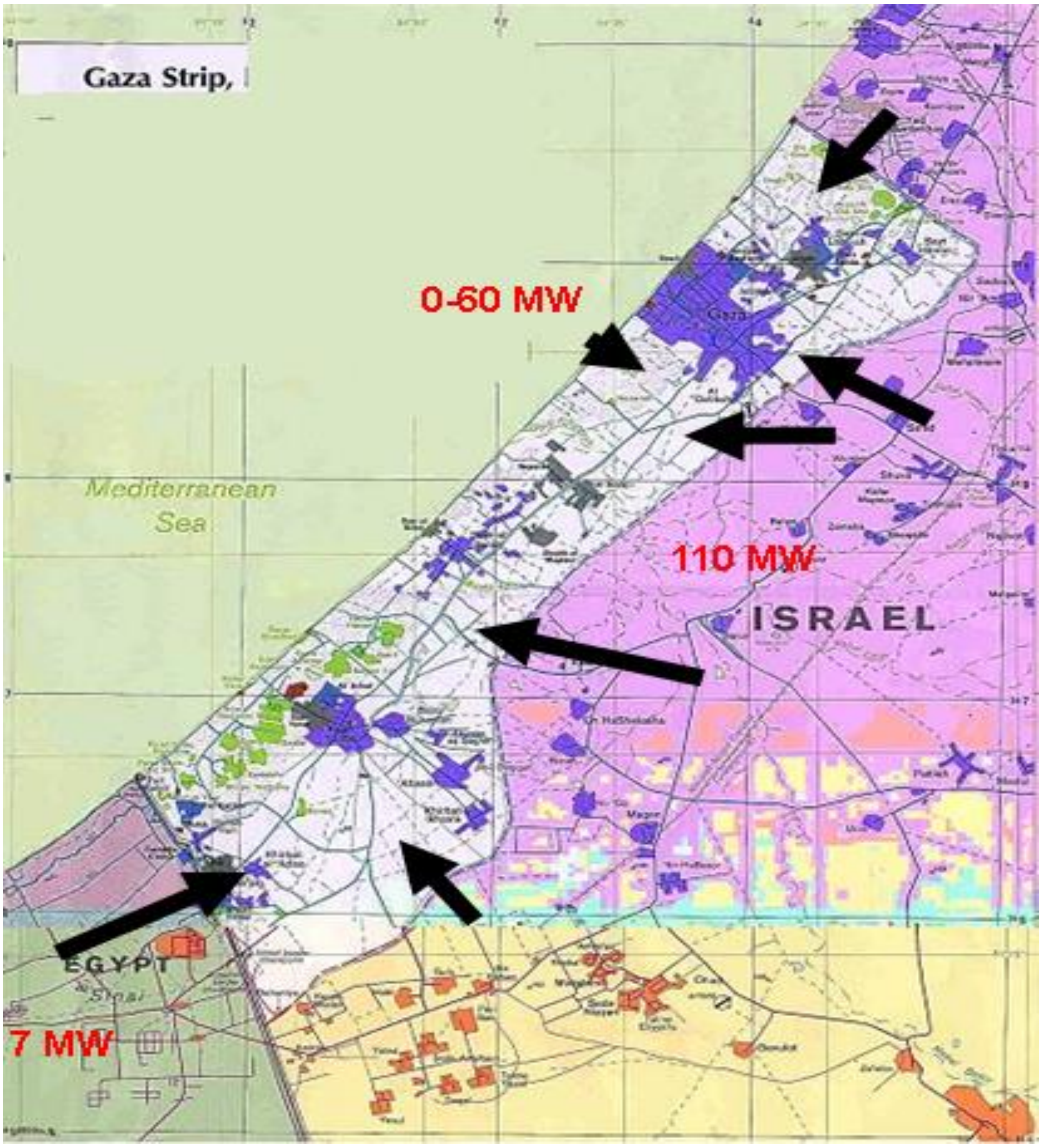

Figure (1.3): Gaza Electricity Supplies [13]

Table (1.4): Gaza Electricity Supply 2009 [13]

Supply Source	Amount MW
Israel	110
Egypt	17
GPP	0-60
Total	137-197
Peak 2009	210
Annual Peak 270	
Load shedding 13MW	

The plant has actually been used at lower utilization rates than anticipated, partly because of the high cost of power from the plant when it is run on gasoil relative to the cost of power from IEC.

Today the Gaza Strip needs a total electricity supply of 280 MW at times of peak demand in the summer and winter: 120 MW comes from Israel, 17 MW from Egypt and the rest of the needed electricity, 143 MW, is supposed to be supplied by the Gaza power plant, whose actual manufacturing capacity is limited to 60-70 MW because of shortages of spare parts and/or industrial diesel. Therefore, there is a permanent deficit in Gaza of at least 73 MW, or nearly 26% of the required electricity. [17]

As a result, the Gaza Strip is subject to power outages, lasting 35-40 hours per week. In addition to the impact on the daily lives of Gaza residents, the power outages disrupt the normal functioning of civilian infrastructure in the Gaza Strip, including health and educational institutions, water and sewage facilities and the agricultural sector. [17]

The percentage of Palestinian households that are connected to the electricity national grid is 99.3% in 2009. This percentage raised up to 99.8% in 2012. The percentage of households that have Solar Water Heater in 2009 was 59.6%, this percentage raised to 66.9% in 2012. The monthly average of household's consumption in 2009 was 275.0 kWh, this consumption decreased to 260.0 kWh in 2012. In table (1.5) there are some indicators about household's energy in Palestine from 2009 to 2012. [11]

Table (1.5): Household Indicators [11]

Indicator	2009	2010	2011	2012
Percentage of households connected to the grid	99.3%	99.9%	99.8%	99.8%
Percentage of households have SWH	59.6%	61.6%	63.7%	66.9%
Average Household Consumption of Electricity (kWh)	275.0	254.0	266.0	260.0
Average Household Consumption of LPG (kg)*	21.0	20.0	21.0	22.0
Average Household Consumption of Kerosene (liter)*	24.0	14.0	10.0	11.0
Average Household Consumption of Wood (kg)*	287.0	209.0	228.0	204.0

Notation: * For Households that Used Fuel.

1.1.2 Future Plan of Transmission and Generation in Palestine

Before talking about the planned development for the generation and transmission in Palestine, we must talk about the load forecasting study which appears in figure (1.3) and figure (1.4) and the scenarios that are related to the development plans.

There are two different scenarios for the electrical sector in the West Bank which includes the generation and transmission development, where scenario two is divided into two situations: Normal operation and emergency supply.

The forecast levels for the peak loads in the West Bank and Gaza are the low, medium and the high forecast. Al these forecast levels done in term of energy and peak load. [14]

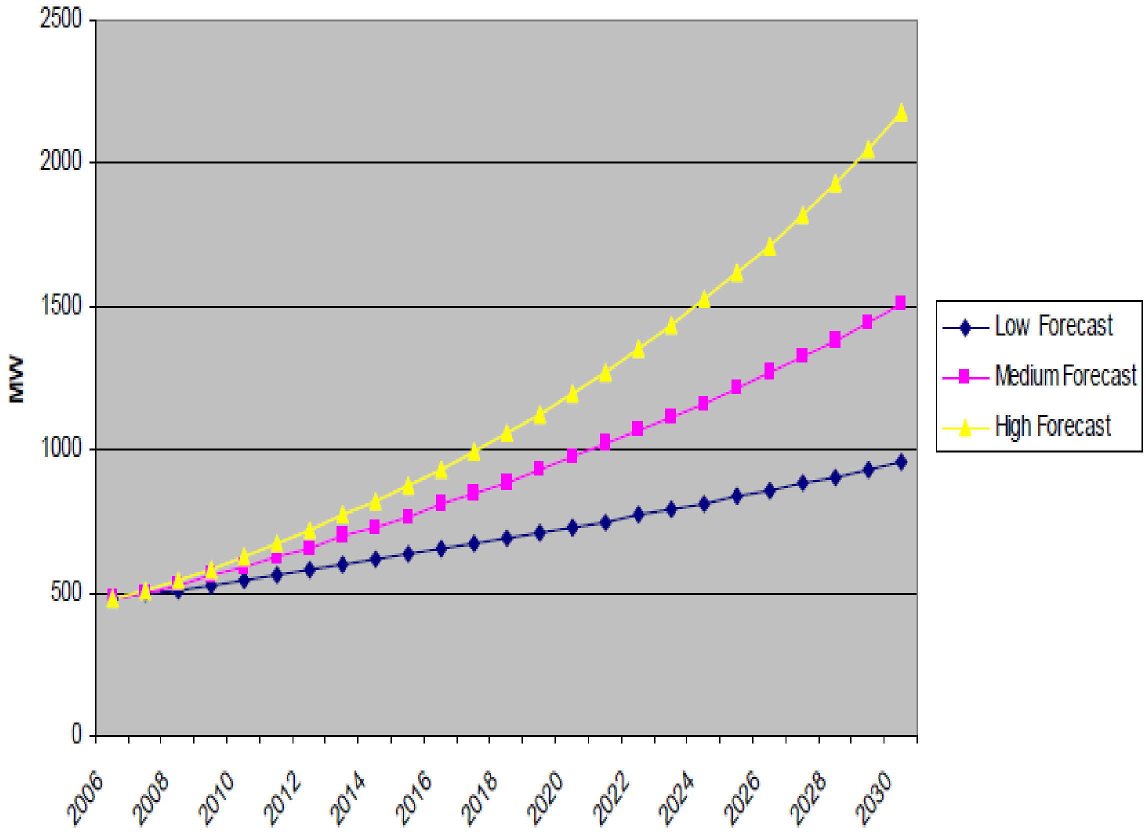

Figure (1.4): First Scenario Forecast Levels [14]

The scenarios are:

1. Power generation in West Bank, no import ("Without Interconnection (Isolated Supply)")

2a. Power generation in West Bank and an interconnection to Jordan ("50% Firm Power Import from Jordan")

2b. Generation in West Bank unavailable, import from Jordan ("100% Emergency Import from Jordan")

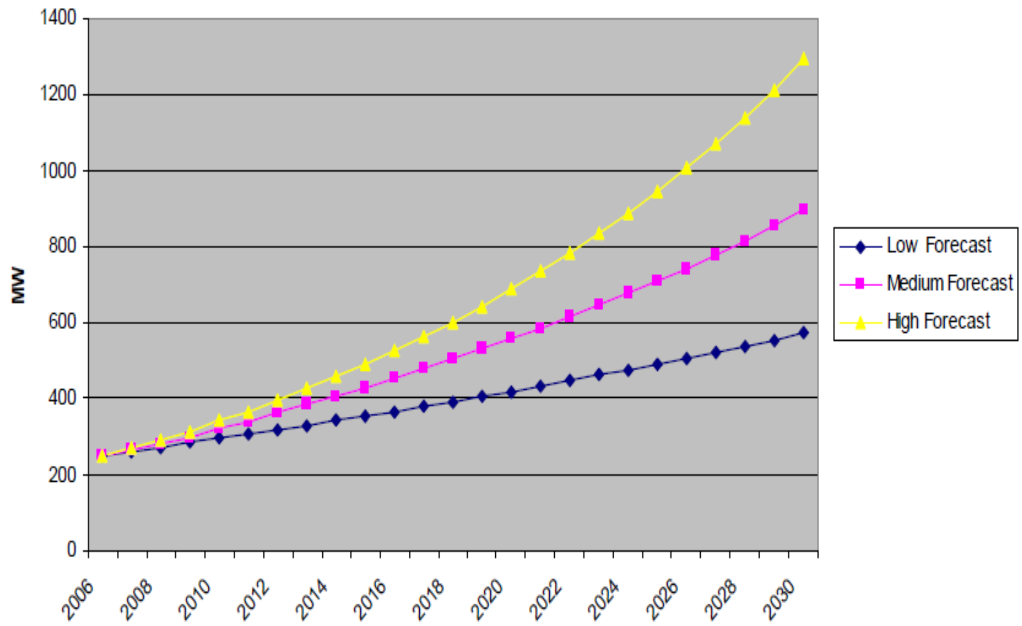

Figure (1.5): Second Scenario Forecast Levels [14]

The two scenarios were studied at two voltage levels for each one of them for the transmission; the first level at 132 kV and 220 kV. See figure (1.5) which shows a techno-economic study of without interconnection scenario. See figure (1.6) which shows the techno-economical study for the 50 % power imported from Jordan scenario. [14]

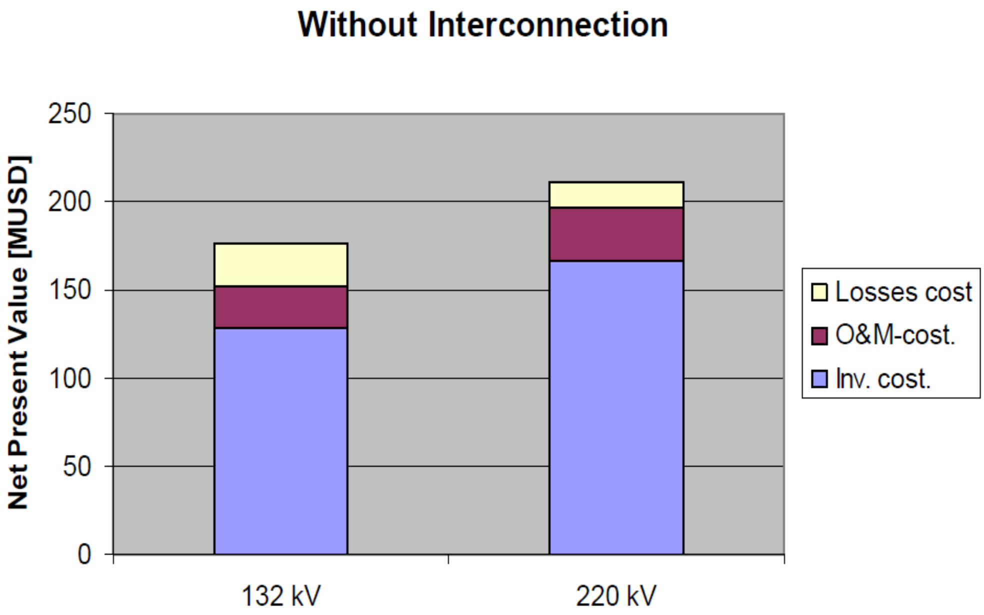

Figure (1.6): Techno-Economic Study of the No Interconnection with Jordan [14]

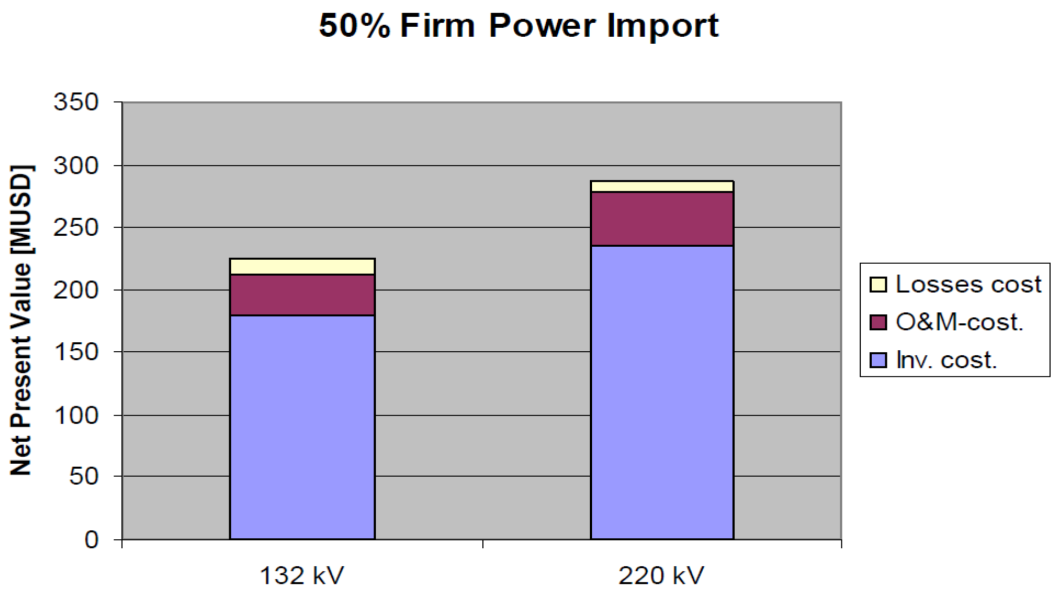

Figure (1.7): Techno-Economic Study to 50% Interconnection with Jordan [14]

The PEA starts large developing plans in the electrical sector in Palestine.

The first plan is to build two combined cycle gas generation plants of 200 MW in West Bank; one at north in Al-Jalamah-Jenin District or in Joyous in Qalqilia and the second in Tarqoumia in Hebron District.

- Al-Jalamah or Joyous Power Plant

A 200-megawatt combined cycle power plant run on natural gas in the northern West Bank area of Jenin or area of Qalqilia. The project aims to meet Palestine’s energy demands.

- Tarqoumia Power Plant in the southern West Bank area of Hebron. [17]

The two plants are combined cycle power plant run on natural gas and will produce 200 MW at the first stage and will reach 375.0 MW in the next stage due to the results of the load forecasting until 2030. [17]

The figure below figure (1.7) shows a single line diagram for the planned connection between substations in West Bank and the connection between Jordan and Jericho.

The Palestinian Power Generation Company (PPGC) and the Palestine Energy and Natural Resources Authority (PENRA) are in the process of developing the feasibility study of the projects, as well as negotiating the license and power purchase agreements for PPGC to become the sole domestic supplier of electricity to the West Bank. [17]

The second plan is to install nine Transformation substations of (161/33 kV) in the West Bank, separates into three stages and new transmission system will be installed, which is to connect these aimed substations together all around the west bank.

See figure (1.8) which shows the lines routing in the West Bank.

The transformation substations plan stages are:

- The first stage aims to build 4 substations in:

1. Jenin (industrial area 3*45 MW)
2. Nablus (Sarra, 3*45 MW)
3. Ramallah (Qalandia 4*45 MW)
4. Hebron (Bitola- Tarqoumia 2*45 MW)
5. The second stage of transformation stations will be : one on north of Ramallah and one in East of Nablus
6. The third stage will be: one between Tulkarem & Qalqilia and one between Hebron and Bethlehem [17]

The third plan is to install an interconnection line between Jordan and the West Bank of 400 kV, will be designed to feed 50% of the West Bank demand. The 101 kilometer long 400 kV transmissions line Jordan - West Bank is assumed to be designed. Figure (1.9) shows the 400 kV transmission line. [18]

The line will originate from Samra Thermal Power Plant north of Amman, Jordan, and will be connected to a new 400 kV substation in the Jerusalem area in the West Bank. Figure (1.10) shows the 400 kV line route from Samra Thermal Power Station (TPS) across Jericho to JDECO substation near Jerusalem. [18]

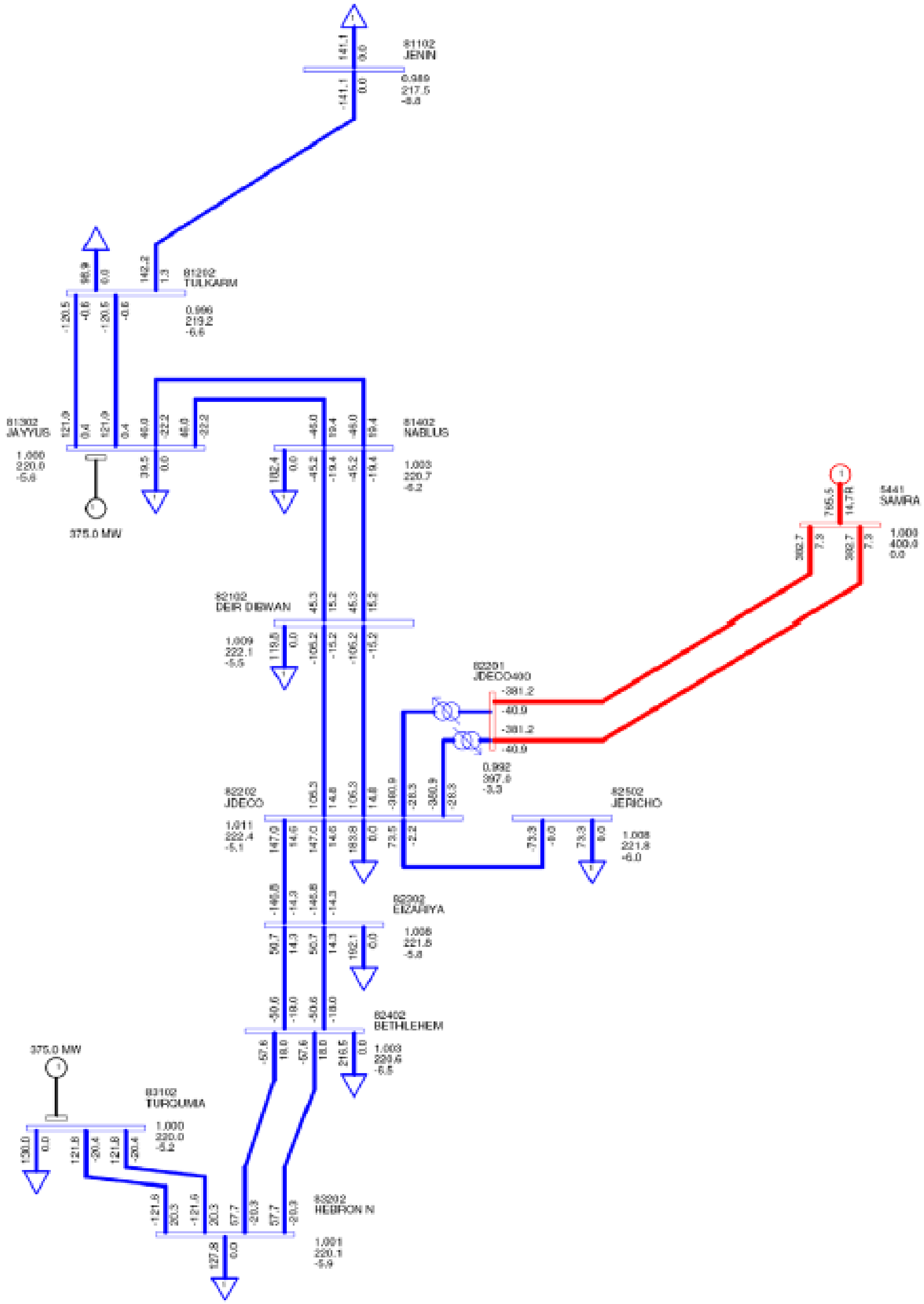

Figure (1.8): Single Line Diagram of the Planned Generation and Transmission [14]

Figure (1.9): Routing in the West Bank [18]

Figure (1.10): 400 kV transmission line [18]

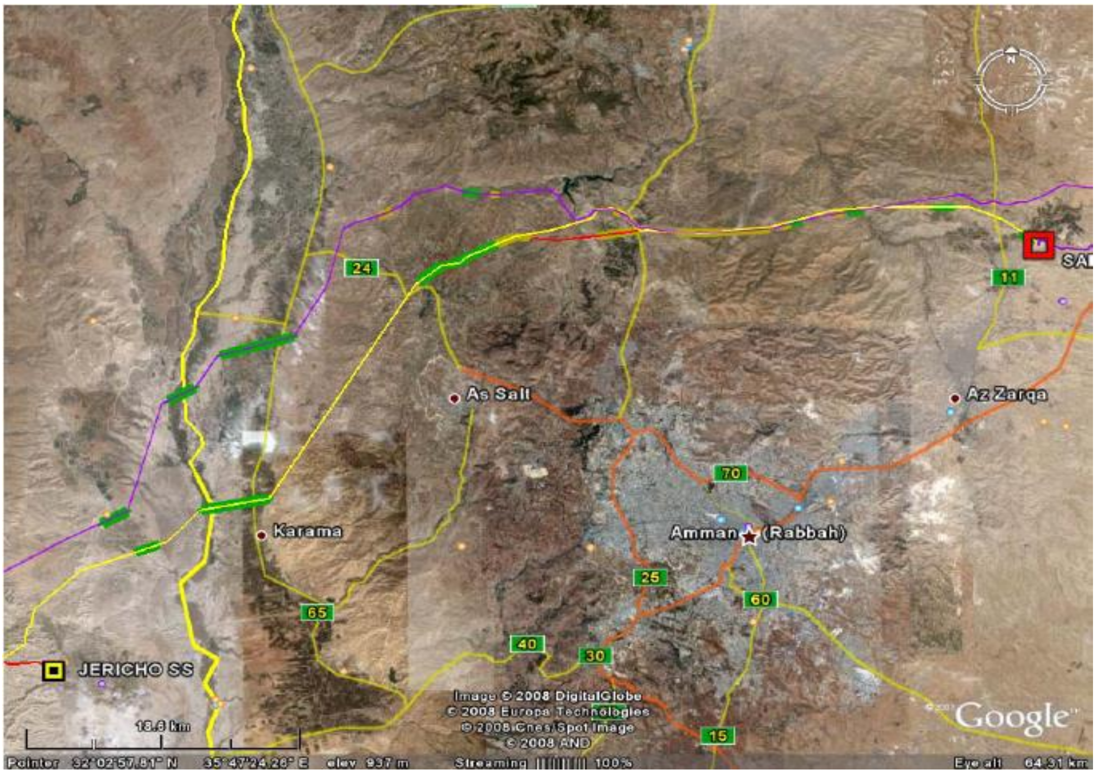

Figure (1.11): 400 kV line route from Samra Thermal Power Station (TPS) across Jericho to JDECO substation [18]

In the study, the substation JDECO have been chosen for the connection of the 400 kV line from Jordan. The length of this line is estimated to be 101 km. [18]

The figures below figure (1.11) and figure (1.12) show the connection between Jordan and Jericho.

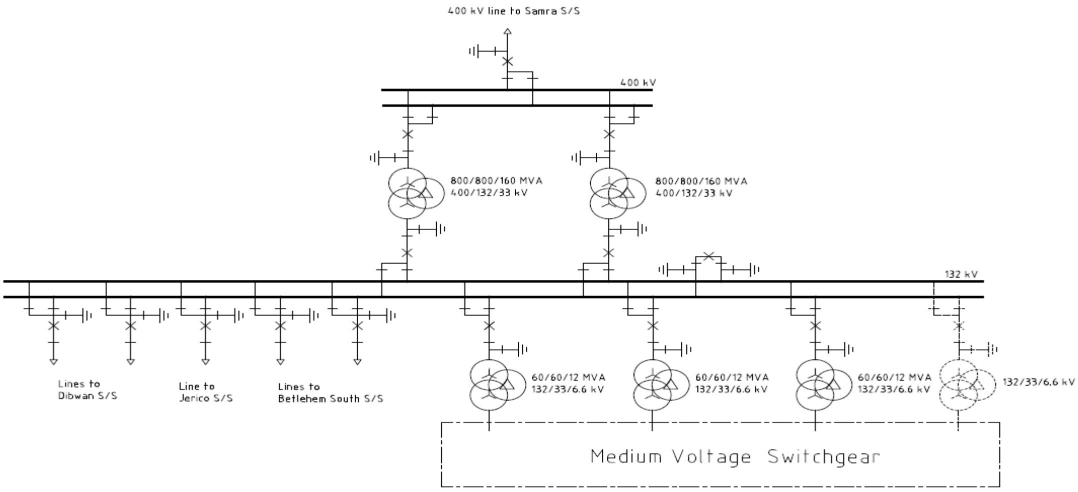

Figure (1.12): Interconnection with Jordan Samra Side [18]

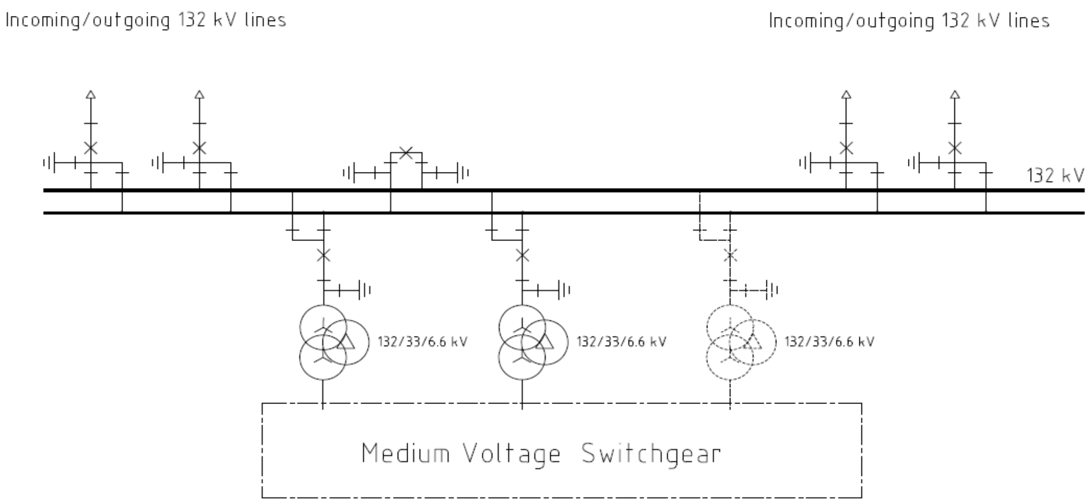

Figure (1.13): Interconnection with Jordan West Bank Side [18]

1.2 Electricity Distribution in Palestine

The new Palestinian electricity distribution system consists of four main distribution companies (JDECO, NEDCO, SELCO and HEBCO). These companies control the electricity distribution in West Bank. See figure (1.13) which shows the areas of each electric company.

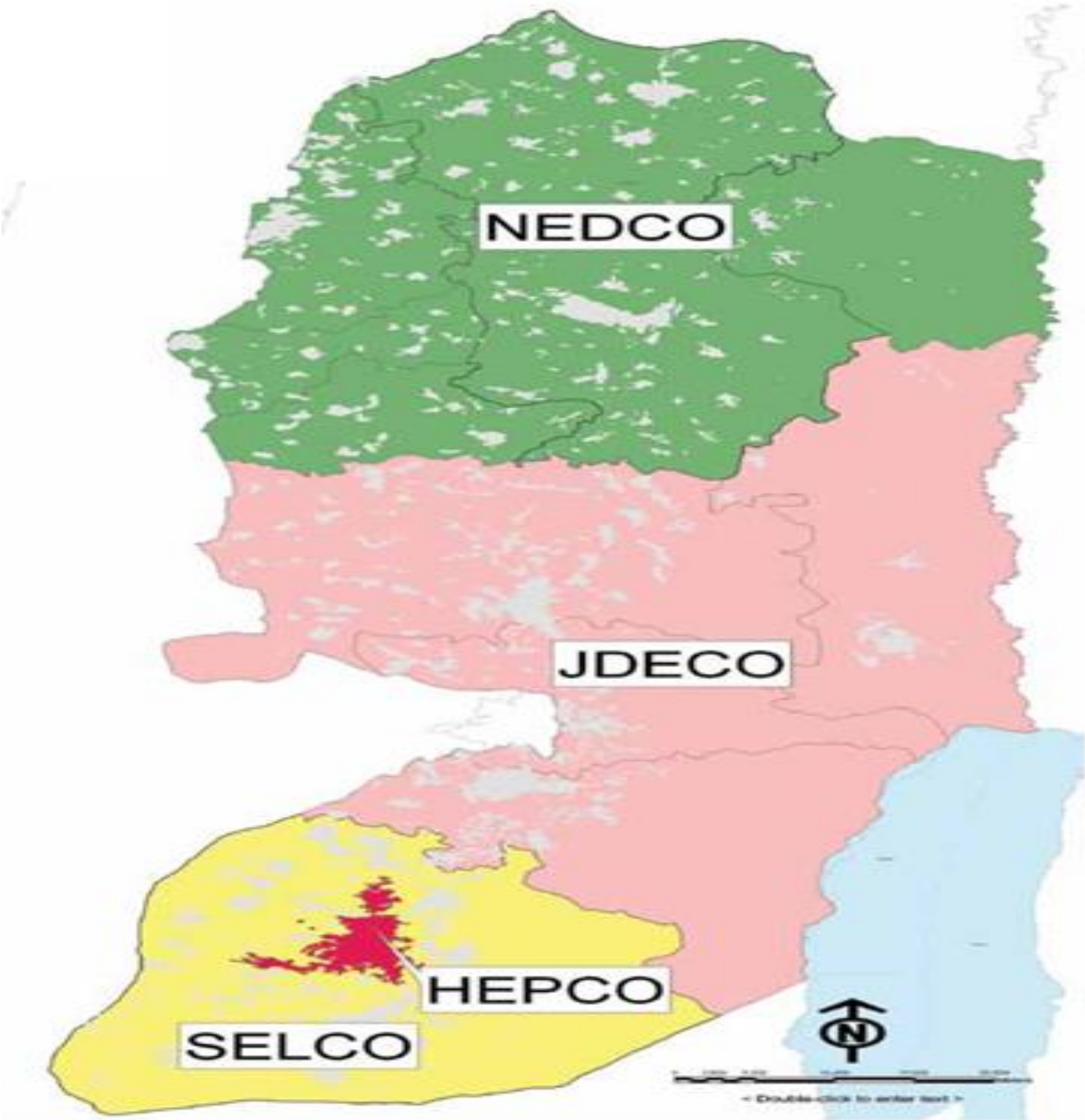

Figure (1.14): Areas of Each Electric Company [10]

Still 31% of the total number of consumers in almost 305 municipalities and village councils, of which 230 located in NEDCO's concession area, and 75 other bodies located in SELCO's concession area, are not bounded to any distribution company [10]. See figure (1.14) which shows the percentage of each electric company and the percentage of the municipalities that uncontrolled by electric companies.

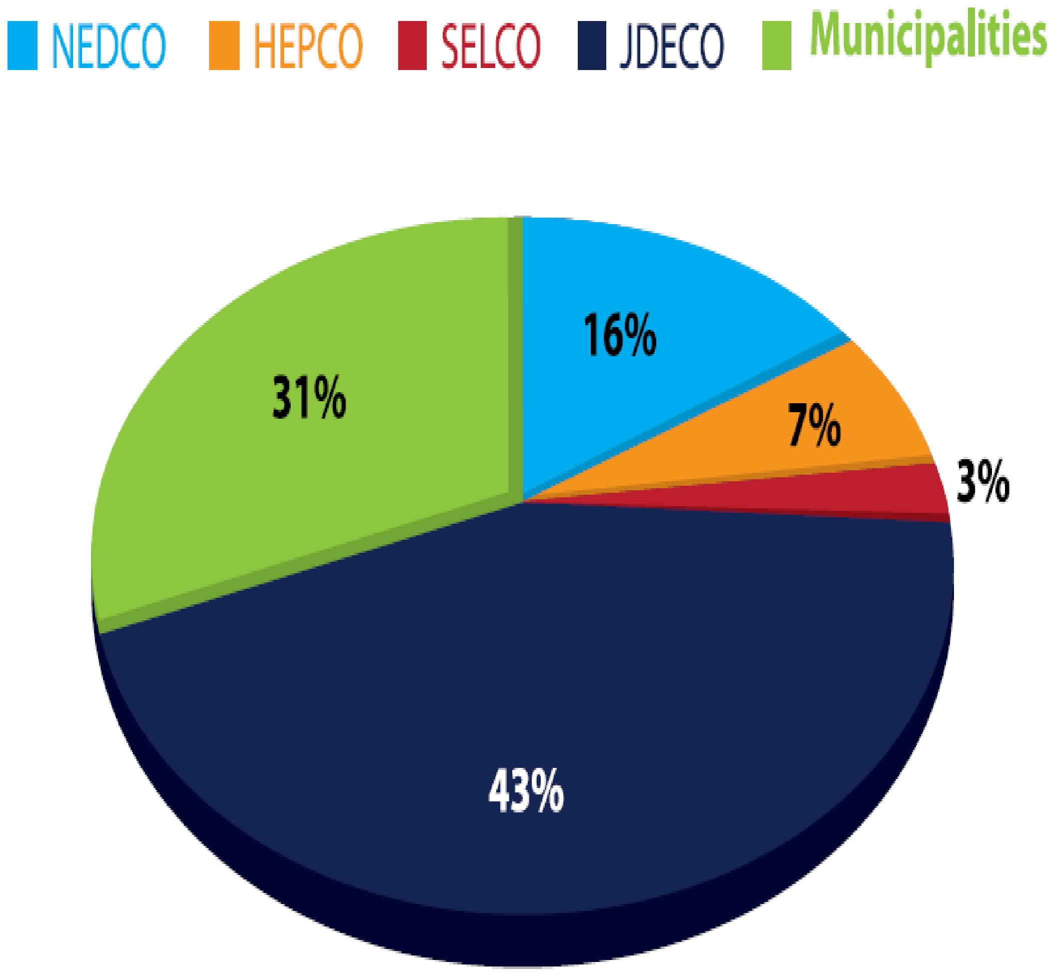

Figure (1.15): Percentage of Each Electric Company and the Percentage of the Municipalities that Uncontrolled by Electric Companies [10]

1.2.1 North Electricity Distribution Company (NEDCO)

NEDCO was established officially in January of 2008, and began its work in July of 2010 by joining electricity departments in the municipalities of Nablus and Jenin in September of the same year until December 2011 the total number of municipalities that joint NEDCO reached 33 municipalities.

The number of consumers of NEDCO reached 80,000 consumers in 2012, representing 40% of the total number of consumers in the six Northern provinces (Nablus, Tulkarem, Jenin, Salfit, Qalqilia and Tubas) located in the company's connection. [10]

The company has a single source of power of 6 connection points on medium voltage, and a capacity of 108 MVA from the Israeli Electric Corporation (IEC).

The company works to merge the rest of the municipalities and village councils, almost 270 located in the connection area. Then, the number of consumers will reach 200,000 consumers [19]. See table (1.6) which shows information about NEDCO in 2012.

Table (1.6): NEDCO in 2012 [10]

Number of Customers	Number of Purchased Units (MWh)	Number of soled Units (MWh)	Losses Percentage
92,142	474,000	392,000	17%

The distribution inside NEDCO area can be included in these points:

- Nablus city distribution network has 5 connection points, 2 connection points from Howara south 43 MVA (20 +23) MVA, 2 From Sarra point west 40 MVA, and 1 from Anabta area 5 MVA. Jenin city distribution network,1 connection point east of Jenin (Faqoaa Line) 30 MVA which includes Qabatia and 8 villages overloaded especially in summer times [19].

- Tulkarem city distribution network has 2 connection points west of Tulkarem city 22 KV about 20 MVA which is loaded and failure in summer times.

- Qalqilia city distribution network has 1 connection point from north 5 MVA 22 KV loaded.

- Salfit city distribution network has 1 Connection point from Ariel side 5 MVA.

- Tubas city distribution network has 1 Connection point from Beisan side North of Tubas city 10 MVA near Tyaseer village. [19]

In 2011, the total purchased energy by the company reached 418 GWh and the total energy sold by the company reached 337 GWh [NEDCO final report]. The percentage of energy losses is about 19% of the purchased energy by the company. The total number of consumers reached 83,564 by the end of 2011 [10].

The power of the transformation stations is 318 MVA, where the power provided by supplying stations is 113 MVA [19].

The transformed power to the consumers in the two branches of Nablus and Jenin is shown in table (1.7).

Table (1.7): Transformed Power to the Consumers in the Two Branches of Nablus and Jenin [19]

Branch Name	Old Power Capacity (MVA)	Current Power Capacity (MVA)
Nablus	170	183
Jenin	35	42

NEDCO developed some connection points and create others, see table (1.8).

Table (1.8): Connection Points Developed and Created [19]

Connection Point	Old Power Capacity (MVA)	Current Power Capacity (MVA)
Howara	13	20
Asker	23	23
Sarra 1	12	20
Sarra 2	-	20
Anabta	5	8
Total	53	91

The growth of electricity consumption of the company can be calculated from the electricity consumption in 2010 is 364 GWh and in 2011 is 418 GWh, so the growth is 15% [19].

The growth of the number of consumers can be calculated from the consumers number in 2010 was 75,693 consumers and in 2011 was 83,564 consumers, so the growth of the number of consumers is 10.4% [19].

1.2.2 Jerusalem District Electricity Company (JDECO)

JDECO is a joint stock company limited distribution of electrical power for 217,496 subscribers (900,000 people) in the central West Bank area (governorates of Jerusalem, Ramallah, Bethlehem, Jericho) in a geographic area stretching south from Bait Fajar to snuggle north and the Green Line (the Medea, Padres) Dead Sea in the west to the east, and employs 811 staff [10].

JDECO was established in the year 1914, one of the most prestigious companies for generation, transmission and distribution of electricity in Palestine. A national institution linking Jerusalem with the West Bank and its history became an integral part of the history of Jerusalem. The company worked under the franchise (generation, transmission and distribution) British Mandate granted for a period of 60 years ended in 1988 and was renovated by the Jordanian government and with the approval of the Jordanian Parliament for another 60 years. After the stopping of the central power station in Shuafat 1987, the company was forced to rely entirely on the IEC to buy energy to supply its customers through 34 anchor point, the total capacity of 486.5 MVA, at 33kV. At the beginning of the year 2008 the company started supplying the Jericho area by linking with the Hashemite Kingdom of Jordan card up to 20 MVA and was soon to be increased to 30 MVA [20].

In 2007, the total number of customers served by JDECO reached 187,164 customers as shown in figure (1.15). About 42,134 (22.51% of the total customers) are without bill (illegal customers); figure (1.16) shows the number of the customers without bill from 2004 to 2007 [10].

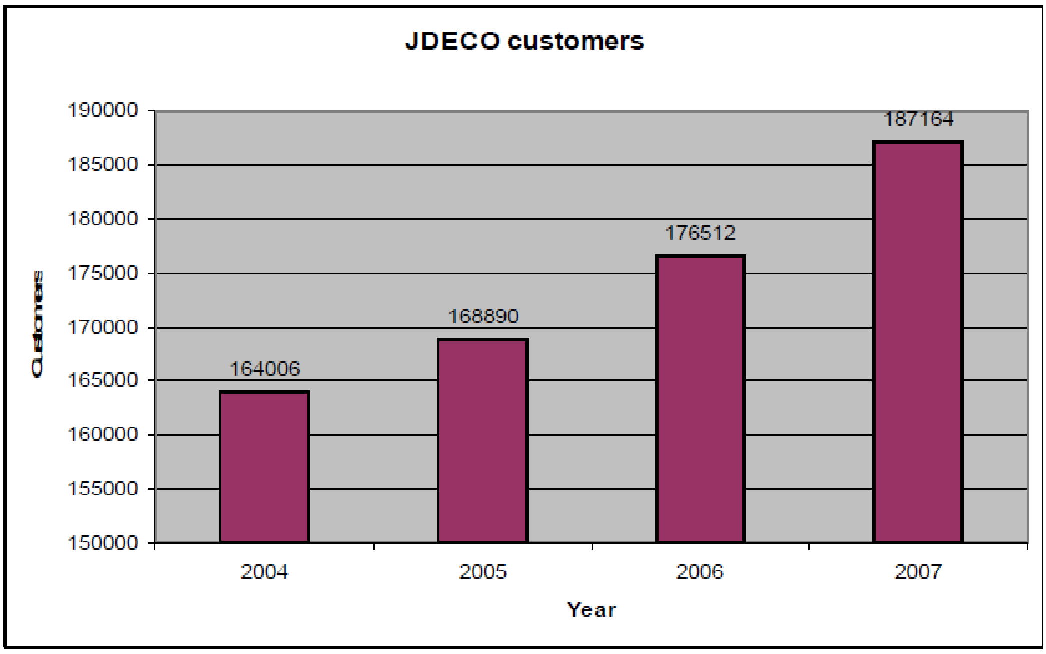

Figure (1.16): Total Number of Customers Served by JDECO [20]

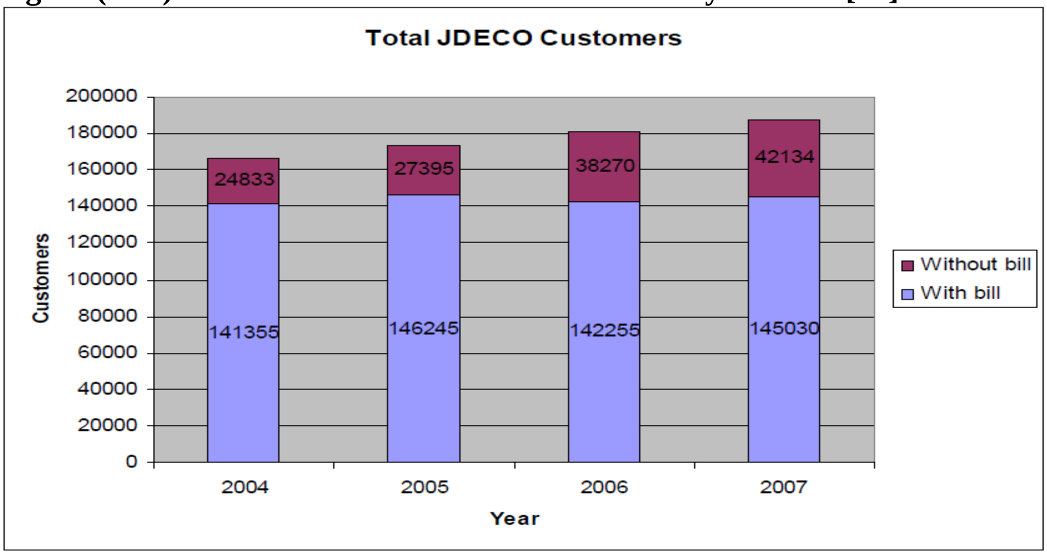

Figure (1.17): Number of the Customers without Bill from 2004 to 2007 [20]

Despite the uncertain and difficult situation, JDECO has had a reasonably satisfactory performance with sales growing at an annual rate of 17% during 2005. System losses have gone down from a high of 20% in 2004 to 18% in 2005 and back up to 23-25% in 2007 and 2008. The company has had a significant drop in trading margin (total sales minus import cost) in recent years. Against the annual increase of 17% in sales in recent years, the import cost of electricity has been growing by an annual rate of 25% during the same period causing the trading margin to drop. Increased efforts for efficiency improvements together with adjustments in the sales tariff should result in a better margin for JDECO to cover its operating and financing costs [20].

The number of customers of JDECO network increased yearly in average about 15,088 customers per year after 2009. See Table (1.9), see figure (1.17).

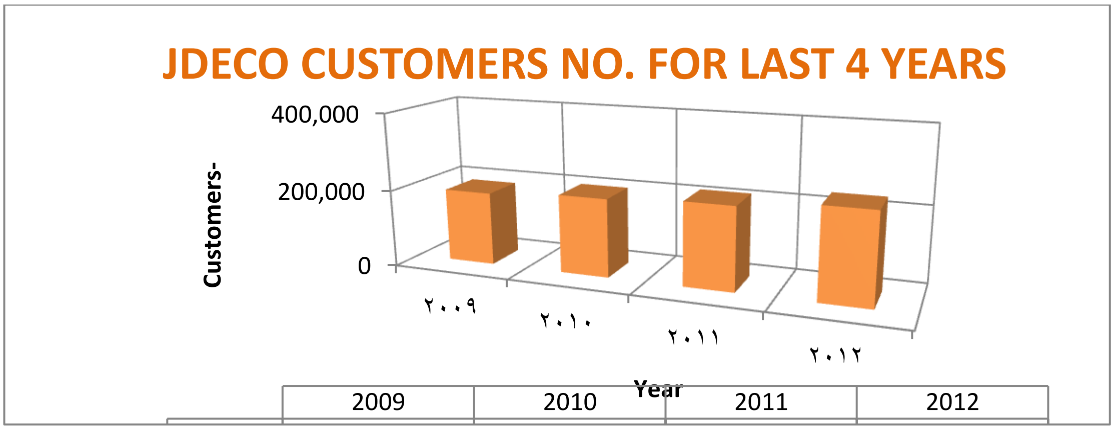

Figure (1.18): Number of Customers of JDECO Network [20]

Table (1.9) Number of Customers of JDECO Network [20]

Consumers Average Consumption kWh	Yearly Increment	Number of Customers	Year
6,050	13,140	190,325	2009
5,536	13,281	203,606	2010
5,607	12,058	215,664	2011
5,763	19,926	235,590	2012

JDECO distribution system peak load per year from 2010 till 2012 is shown in table (1.10), and figure (1.18).

Table (1.10): JDECO Distribution System Peak Load [20]

Year	2010	2011	2012
95%	304.45	333.45	384.45
Peak Load MW	321.02	351.00	405.00
5%	337.07	368.55	425.25
15%	369.17	403.65	465.75
20%	387.63	423.83	489.04

See table (1.11) which shows some information about JDECO in 2012.

Table (1.11): JDECO in 2012 [10]

Number of Customers	Number of Purchased Units (MWh)	Number of soled Units (MWh)	Losses Percentage
224,231	1,943,000	1,299,000	27%

The losses percentage reaches 28% in 2011, but in 2012 it decreased to 27%. The number of consumers of JDECO is 235,590 costumers at the end of 2012, with 20% increment on their number at the end of 2011 which is 215,664 costumers. The average consumption of one consumer in 2012 is 5,763 kWh [10].

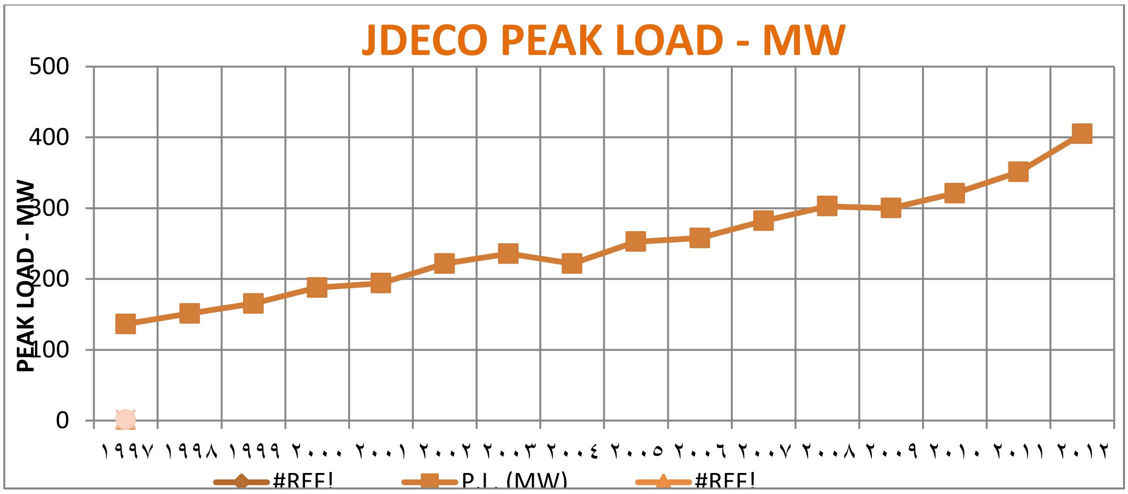

Figure (1.19): JDECO Distribution System Peak Load [20]

The maximum power and the total consumption in JDECO network areas in 2012 are:

- Ramallah area has 158.5 MW, maximum power, where the total consumption in Ramallah area is 736,987,975 kWh.

- Jerusalem area has 172.723 MW, maximum power, where the total consumption in Jerusalem area is 732,624,394 kWh.

- Bethlehem area has 71.028 MW, maximum power, where the total consumption in Bethlehem area is 381,398,806 kWh.

- Jericho area has 10.97 MW, maximum power, where the total consumption in Jericho area is 113,964,857 kWh. [20]

1.2.3 Hebron Electric Power Company (HEPCO)

Hebron Electric Power Company (HEPCO), which works in Hebron and Halhul areas. The total consumption in 2011 was 282,033,427 kWh, with 22% losses percentage. HEPCO established new Main Power Control station (MPC) and Halhul new station buildings and Purchasing 2 power transformers 33/11 K.V, 13 MVA each [21]. See table (1.12) which shows some information about HEPCO in 2012.

Table (1.12): HEPCO in 2012 [10]

Number of Customers	Number of Purchased Units (MWh)	Number of soled Units (MWh)	Losses Percentage
36,644	369,000	300,000	19%

In Halhul network and Due to the increase of electric loads and demands at Halhul area，HEPCO established a building for a new station with capacity of 10 MVA, demanded a purchase of 5 MVA from IEC as a first stage [21].

During 2011 new feeders and sub lines were installed in order to meet load demands and industrial needs, such as the following projects and lengths of cables:

- Lilyan building project 200m.
- Al-herbawi building in Ain Sara 300m.
- New feeder extending from alras substation with the length of 2 Km underground cables in addition to 500m overhead network.

HEPCO installed and operated SCADA system from Schneider Electric for connecting and controlling all the primary substations via a single control room. This system facilitates and accelerates re-connect and the identification and repair of any defect on the system as well as the significant contribution of this system in preparing a reliable database which will contribute significantly in the future planning for the development of the electrical system. [21]

At a later stage, system will be used to connect and control Ring main units the flexibility of 11 KV in order to increase the system and provide the possibility of control of the sub-networks and exchange of loads between stations. The purchases and sales of HEPCO in 2011 were shown in figure (1.19).

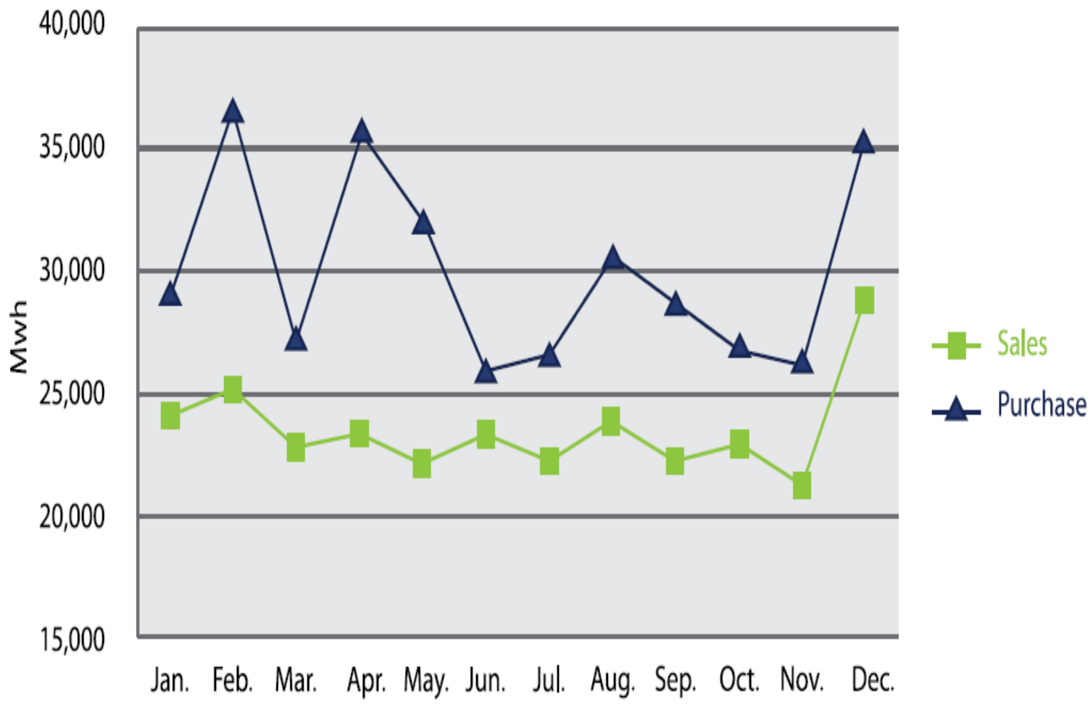

Figure (1.20): Purchases and Sales of HEPCO in 2011[21]

The purchases of HEPCO in 2012 were 369 GWh, the sales were 300 GWh and the losses were 69 GWh. [21]

1.2.4 Southern Electricity Company (SELCO)

SELCO was established officially in 1998, and began its actual work in March 2004 in a partnership of five municipalities established with the Ministry of Local Government as a representative of the rest of municipalities; (Yatta, Daharia, Dura, Bait Ummar, and Halhul). The company actually began its services in four municipalities, where Halhul actually feed from HEPCO. The municipality of Bait Ummar quit the partnership in 2005 followed by the municipality of Dura in 2011. Currently, the company has 3 municipalities. [10]

The company's concession area is fully located in Hebron province, excluding the area of HEPCO, the number of consumers belonging to SELCO is about 13.000 consumers representing 22% of the total number of consumers in the company's concession area. See table (1.13) which shows some information about SELCO in 2012.

Table (1.13): SELCO in 2012 [10]

Number of Customers	Number of Purchased Units (MWh)	Number of soled Units (MWh)	Losses Percentage
92,142	79,000	44,000	34%

The company has a single source for power of 3 connection points on medium voltage, and a capacity of 13MVA from the Israeli Electricity Corporation (IEC).

The company aspires to join the rest of the municipalities and village councils, almost 75 located in the concession area bringing the number of consumers to around 55,000 consumers. The purchased and sales of SELCO in year 2011 are shown in figure (1.20). [22]

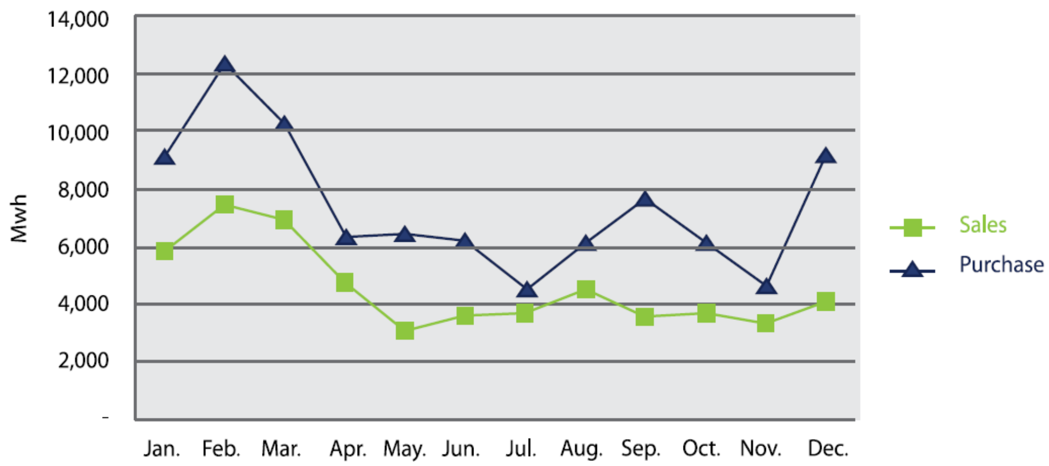

Figure (1.21): Purchased and Sales of SELCO in 2011 [22]

The purchases of SELCO in 2012 are 79 GWh, the sales are 52 GWh and the losses are 27 GWh. [22]

1.3 Potential of Renewable Energy in Palestine

1.3.1 Solar Energy Potential

Solar energy can be a major contributor to the Palestinian energy supply future, with its high potential in the area. Palestine is one of the leading countries worldwide in usage of solar water heaters for domestic applications, according to the Palestine Central Bureau of Statistics (PCBS); approximately 67% of Palestinian homes use solar water heaters, drying of crops as vegetables and fruits, water desalination, water pumping and electrification of remote locations isolated from the electrical networks [23]. Rooftop photovoltaic installations can play a small role in providing electricity to the Palestinian grid as well. The houses in Palestine have an average area of $150m^2$ each. Using only 10% of the rooftop area for photovoltaic installation would generate around 146 GWh per year. Such rooftop installations would cover approximately 2.7% of the Palestinian electricity needs [23]. PEA aims to feed 10% of West Bank demand from renewable energy generation strategy which is aimed by PSI in year 2020.

Palestine is located between $34^\circ 20' - 35^\circ 30' E, and 31^\circ 10' - 32^\circ\, 30' N$. Its elevations range from 350m below sea level in Jordan Valley, and exceed 1000m above sea level at some locations in West Bank. Climate conditions in Palestine vary widely. The daily average temperature and humidity in West Bank vary in the ranges $8 - 25°\mathrm{C}, and\ 51 - 83\%$

respectively [24]. In Jericho and the Jordan Valley, almost no heating is needed during winter while high cooling during summer is needed. Palestine has about 3000 sun shine hours per year. The annual solar radiation on horizontal surface varies from $2.63\,kWh/m^2$ daily in December to $8.4\ kWh/m^2$daily in June [24].

Palestine has an average solar radiation of $5.4\ kWh/m^2$ daily [24]. This average solar radiation can be used in several applications, specially the electrical applications either off grid or on grid. See Figure (1.21).

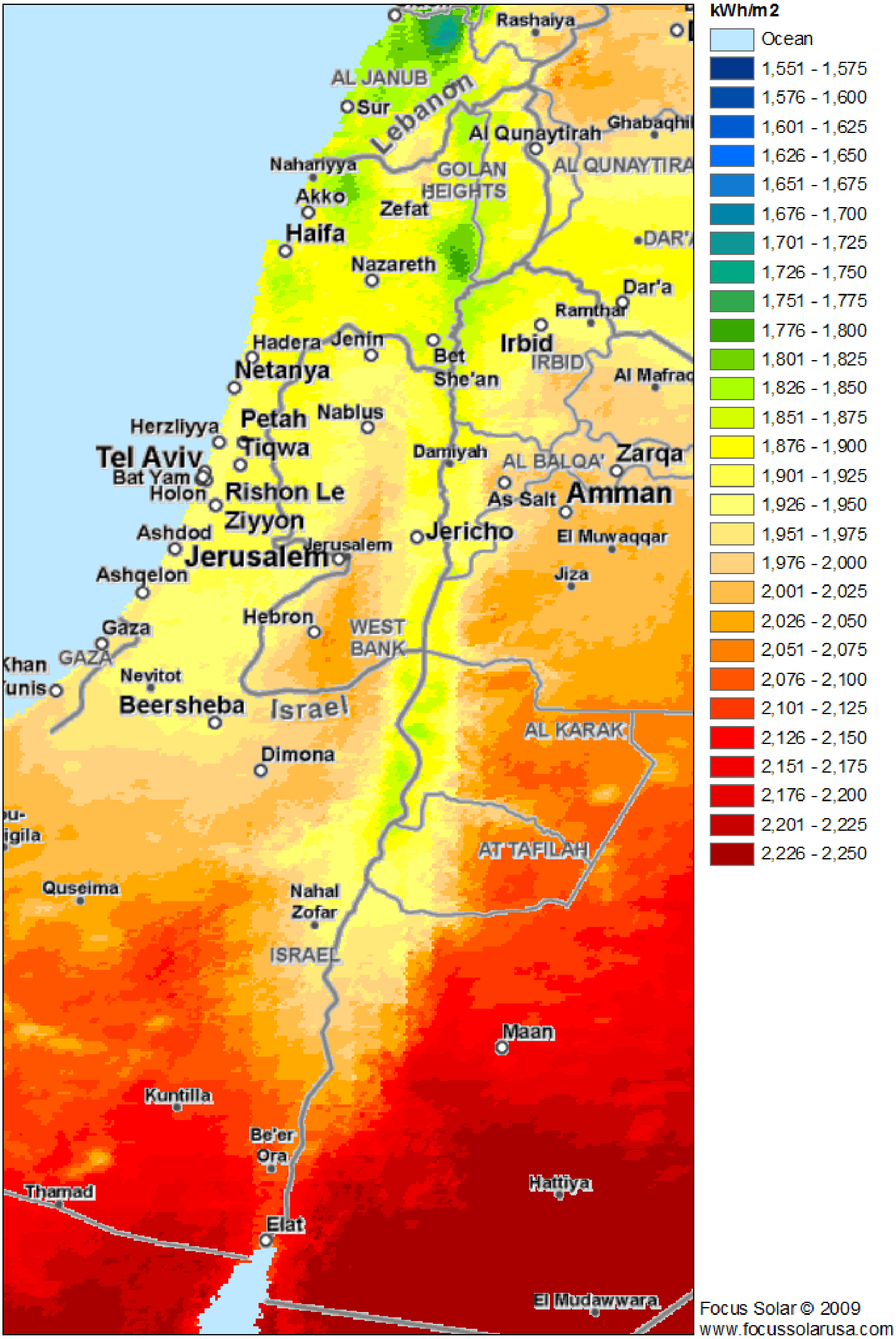

Figure (1.22): Solar Map of Palestine [25]

Table (1.14) shows the monthly average solar potential in Tubas area and figure (1.22) shows the column diagram of table (1.14).

Table (1.14): Monthly Average Solar Potential in Tubas Area [24]

Month	kWh/m²-day
January	2.885
February	3.247
March	5.226
April	6.247
May	7.565
June	8.245
July	8.167
August	8.099
September	6.304
October	4.7
November	3.562
December	2.84

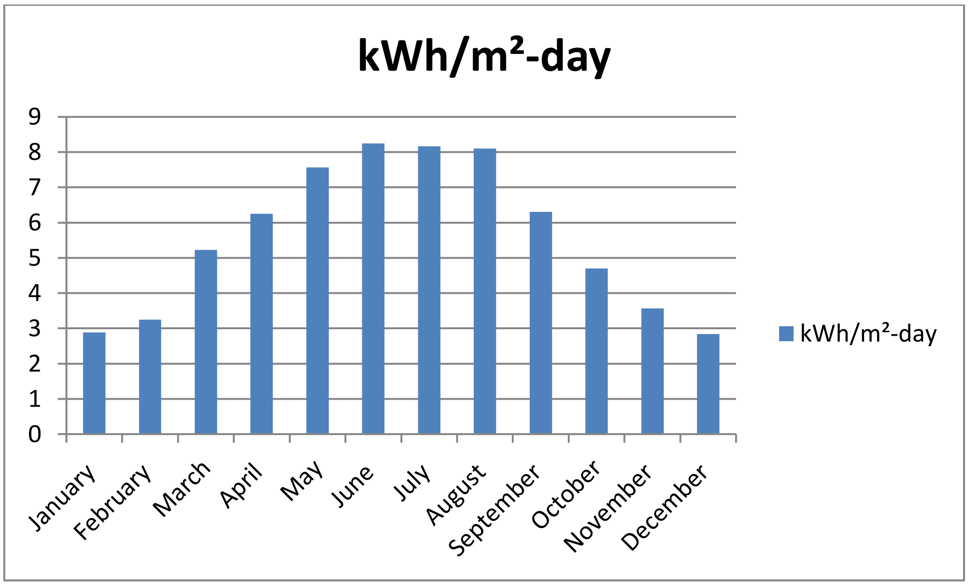

Figure (1.23): Column Diagram of Monthly Average Solar Potential in Tubas Area [24]

Table (1.15) shows the monthly average solar potential in Nablus area and figure (1.23) shows the column diagram of table (1.15).

Table (1.15): Monthly Average Solar Potential in Nablus Area [24]

Month	kWh/m²-day	Month	kWh/m²-day
January	2.89	August	8.1
February	3.25	September	6.3
March	5.23	October	4.7
April	6.25	November	3.56
May	7.56	December	2.84
June	8.25		
July	8.17		

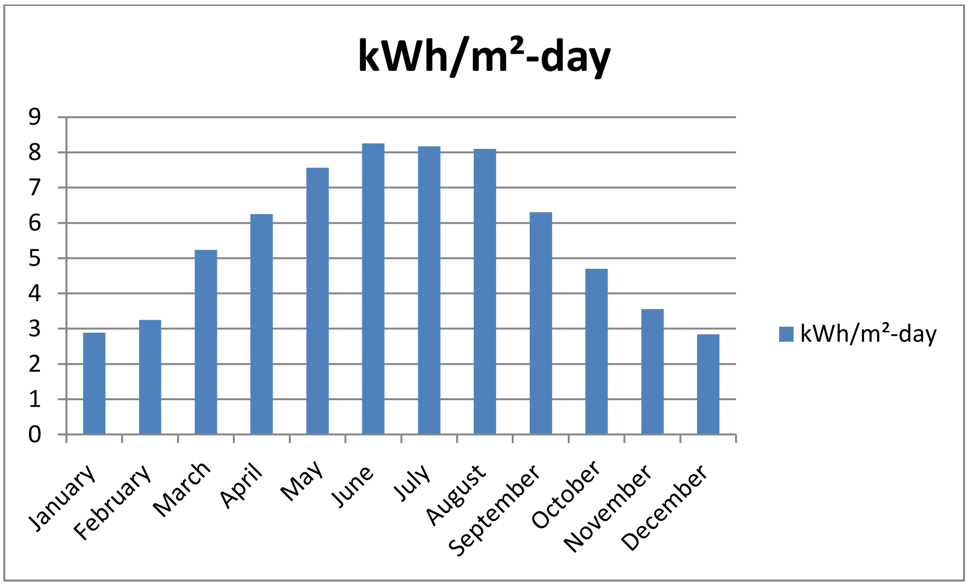

Figure (1.24): Column Diagram of Monthly Average Solar Potential in Nablus Area [24]

1.3.2 Wind Energy Potential

Wind energy is a mature electricity production technology that is not only the economically attractive option in meeting the constantly increasing global energy demand, but it also constitutes a major part of the renewable clean energy solution for the sustainable development of nations. In Palestine, there are no such long-term measurements. At 100 meters in height, the wind speed will be 5.7 and 6 m/s in the northern and southern West Bank, respectively. Using a 100-meter wind turbine with blade length of 52 meters and power coefficient of 0.4, the annual power that can be generated is 3.3 and 3.8 GWh for the northern and southern West Bank, respectively. Using a wind farm of 50 turbines, each would generate 355 GWh/year, which could account for 6.6% of the electricity need in Palestine [26].

Wind energy could make an important contribution to meeting the energy needs for Palestinians who reside in rural areas (17% of the population). The low speed winds in Palestine may encourage using wind energy in stand-alone systems to provide small electricity loads, such as for water pumping, grain grinding and other purposes [23].

Successful examples of small scale wind turbines include providing basic electricity services to about 500 people living in small rural communities in the area of south Hebron, with the addition of solar panels. Another successful example is the installation of a large scale wind turbine in Palestine, at the Al-Ahli hospital in Hebron that provides about 40% of all the hospital's energy needs [23]. This is, however, the only such case.

1.3.3 Biomass Energy Potential

Biomass is considered a strategic energy resource since it may be grown almost anywhere, since it contributes to environmental protection and since it is a source of fuel for motor vehicles. Biomass is of great importance both for developed and developing countries [26]. Biomass, if utilized properly, could become one of Palestine's major energy resources.

Currently, biomass energy constitutes approximately 15% of Palestinian energy supply; it is used mainly for heating purposes.

Palestine is known, historically, for its agriculture and trading. Agriculture is still a predominant economic activity [25]. As a result, Palestine has a strong potential for biomass energy. People living in rural areas may benefit from producing biomass energy in various forms, including wood, crop residues and biogas. Presently, no crops are grown in Palestine specifically for use as fuel. Abu Hamed et. al. calculated the potential energy production from the agricultural waste in Palestine according to the methodology suggested by Unal and Alibas [26].

The result showed that about 2 TJ can be extracted in energy through the biomass gasification method, while producing 22,800 tons of **biodiesel** through a biomass-to-liquid (BTL) thermo chemical process, which would account for about 5% of the national diesel consumption. **Biogas** is a clean source of energy, with a high calorific value. It can be used for heating purposes, can be converted to electricity and fed to the grid, can be used as fuel in vehicles and can substitute natural gas after upgrading (gas cleaning). Biogas can be produced from various agricultural, industrial and municipal organic wastes [27]. The anaerobic biogas production processes have many advantages: low energy requirement for operation, low initial investment cost and low sludge production [28].

Chapter Two

Photovoltaic Systems Characteristics

Chapter Two
Photovoltaic Systems Characteristics

Introduction

In 1839, French physicist Edmund Becquerel discovered that certain materials produced small electric currents when exposed to light. His early experiments were about 1 to 2 percent efficient in converting light into electricity and precipitated research into these photovoltaic effects. The next breakthrough came in the 1940s when material science evolved and the Czochralski process was developed to produce very pure crystalline silicon (The process is named after Jan Czochralski, the Polish scientist credited with inventing it). In 1954, Bell Labs used this process to develop a silicon photovoltaic cell that increased the light to electricity conversion efficiency to 4 percent. Photovoltaic systems, commonly known as solar panels, are currently widely available, produce no emissions, are reliable, and require minimal maintenance to operate. Photovoltaic systems are not used widely because they are one of the most expensive DG technologies to buy, only work while sunlight is available, and have a fairly large footprint. [29]

2.1 Photovoltaic Module

2.1.1 Concept

The PV module is a package of PV cells which are connected in parallel and or in series, this package is the basic element which can produce useful power in the both PV system; either the On-grid or the Off-grid PV systems. See figure (2.1) which shows the PV module.

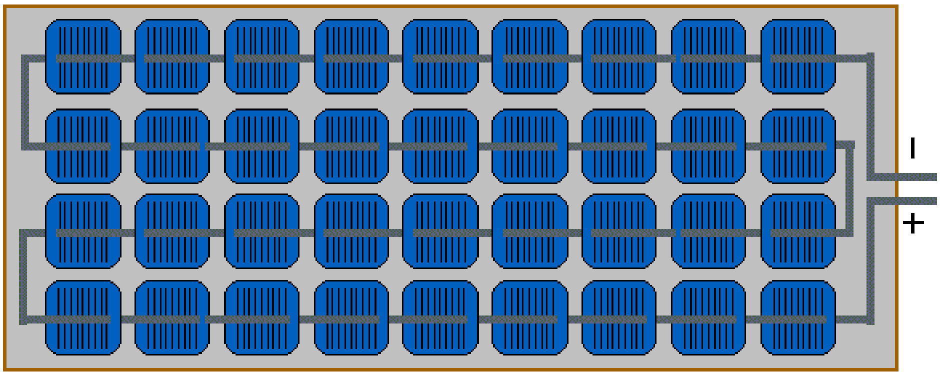

Figure (2.1): PV Module Diagram [30]

The Photovoltaic constructed of Semi-Conductors especially the Silicon element (Si), which is extracted from an intensive purification processes on the sand that contains silicon dioxide (SiO_2) by heating the sand in the Oven with temperature up to 2000°C for complete melting of the sand. The second process is crystallization as the Czo-Chaski Method on the pure Silicon. After that, the P-type and N-type doping, then the PV cell is ready to use after installing the grid connections on it. In fact, there is no commercial or applicable use of PV cell. But a Combination of PV cells which we called PV Module is the most commercial and applicable element in PV systems.

The PV cell has three types:

- Mono Crystalline Silicon Cell
- Poly Crystalline Silicon Cell
- Thin Film (Amorphous) Silicon Cell

These types have different configurations; the output voltage and current, the responsibility to the temperature rising and falling and the effectiveness of absorbing the Solar Radiation. Here each type with some configurations at standard test conditions

(STC:$T_{cell} = 25℃, G = 1000\,W/m^2, Airmass = 1{,}1.5\ andV_w \leq 2\,m/s$)

- Mono Crystalline Silicon Cell
  - Open Circuit Voltage $V_{oc} = 0.6 - 0.62\,V$
  - Short Circuit Current $I_{sc} = 3.4\,A/100cm^2$
- Poly Crystalline Silicon Cell
  - Open Circuit Voltage $V_{oc} = 0.55 - 0.57\,V$
  - Short Circuit Current $I_{sc} = 2.6 - 3.1\ \ A/100cm^2$
- Thin Film Silicon Cell
  - Open Circuit Voltage $V_{oc} = 0.65 - 0.78\,V$
  - Short Circuit Current $I_{sc} = 1 - 2\ \ A/100cm^2$

The basic element in PV system's design is the PV module (Solar Panel), which consists of series combination if cells. [31]

2.1.2 PV Module Operation

Photovoltaic (PV) solar modules are composed of discrete cells connected together that convert light radiation into electricity. The PV cells produce direct-current (DC) electricity. Since the electricity supplied by the electric utilities and used by most residential end-users is AC electricity, the electricity generated by solar panels cannot be used until it is converted from DC to AC using an inverter. In some instances, additional power conditioning equipment may be required if the solar panel is connected to the electric grid. [30]

Insulation is a term used to describe available solar energy that can be converted to electricity. The factors that affect insulation are the intensity of the light and the operating temperature of the PV cells. Light intensity is dependent on the local latitude and climate and generally increases as the site gets closer to the equator. Another major factor is the position of the solar panel. In order to maximize light intensity, the panel should be positioned to maximize the duration of perpendicular incident light rays. Even with these adjustments, the maximum theoretical efficiency that can be attained by a PV cell is 30 percent. [30]

2.1.3 PV Module Equivalent Circuit

In order to understand the operating characteristics of a PV panel, one must know the fundamental electrical circuit components of the PV equivalent circuit model, which dictate how a PV panel operates. Figure (2.2) shows the equivalent circuit model.

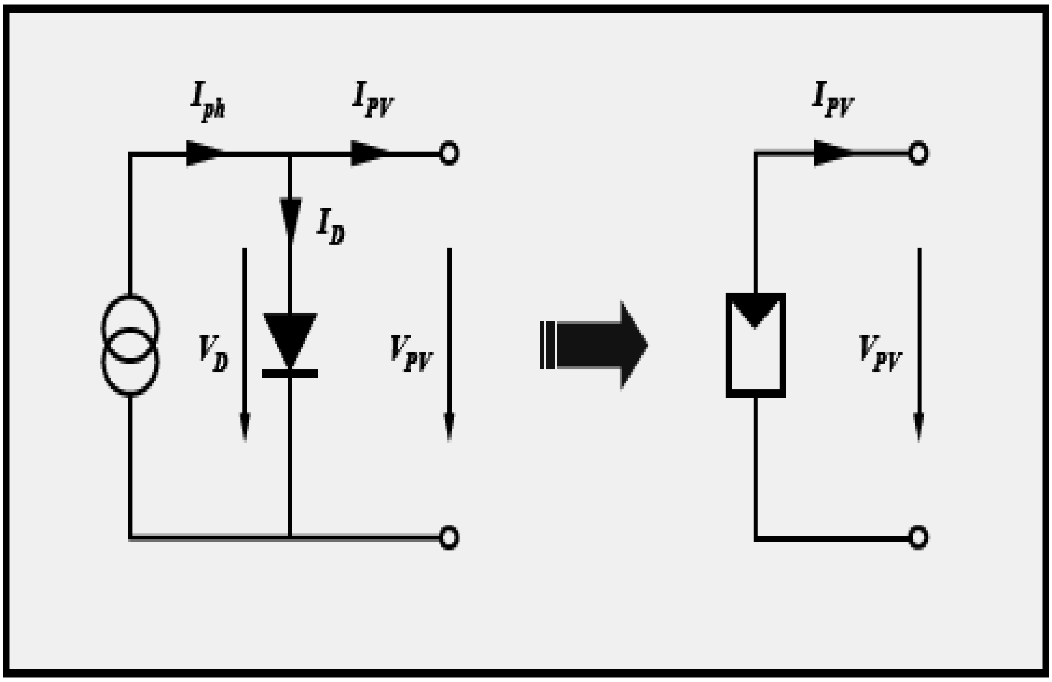

Figure (2.2): Equivalent Circuit of PV Module [31]

The mathematical function of an ideal illuminated solar cell is illustrated in the following equation:

$I_{PV} = I_{ph} - I_0(\mathrm{e}^{\frac{qV}{KT}} - 1)$ …………….. (Equation 2.1)

Where:

I_{PV}: Load current [A]

I_{ph}: Photocurrent [A]

I_0: Dark current [A] or saturation current

q: Elementary charge [e =$1.6x10^{-19}As$]

V: Voltage [V]

T: Diode temperature [̊K] [31]

K: Boltzmann constant [$8.65x10^{-5}\ {eV}/{\circ K}$]

The PV module equivalent circuit parameters are:

- Short Circuit Current (I_{sc}): the maximum current provided by the module when the connectors are short circuited

- Open Circuit Voltage (V_{oc}): the maximum voltage that the module provides when the terminals are not connected to any load

- Maximum Power Point (P_{mpp}): the point where the power supplied by the module is at maximum. The maximum power point of a module is measured in Watts (W) or peak Watts (W_p). It is important not to forget that in normal conditions the module will not work at peak conditions, as the voltage of operation is fixed by the load or the regulator. Typical values of V_{max} and I_{max} should be a bit smaller than I_{sc}andV_{oc} [31]

The operation of PV depends on the IV-Characteristics curve, which is the most important requirement to design. The figures below [Figure (2.3), Figure (2.4) and Figure (2.5)] describe the IV curve with some relations with solar radiation and temperature.

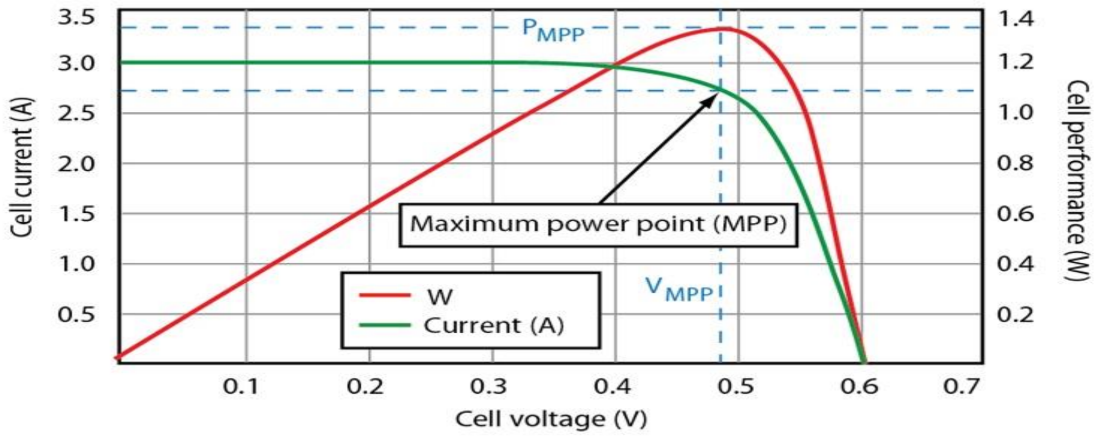

Figure (2.3): Current VS Voltage [32.a]

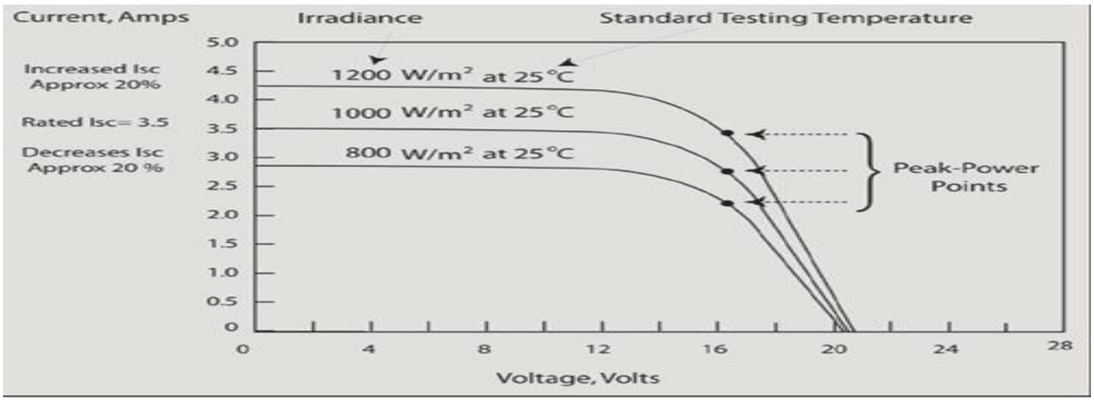

Figure (2.4): Current's Variation with Solar Radiation [32.b]

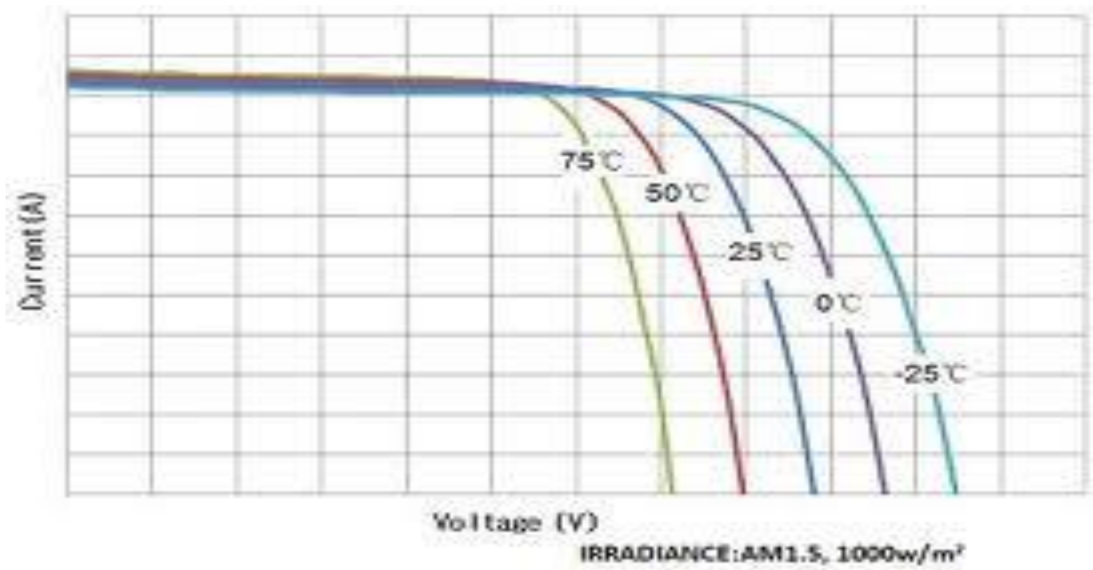

Figure (2.5): Voltage's Variation with Temperature [32.c]

The rated power of a module is basically reported in "peak watts" [Wp] and measured under internationally specified test conditions, namely

Standard Test Conditions (STC), which refers to solar radiation 1000 W/m^2 incident perpendicularly on the cell or the module, cell temperature 25 °C and AM 1.5 (AM: air mass). Photovoltaic modules have current voltage relationship which is represented in I-V curve. [31]

Figure (2.6) shows a single 100 cm^2 silicon PV cell connected to a variable electrical resistance R, together with an ammeter to measure the current (I) in the circuit and a voltmeter to measure the voltage (V) developed across the cell terminals. Let us assume the cell is being tested under standard test conditions.

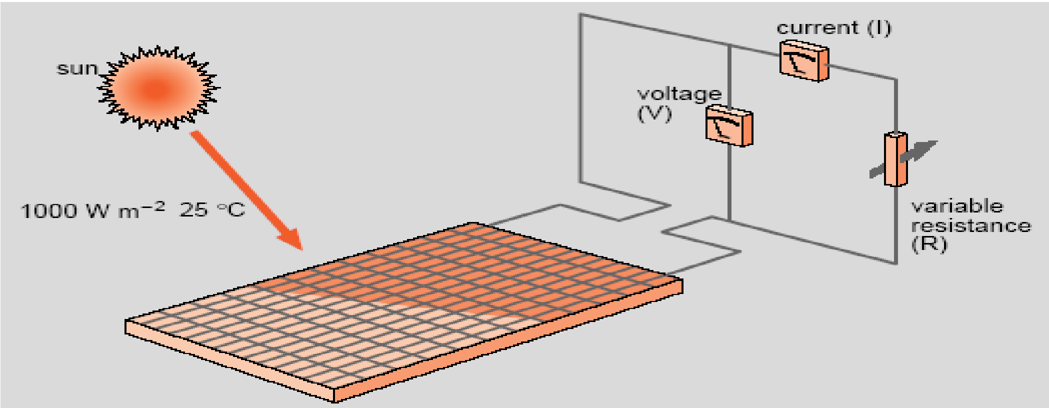

Figure (2.6): Test of PV under STC [32.a]

When the resistance is infinite (i.e. open circuited) the current in the circuits at its minimum (zero) and the voltage across the cell is at its maximum, known as the ‘open circuit voltage’ (Voc). At the other extreme, when the resistance is zero, the cell is in effect ‘short circuited’ and the current in the circuit then reaches its maximum, known as the ‘short circuit current (Isc).

2.1.4 Performance of PV Module

The performance of PV modules and arrays are generally rated according to their maximum DC power output (watts) under Standard Test Conditions (STC). Standard Test Conditions are defined by a module operating temperature of 25℃, and incident solar irradiance level of $1000W/m^2$and under Air Mass 1.5 spectral distribution. Since these conditions are not always typical of how PV modules and arrays operate in the field.

Several factors influence the performance of all photovoltaic modules, including solar irradiance level, operating temperature, soiling, solar spectrum, and the angle-of incidence at which sunlight strikes the module. For a-Si modules the situation is further complicated. In that the a-Si, material properties also change, somewhat reversibly, with the solar irradiance and operating temperature history of the module. [36]

The cumulative effect of environmental factors on performance of a-Si modules as they age is commonly referred as the "stabilization" process. Analysis of hundreds of performance measurements on modules continuously exposed outdoors enabled the experts to separate the effects of various factors influencing a-Si module performance, resulting in an improved understanding of the performance characteristics that can be expected in different system applications. [33]

The complexity and uncertainty associated with system design using a-Si modules will be minimized when the influences of all relevant factors on module performance have been quantified. [36]

2.2 Types of PV systems

2.2.1 Stand-Alone Systems

Specifications:

- Operate autonomously, independent of utility grid.
- Typically use energy storage (batteries), hybrid systems use engine generator, wind turbine or other backup.

See figure (2.7) which shows the Stand Alone System.

Specifications:

- PV system supplements on-site energy usage, electrical loads are supplied by either the PV system or utility or a combination of both, depending on the amount of PV generation and magnitude of the load.
- PV array is directly connected to the inverter input, and inverter AC output is connected to the utility grid.
- PV system operates in parallel and synchronously with the utility grid.

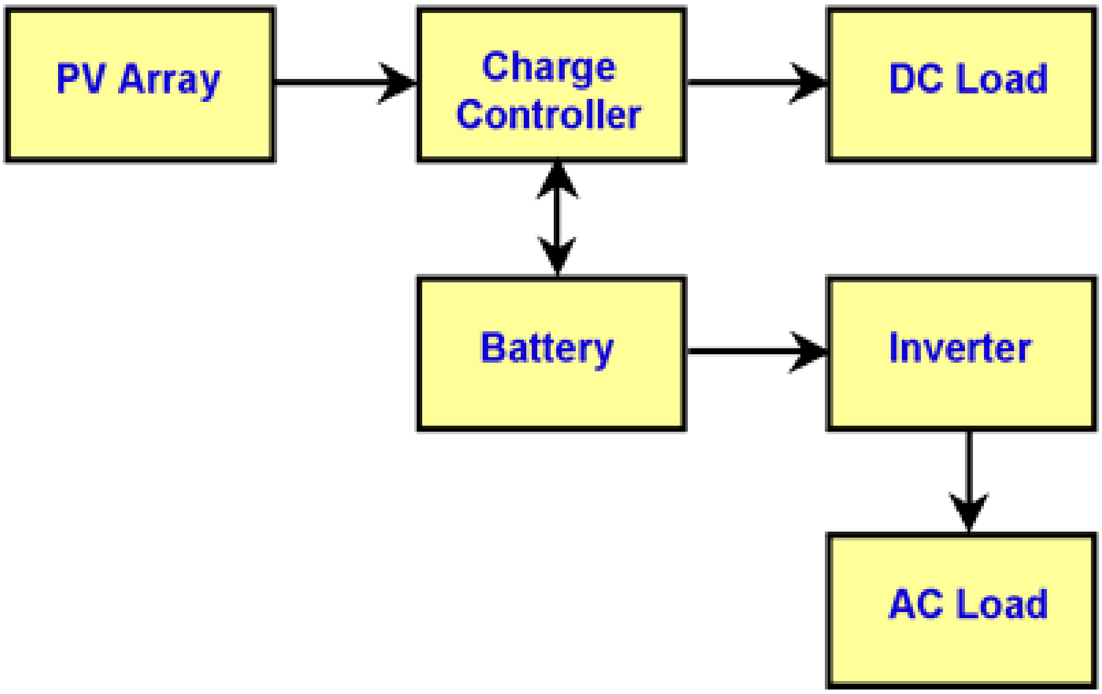

Figure (2.7): Stand Alone PV System

2.2.2 Simple Utility-Interactive

See figure (2.8) which shows Simple Utility-Interactive System.

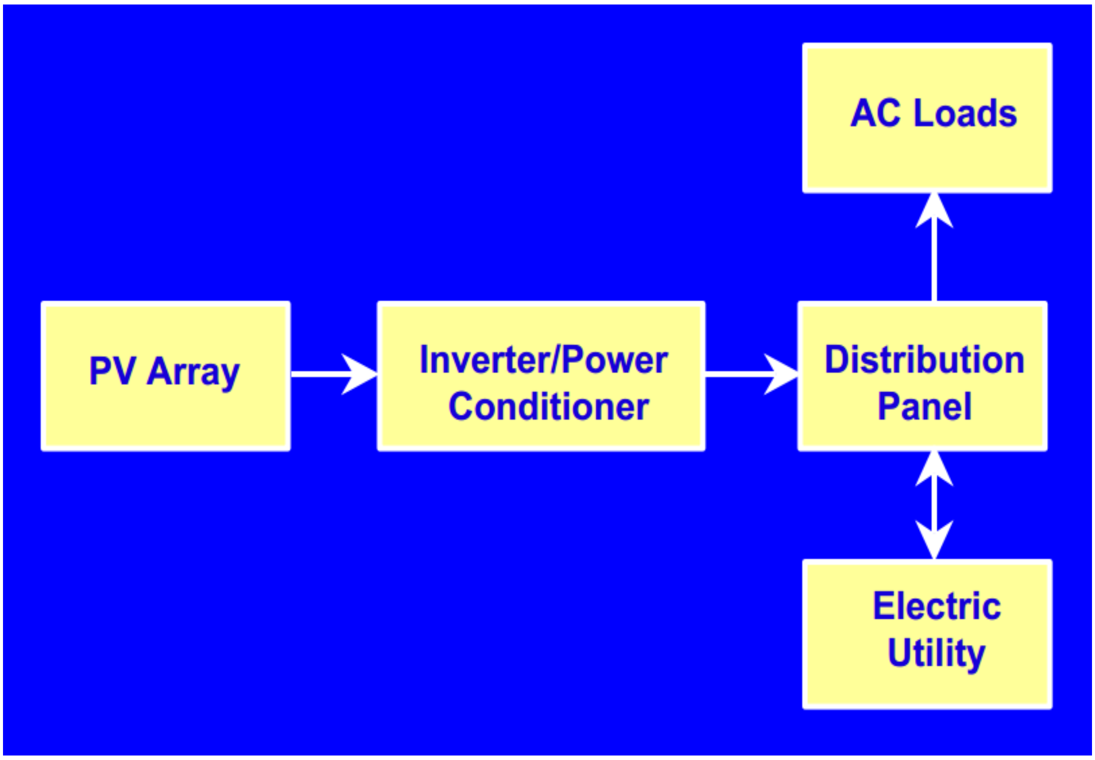

Figure (2.8): Simple Utility-Interactive PV System [30]

2.2.3 Utility Interactive with Battery Storage

Specifications:

- Can operate either in interactive or stand-alone mode, but not simultaneously.
- PV, inverter and battery subsystems interface between the customer's main service panel and dedicated load subpanel.
- In interconnected mode, excess PV energy not required for battery charging is inverted and supplements on-site loads or is sent back to utility.
- When the grid de-energizes, inverter isolates from grid and powers load subpanel directly from batteries, similar to a UPS system.

See figure (2.9) which shows the Utility Interactive with Battery Storage System.

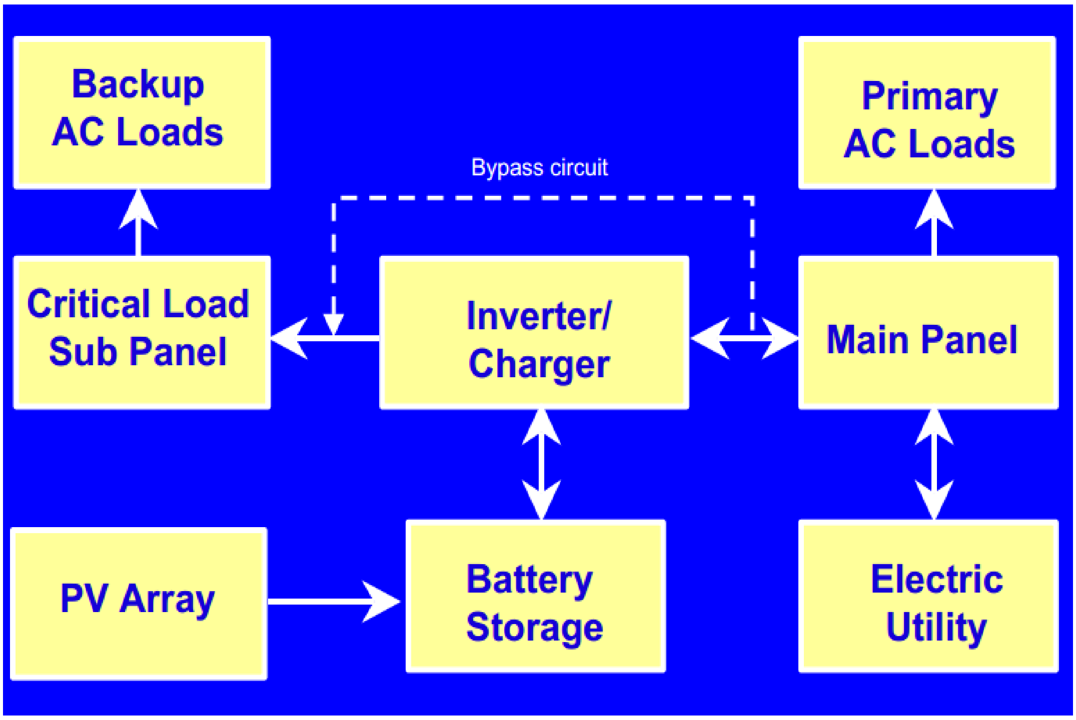

Figure (2.9): Utility Interactive with Battery Storage PV System [30]

2.3 Elements of Grid Tied PV System

Introduction

Photovoltaic (PV), or solar panels, are made from a semi conductive material and utilize the energy from the sun to produce electricity. This electricity is DC, whilst the majority of appliances and the electricity grid are AC. Thus a PV system is usually connected to an inverter which converts DC to AC. [49]

The Grid-Tied PV elements are very special due to the situation of solar potential which depends on the availability of the sun and the amount of power that comes from the sun to the PV system.

The generated power from Grid-Tied PV systems has great potential to be of assistance to NSP’s. With PV in the grid, transmission losses are reduced because the power can be supplied closer to the loads, thus less current flows along the lines and ohmic losses are reduced ($P_{loss} = I^2R$). Furthermore the power produced by the PV has the potential to reduce peak loads and thus delay line upgrades, resulting in economic benefits for NSP's. [49]

There are two types of Grid-Tied systems; one depends on storage system and the other doesn't have a storage system. The difference between them is that the one which depends on the storage system needs a Charge to control the income and the outcome energy from the PV modules to the storage system and the output from the storage system.

The total components and subsystems that, in combination, convert solar energy into electrical energy suitable for connection to utilization load. See in figure (2.10) the total components.

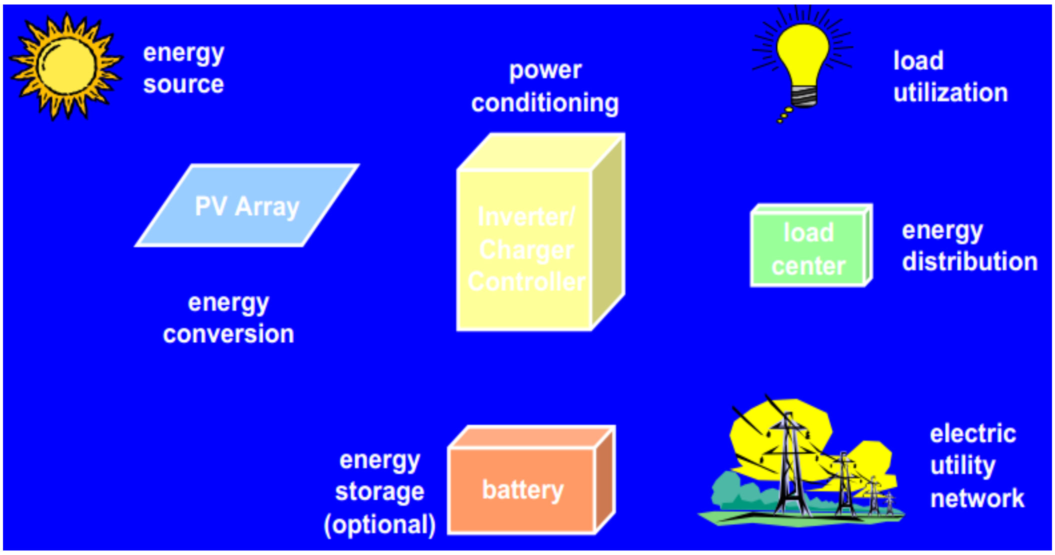

Figure (2.10): Total PV system Components [30]

2.3.1 PV Generator

Photovoltaic cells are connected electrically in series and/or parallel circuits to produce higher voltages, currents and power levels. Photovoltaic modules consist of PV cell circuits sealed in an environmentally protective laminate, and are the fundamental building blocks of PV systems. Photovoltaic panels include one or more PV modules in one package. A photovoltaic array is the complete power generating unit, consisting of any number of PV modules and panels. See figure (2.11) which shows the PV cell, module and array.

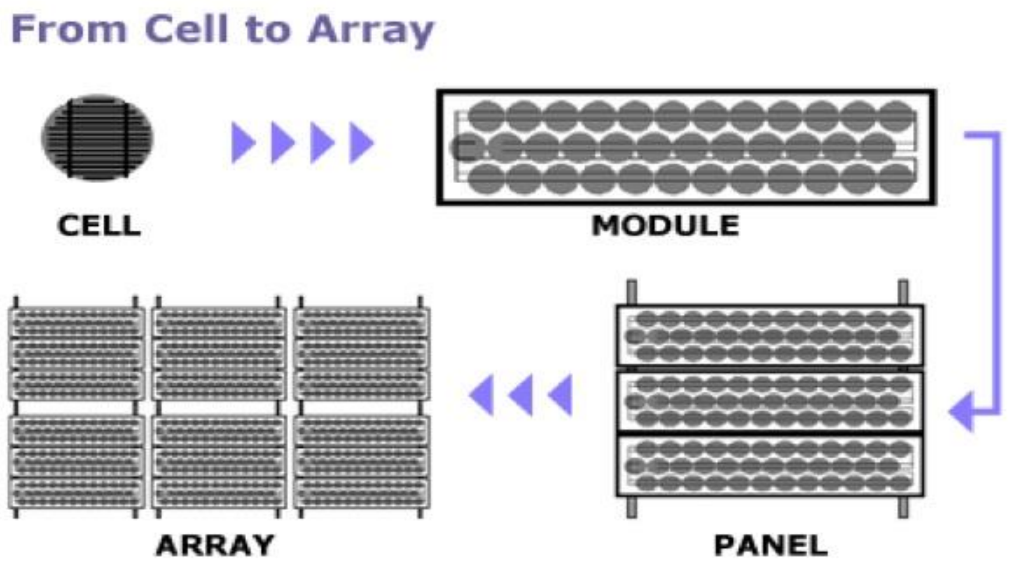

Figure (2.11): PV from Cell to Array [32.c]

2.3.2 Grid Tied Inverter

The Grid-Connected Inverters convert the direct current (DC) power provided by an array of PV modules to alternating current (AC) power compatible with the electric grid, See figure (2.13).

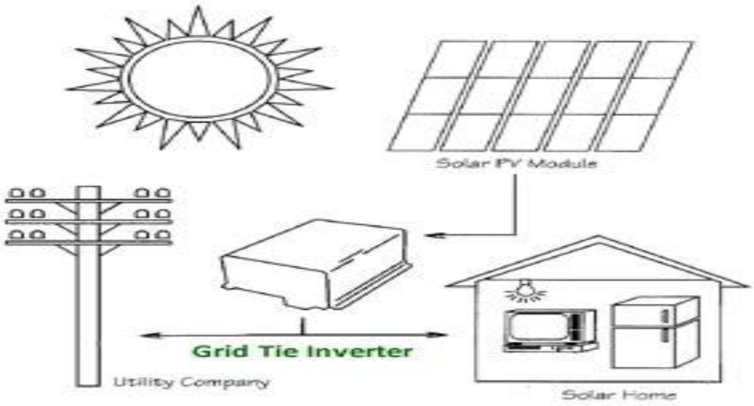

Figure (2.12): Grid-Tied Inverter [36]

These Inverters have special properties that differ from the normal Inverters in the operating situation and the capability of this Inverter to respond the variation in the solar potential and the variation in the electric grid.

The main difference between a standard power inverter and a grid tie power inverter is that the latter also ensures that the power supplied will be in phase with grid power. On the PV side which is the DC side, the power output of a module varies as a function of the voltage in a way that power generation can be optimized by varying the system voltage to find the maximum power point. Most inverters therefore incorporate maximum power point tracking (MPPT). [36]

Grid-Tie inverters are also designed to quickly disconnect from the grid if there is a fault in the electric grid, the grid tie inverter will shut down to prevent the energy from transferring to the grid and sometimes the leakage from the PV system to the grid could cause injuries to the electricity fixing technicians. [38]

2.4 PV System Applications in Palestine

This section will talk about two of PV projects that are installed in two villages in the West Bank. These projects implemented by the Energy Research Center ERC at An-Najah National University. This section will also talk about the PV station in Jericho which is implemented by the Japanese Government in Jericho, West Bank.

2.4.1 Emnazel Solar Electrification Project

Lighting project of Emnazel village which lies south of Yatta in Hebron is executed by installing solar system central (solar cells) with capacity of 13 kW, which is the largest project that is being implemented by the Energy Center for generating electric power through a system of solar cells central to feed the entire village.

The village is located to the south of Yatta, near the wall, with population of nearly 400 people, and there are approximately 40 beta. It has a school and a mosque, and suffers from the lack of infrastructure such as water and electricity. Moreover the electricity service was not available in the village and it was in total darkness during the last period. Electricity was supplied to the voltage on Thursday, 18/12/2009 for the first time, through a system of centralized solar cells that were connected to the electricity generator to help charge the batteries in the event of a lack of shipping - solar cells.

This project was implemented by the Center and in collaboration with CEBA Foundation, TTA, Spanish art, and with the support of the Spanish government - the Spanish Cooperation Agency, and with the participation of the Community Service Center at An-Najah University, the Energy Authority PEA and Southern Electricity Company SELCO.

The project is the second of its kind to be implemented by the Energy Research Center at the university, where the project was implemented first in the village of compassionate - the northern West Bank by lighting 25 house, a school and a mosque, and there are proposed projects at the Center for the use of renewable energies in other projects, including the use of solar energy to feed the other small villages, and communities far from the electricity grid, or that cannot be fed through the traditional voltage. [25]

2.4.2 Attuf Solar Electrification Project

The Attuf village is located to East of Tammoun village in Tubas district, West Bank. It has a population of about 120 people living in 22 houses. Until a few months ago, a diesel engine with capacity of 20 KVA that worked for 4 hours a day was feeding the electrical loads in the village, consisting of the houses, a mosque, a school and street lighting.

As a result of high fuel prices (diesel) in the recent years, the village was not able to buy fuel to run the diesel generator. So, it was deprived from an electricity source. So a study of the village’s electrical loads was done by the Energy Research Center at An-Najah University, which as a result has designed a central solar system to feed the entire village through solar cells. A project proposal was presented to the Spanish government to illuminate the entire village by solar cells. Funding was approved for the project in cooperation with the Foundation for SEBA - Spanish, with installation of the system's ability 12KW with all the necessary batteries, battery charger, adapter DC to AC, organizer shipping and all it takes. The implementation of the project was completed in October 2007, and since then the whole village has being fed by a system of solar cells around the clock, without any significant problems. [25]

2.4.3 Jericho PV station

The PV station in Jericho is an introduction of clean energy by solar electricity generation system in Palestine. It was implemented by Japan International Cooperation Agency. This station has a PV capacity of 300 kWp, and it is connected to the distribution network in Jericho under JDECO electrical network. [25]

This station is this thesis study case, so it will talk about this station in the study case chapter.

2.5 Palestinian Solar Initiative (PSI)

Renewable energy is an appropriate option for serving Palestine energy’s needs. Therefore, PEA set a forth renewable energy strategy to encourage RE deployment in Palestine. The Palestinian government had set a goal in which 10% of electricity generated in Palestine is going to be generated through renewable resources by the year 2020. With the expected growth in electricity consumption in Palestine, RE facilities are needed to help achieve security of supply [15].

As part of the overall RE strategy, the Palestinian Solar Initiative (PSI) aims to achieving a target of 5 MW RE generations by 2015, through installing PV panels on the rooftops of Palestinian households. The initiative will include capacity building and training component for all relevant stakeholders and the preparation of required detailed studies and documents necessary for the implementation the overall RE strategy.

The rationale behind PENRA's solar initiative is as follows:

- Spreading the technology and know-how within the Palestinian society.
- Getting international accreditation in the global RE society through hosting a "loud" kick off for the initiative.
- Encouraging the Palestinian people to use RE technologies, namely PV panels, this will drive their prices down.
- Achieving environmental benefits resulting from the reduction of Carbon Dioxide emissions in Palestine.
- Achieving political benefits through gaining independence from Israel energy sources.
- Building the Palestinian people RE knowledge and capacity in order to be able to produce PV panels locally in the future.

The RE strategy identified the different renewable technologies that can be exploited in Palestine in 2020. This table [Table (2.1)] explain the RE strategy up to 2020.

The initiative CAPEX assumptions for 5kWp standard installations are shown in Table (2.2).

Based on the base case scenario, the required FIT will amount to roughly ILS$0.54/kWh$. This will result in an IRR of 8.75% and approximately USD$9.2k$ of net income for each participating household over the 20 year project life time [15].

Table (2.1): RE Strategy up to 2020 [15]

RE Technology	**Capacity (MW) by 2015**	**Capacity (MW) by 2020**
On ground PV	5	25
PV small	5	20
CSP	5	20
Biogas landfill	6	18
Biogas animal	0.5	3
Small-scale wind	1	4
Wind mills	2.5	40
Total	25	130
Palestine Solar Initiative		
location		Installed Capacity (MW)
North West Bank		1.5
Central West Bank		1.5
Southern West Bank		2
Total		5

The Palestinian solar initiative will towards a substantial reduction in Carbon Dioxide emissions whereas the total avoided cost of Carbon Dioxide is projected to total approximately USD 0.5m over 15 years [15].

Table (2.2): The Initiative CAPEX Assumptions for 5kWp [15]

Assumptions for 5kWp	
Load hours PV (hours)	1,500
MW capacity PV	5.00
Number of household	1,000
Cost 1kWp (USD/kWp)	3,200
Size of PV per household	5
Subsidy splits	
Investment subsidy USD/kWp	1,500
Investment subsidy program in USD	7,500,000
Subsidy	47%
Investment subsidy household in USD	7,500
Total cost Per Initiative in USD	16,000
Investment per household after subsidy in USD	8,500

Chapter Three

Grid tied PV System and Distributed Generation Photovoltaic Systems

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Grid tied PV System and Distributed Generation Photovoltaic Systems

Introduction

Due to the wide spread use of distributed generation (DG), which is defined as small scale power generation located at or near to the load being served, several system operating issues have come into sight. These concerns involve both the benefits of using DGs and the problem associated with the wide implementation of DG units in a well-established system for several decades [37], See figure (3.1) and figure (3.2).

Distributed generation (DG) technologies can provide energy solutions to some customers that are more cost effective, more environmentally friendly, or provide higher power quality or reliability than conventional solutions. Understanding the wide variety of DG options available in today’s changing electric markets can be daunting. Some of these DG technologies offer high efficiency, resulting in low fuel costs, but emit a fair amount of pollutants (CO and NOx); others are environmentally clean but are not currently cost-effective. Still, others are well suited for peaking applications but lack durability for continuous output. With so much to consider, it is often difficult for decision makers to determine which technology is best suited to meet their specific energy needs. [38]

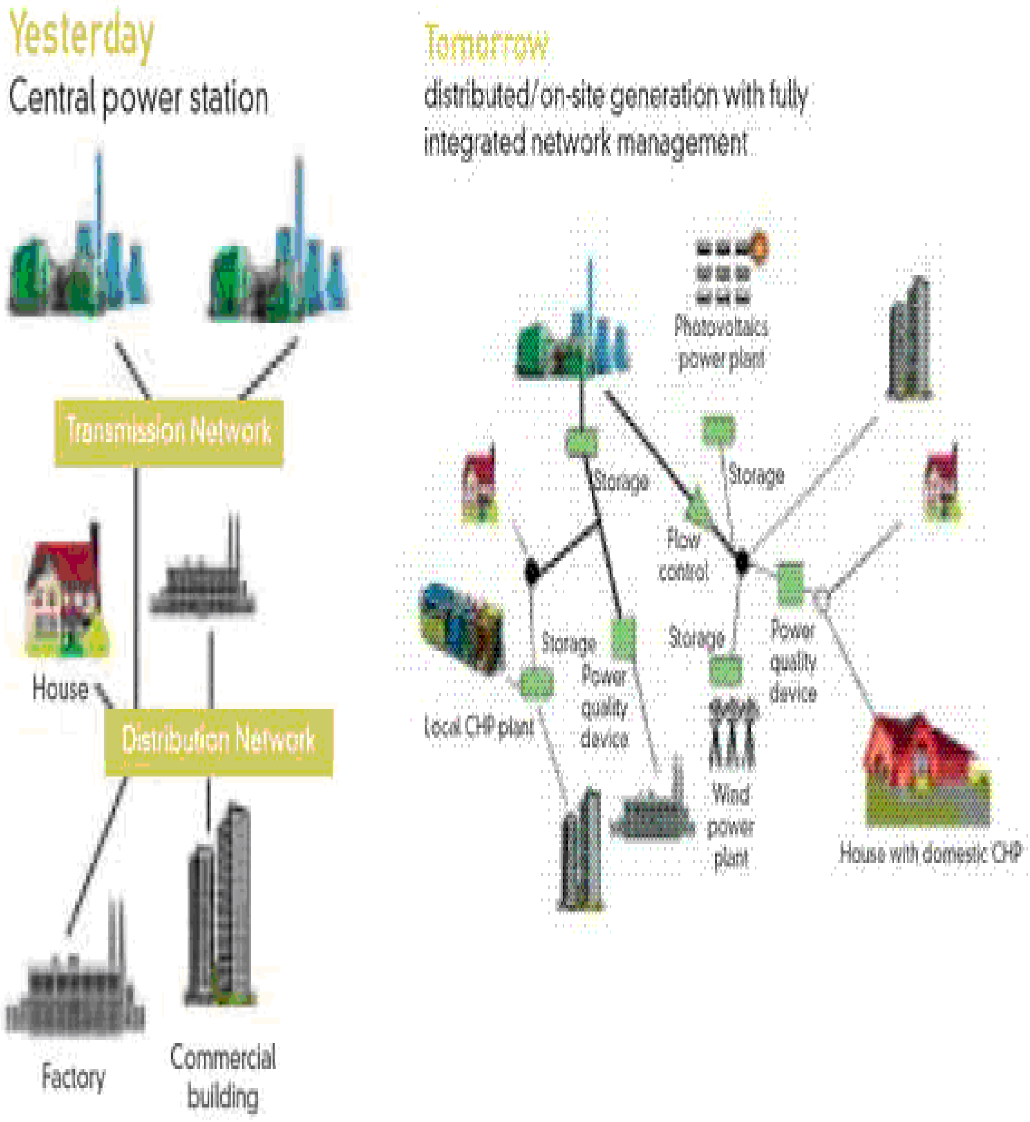

Figure (3.1): From Central Power System to Distributed Generation Power System [37]

This chapter discusses the concept of distributed generation systems, the advantages, disadvantages, the applications of these systems in renewable energy sector and the impacts of installing distributed generation renewable energy systems to electricity network. It will concentrate on the grid connected PV systems. These systems are the most common DG systems in Palestine recently.

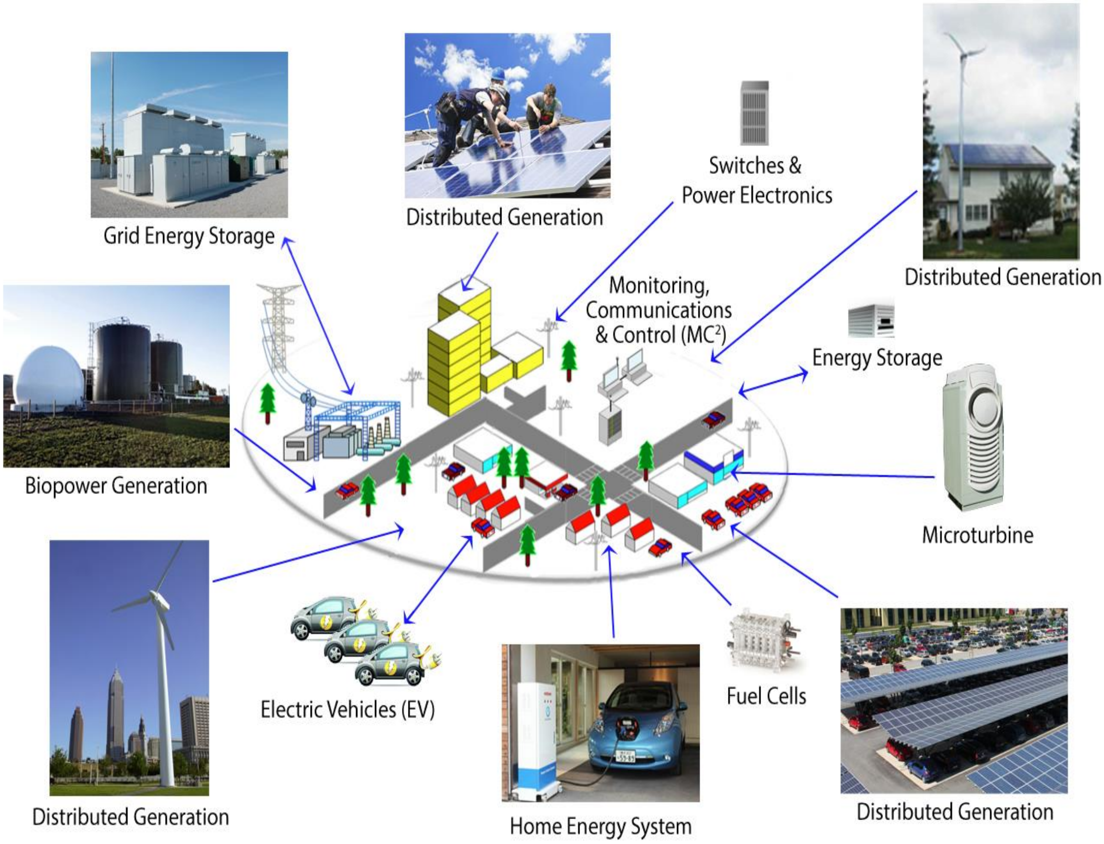

Figure (3.2): Different Distribution Generation Systems

3.1 Concept of Distributed Generation

Distributed generation is an electric power source connected directly to the distribution network or on the customer side of the meter. The distinction between distribution and transmission networks is based on the legal definition. In most competitive markets, the legal definition for transmission networks is usually part of the electricity market regulation. Anything that is not defined as transmission network in the legislation can be regarded as distribution network. It should be noted that the definition does not specify the rating of the generation source, as the maximum rating depends on the local distribution network conditions, e.g. voltage level. Furthermore, the definition does neither define the area of the power delivery, the penetration, the ownership nor the treatment within the network operation as some other definitions do[38], The Palestinian Power System divided the grid to transmission line on 33 KV nowadays and in the future it will be 161 KV, and the distribution system begin from the transformation power transformer stations 33/11 KV through multiple of 11 KV lines to many of distribution transformers that feeds customers grid by 0.4 KV electricity.

Unlike central station power plants, which are typically located far from load centers, distributed generation produces electricity at or near the place where it’s used. Distributed generation technologies can run using fossil fuels, renewable energy resources or waste heat. Equipment ranges in size from less than a kilowatt (kW) to tens or, in some cases, hundreds of megawatt (MW).

The concept of implementing small generation in the distribution system has been in practice for several years as backup, standby, and stand-alone generation. However, as a result of the new modern technology achieved in the generation industry and the benefits expected from this technology implementation, a widespread use of these DG units operated in the system has become a fact. The premise of DG is to provide electricity to customers at a reduced cost and a higher efficiency, especially if the proper technology is implemented for its application, such as use of combined heat and power technologies. Other benefits that DG could potentially provide are: reduction of the system power loss; increase of system reliability; reduced emissions; improved power quality; and deferral of transmission or distribution upgrades. [37]

On the other hand, a lot of problems have been created due to DG integration into the system. These problems are complex and have many related aspects that have to be studied thoroughly.

Distributed generation can meet all or part of a customer's power needs. If connected to the distribution or transmission system, power can be sold to the utility or a third party. Some technologies also provide heat or steam for use at or near the site. Customers, utilities and independent power producers can develop and operate distributed generation systems. They can be located at a customer's site or otherwise near customer loads.

With people attention to sustainable development and environmental pollution, distributed generation DG technology with its unique environment and economy, raises more and more concern. The rapid development of DG technology results in large-capacity distributed power connected to the grid. However, DG affected by natural conditions cannot output power continuously and stably. Moreover, DG is usually incorporated into the electric power system at the distribution networks side, which will cause the system stability problems to be increased. In order to fully play the role of distributed power, avoid the adverse effects of its existence, it is necessary to study in depth on DG and the technology of its connected to the grid. [40]

There are two important goals behind using the DG RES:

- Increase the security of energy sources and decrease the dependency on importing fossil fuels like natural gas, oil and coal.
- Reduce the emissions of gases specially carbon dioxide that dangerously affect the environment, which is known as Green House or Global Warming.

Presently, the impact of DG on the electric utility is normally assessed in planning studies by running traditional power flow computations, which seems to be a reasonable action, since the penetration ratios of the DG are still relatively small. However, as the installed capacity of DG increases, its impact on the power system behavior will become more expressed and will eventually require full-scale detailed dynamic analysis and simulations to ensure a proper and reliable operation of the power system with large amounts of DG. [39]

The traditional electrical grid was built many hundreds of years ago. It was planned and designed to feeds unidirectional flow. The main problem of DG integration to the power grid is that: the classic electrical power system have been designed vertically from the highest voltage level (Power station) to the lowest voltage level (customer point), in unidirectional feeding system. It didn’t take in mind that one day in the future these grids will be connected to on gird DG system and reverse power flow may occur. So, the system will convert to bidirectional system, and with growing penetration of DG on the grid, the power flow will become more complicated since many issues had to be reviewed like: voltage rise, reverse power flow, protection calculation and schemes, sizing of conductor and transformers.

3.1.1 Advantages

Many advantages had been considered about the distribution generation systems, there are some terms:

- Simple to install
- High efficiency
- Reliable, reliability improvement
- Flexible
- Decreasing transmission losses.
- Avoidance of overcapacity, eliminating the unnecessary transmission and distribution costs. Reduce maintenance investments.
- Peak load reduction
- Reduction of grid losses
- Power quality support

DG facilities offer potential advantages for improving the transmission of power. As they produce power locally for users, they aided the entire grid by reducing demand during peak times, by minimizing congestion of power on the network and by building large numbers of localized power generation facilities rather than . few large-scale power plants located distantly from load centers. DG can contribute to deferring transmission upgrades and expansions at a time when investment in such facilities remains constrained. DG technologies may improve the security of the grid. Decentralized power generation helps reducing the terrorist targets that nuclear facilities and natural gas refineries offer, and in the event of an attack better insulate the grid from failure if a large power plant goes down. DG technologies may provide benefits in the form of more reliable power for industries that require uninterrupted service [41].

In addition, the DG technology is environmentally friendly, due to that most of the DG systems are from renewable energy sources. But the initiation of these systems is not environmentally friendly, as the formation of PV cells is from the crude silicon.

3.1.2 Disadvantages

- The initial investment in RE systems is often larger than for non RES
- Specific requirements of the site for power generation
- The availability of renewable energy (sun, wind, water) largely determines the feasibility of RES.
- The unpredictability of RES also means a higher cost for balancing the electricity grid and maintaining reserve capacity.

- Negative impact on the electricity grid at high penetration level and impact the power quality of supply which is a big concern for the NSP’s at the integration points. [24]

3.1.3 Electrical Connection of DG

Any system that produces even small amounts of electricity can be potentially dangerous, creating the possibility of electrocution and fire hazards. Improperly installed systems will create serious safety hazards to property owners, their friends, family, employees and local electric distribution company workers.

Before installing any type of distributed generation, whether it stands alone or is connected to the grid, it is important to understand the safety requirements. The safety regulations, the codes and the associated safety technical standards can be confusing and difficult to understand. This guideline is intended to simplify these and provide basic safety advice to home, farm and business owners who are considering the installation of Inverter-Based Micro generation systems. Also, the connection of DG differs from type to type of the DG. The table below (table (3.1)) describes four categories of distributed generation.

Table (3.1): Categories of Distributed System

Generator	Classification Rating
Micro	< 10 kW
Small	(a) < 500 kW connected on distribution system voltage
	(b) < 1 MW connected on distribution system voltage
Mid-Sized	(a) > 500 kW connected on distribution system voltage
	(b) >1 MW < 10 MW connected on distribution system voltage
Large	> 10 MW

The simple design of a distributed generation system is shown in figure (3.3).

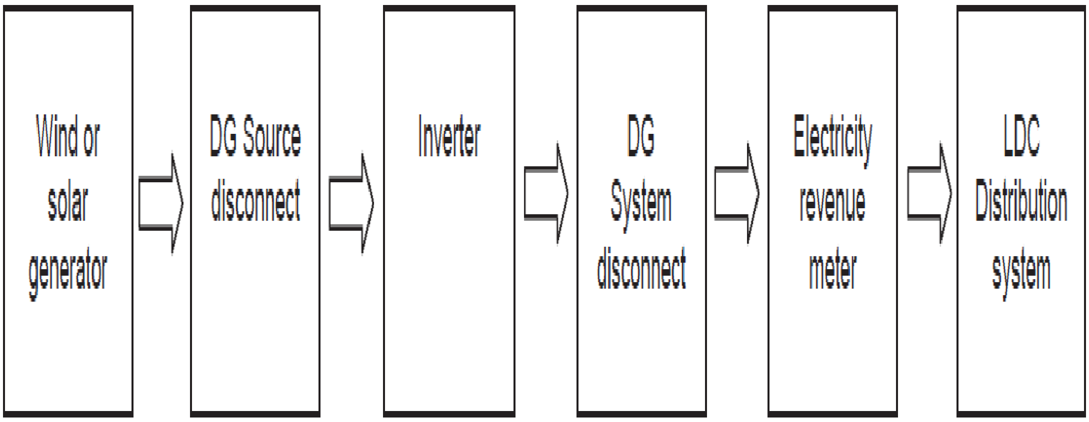

Figure (3.3): DG Block Diagram

There is more information about the electrical connection to the grid which is shown in Appendix (D).

3.2 Grid Connected PV Systems

Introduction

The previous chapter discussed briefly the grid connected PV systems, but this section will discuss the grid connected PV in details. The following paragraphs are an introduction to the grid connected PV systems.

They represent the distributed generation PV systems and the configurations of PV systems that are related to the distribution network.

The grid connected PV system is the simplest method of connecting a system to the electricity grid and it is, in most cases, the easiest method to install. In a normal grid-tied system, solar energy is converted by solar modules into DC electricity, which flows into a grid connected Inverter, being converted into alternating current (AC). The inverter then synchronizes the voltage and frequency with that from the grid, and the electricity can be used at home by standard appliances or fed through a meter, back into the electricity grid.

The grid connected systems will only generate electricity if the electricity grid is available to feed electricity to the home or business. The grid connected Inverter is the system component that interacts with the grid, and is programmed to shut off if there is a grid power failure, and break in the flow of electricity to the grid. In other words, if the grid goes down, the system will shut off. This is a legal electrical code requirement. This is primarily for safety reasons; if a utility employee is servicing a line that they believe has no current, and a private solar system is sending electricity into the grid, it could result is an extremely hazardous situation.

The main difference between a Grid-Tie system and other systems is that there are no batteries, making the system less expensive, simpler to install, and more efficient overall. Grid-Tie systems require little ongoing maintenance, cost less than more complex systems, and are highly reliable.

There are advantages and disadvantages of the grid connected PV systems, and they are shown in table (3.2).

Table (3.2): Advantages and Disadvantages of the Grid Connected PV [41]

Advantages of Grid Tie PV	Disadvantages of Grid Tie PV
High System Efficiency, due to simple system design	There is No Backup Power: The system will not delivering any power during the grid's power failure
Its configurable and low complexity maximizes the efficiency of the system	Sun doesn't available all the time
High System Reliability, due to Fewer system components decrease the risk of component failure	No continuous solar radiation, due to the clouds that decrease the quantity of the radiation (diffused solar radiation)
Cost is low, due to the simple system configuration makes installation easier and faster than other systems, lowering overall cost	
The PV systems eligible for a Power Purchase Agreement (PPA): Grid-Tie systems can be metered separately, and thus qualify for a PPA	

3.2.1 Positive Impacts of On Grid PV Systems

There are many benefits that affect the power system from the integration of distributed PV systems. One of these benefits is related to the environment due to the clean electricity which is generated from the PV, which means no carbon dioxide is being produced from generating electricity from the PV. If we assume the diesel generators operate at 0.26l/kWh and produce 1.22kg/kWh of carbon dioxide emissions. If we take that the monthly average consumption of electricity in Palestine is 260.0 kWh in 2012 (from chapter one). To feed the household by electricity from conventional electricity supply using diesel, it will produce about 317 Kg of carbon dioxide.

The second benefit consists of the peak load shaving, the closeness of PV systems to the load, and the peak solar radiation which means peak electricity generation from the PV, that almost at the same time, so large PV generation systems can take share of the peak load with the utility. If the peak load occurs during sunlight hours then the PV systems will have an effect in reducing this peak demand and thus assist the utility in operating the network more efficiently. As the utilities need to design the size of their networks and generation for the expected peak system loads (and some margin for potentially higher loads than this) and in order to ensure reliable and secure delivery of power to customers, there is considerable potential value in strategies to reduce peak loads (more specifically peak loads as a proportion of average load) so that the network is used efficiently throughout the day, rather than having a large amount of infrastructure used near full capacity for only a small proportion of the time. So, here we can feel the benefits of integration PV to the grid.

The transmission losses (real losses) are reduced as the consumed power is generated closer to the load (in most cases). There is a peak load reduction, thus allowing supply utilities to delay line upgrades resulting in economic benefits. PV systems generate renewable power and thus are seen to be a valid alternative source.

3.2.2 International Standards for PV Integration

Various factors must be considered when designing and installing a PV system to a distribution network. Gaudiness regarding the operation and equipment necessary to ensure compatible operation of PV systems and distribution networks can be found in IEEE and European standards.

Various factors must be considered when design and install PV systems to the distribution network.

Guidance regarding the operation and the equipment necessary to ensure compatible operation of photovoltaic systems and distribution networks can be found in IEEE standard 929-2000 “Recommended practice for utility interface of photovoltaic systems”. This specific IEEE standard contains information and restrictions for personnel safety, utility system operation, equipment protection and power quality.

The IEEE Standard 519-1992 “Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems” specifies the limits of harmonic voltage and current at the point of common coupling between end user and distribution utilities. The approach adopted in this standard requires the participation of both end users and utilities. The limits established by this standard are equal to 5 % for the voltage and current total harmonic distortion that the producer can provide to the customer. The limits for the maximum individual harmonic components are also determined and must be 3 % for voltage lower than 69 kV.

According to the European standard EN50160 (IEC 50160), accommodated by most European Grid Codes, “Voltage characteristics of electricity supplied by public distribution systems”, the limit for total harmonic distortion should not exceed 8 %, including up to the 40th harmonic.

The European standard EN 61727 (IEC 61727) “Photovoltaic (PV) systems - Characteristics of utility interface” has established more restrictive limits for voltage and current harmonics. The limits proposed for harmonics are 2 % for total voltage harmonic distortion and 5 % for total current distortion. The maximum for individual voltage harmonics is also limited and must not exceed 1 %. [42]

Moreover, the tables below show some other standards for installing grid connected PV systems.

Table (3.3): Grid Connected PV Systems Standards [43]

IEC 60364-7-712	Electrical installations of buildings - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems.
IEC 61727	Photovoltaic (PV) systems - Characteristics of the utility interface.
IEC 61683	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency.
IEC 62093	Balance-of-system components for photovoltaic systems - Design qualification natural environments.
IEC 62116	Test procedure of islanding prevention measures for utility-interconnected photovoltaic inverters.
IEC 62446	Grid connected photovoltaic systems - Minimum requirements for system documentation, commissioning tests and inspection.

The next tables show the one standard for rural electrification of small PV or hybrid renewable systems.

Table (3.4): Recommendations for Rural Electrification [43]

IEC/TS 62257-1	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 1: General introduction to rural electrification.

3.3 Integration Issues of on Grid PV Systems

Due to the limited time to provide electricity from the PV generation system and the installation problems of PV like; the wrong tilt angles, wrong orientation; the shadowing on the panels and the high temperature, so these will provide a decrement in the outputs of the PV leads sometimes to take the PV system down, if there is a significant effect.

The stability of the distribution network's system depends on the voltage and the frequency. If there is a rise or fall in the value of voltage or the frequency, the system will be unstable and that will influence the quality of supply to the end user leading to significant problems. The PV generation system could be bidirectional which means if the unstable conditions occur then the electricity will go to the PV system and this will take the PV system down.

The integration of PV systems into the grid will affect the quantity of the voltage, due to the variability in the solar radiation. Besides, the PV output power will affect the power factor because the real power is only provided from the PV. The harmonics in the transmissions will occur as a result of the integration of PV due to the existence of inverters which generate harmonics. These are some integration issues in the distribution network by PV systems. There are many other issues and these issues will be discussed in this section.

3.3.1 Voltage Levels Consideration

Integrating PV into the network has the potential to bring voltage rises at the load end of the feeder. PV can influence the voltage level due to its apparent reduction in load. The PV systems reduce the current on the lines when they are generating, thus leading to smaller voltage drops across the feeder. The voltage drops on a feeder are given by:

Voltage rise at the load end of a feeder is accentuated when the PV systems cause back feeding on a feeder, i.e. current flow is from the load to the substation. In order for current to flow towards the substation the voltage at the load needs to be higher than the voltage at the substation. Obviously the more current that is being back fed (i.e. the higher the penetration of PV) the higher the voltage must be at the load to facilitate this. Thus voltage levels can rise in an extreme way in the situation when load is low and generation is high. In this way PV systems can raise the voltage at the load potentially to the level at the substation by reducing the current to the feeder to zero [56-59]. See figure (3.4).

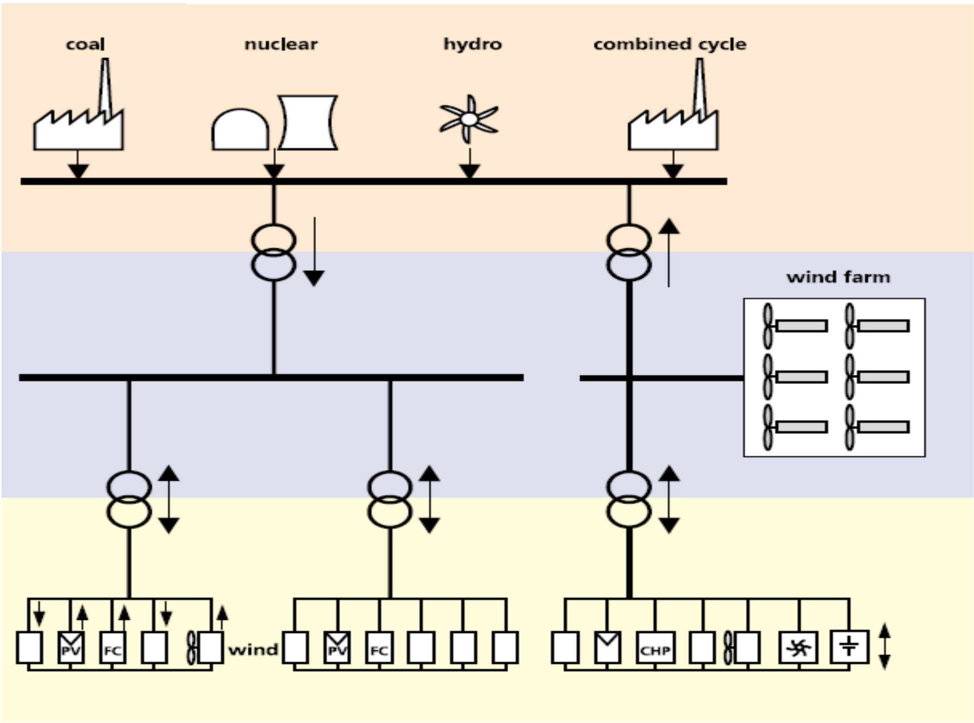

Figure (3.4): Distributed Generation Systems

3.3.2 Power Factor Consideration

The relationship between real and reactive power is represented by the right triangle shown in figure (3.5) where real power falls on the horizontal axis and reactive power rises on the vertical. The vector sum of real and reactive power is called apparent power, whose magnitude is the length of the hypotenuse and whose common unit of measure is the kilo-volt-ampere (kVA). Seen another way, apparent power is the total burden placed on the grid by the load from both its real and reactive parts [54].

In the figure below the cosine of the angle φ represents power factor at the fundamental power line. A lagging power factor is associated with an inductive load, while a leading one is indicative of a capacitive load.

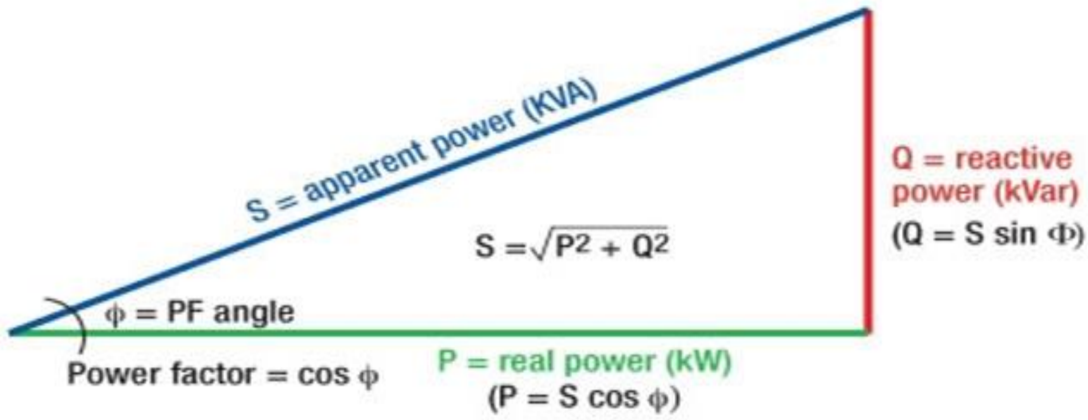

Figure (3. 5): The Relationship between Real and Reactive Power [54]

The power factor represents the degree to which the load is resistive with the ideal occurring when φ is zero degrees and power factor equals one, or unity [54]. At unity power factor, apparent power equals real power, reactive power is zero and the load is purely resistive in nature. If the load also contains reactive elements, reactive power will be non-zero and apparent power will exceed real power as shown in figure (3.5). Therefore, given two loads each consuming the same amount of real power, the one with the higher power factor will be more efficient and draw less circulating current than the other with the lower power factor.

The inefficiencies associated with low power factor require larger power plants and bigger transmission lines to generate and deliver the higher currents. For this reason, the utility must set minimum power factor standards in accordance with applicable tariffs to mitigate the problem. Non-conforming users with sub-par power factor may be penalized with higher rates [54].

Putting it all together having the basics covered, let's focus our attention on figure (3.6), which shows an example of a commercial load connected to the grid through the electric meter [54]. The meter shows that the load draws 1000kW of real and 450kVars of reactive power, which results in a respectable power factor of 0.91 as indicated by the triangle in figure (3.6).

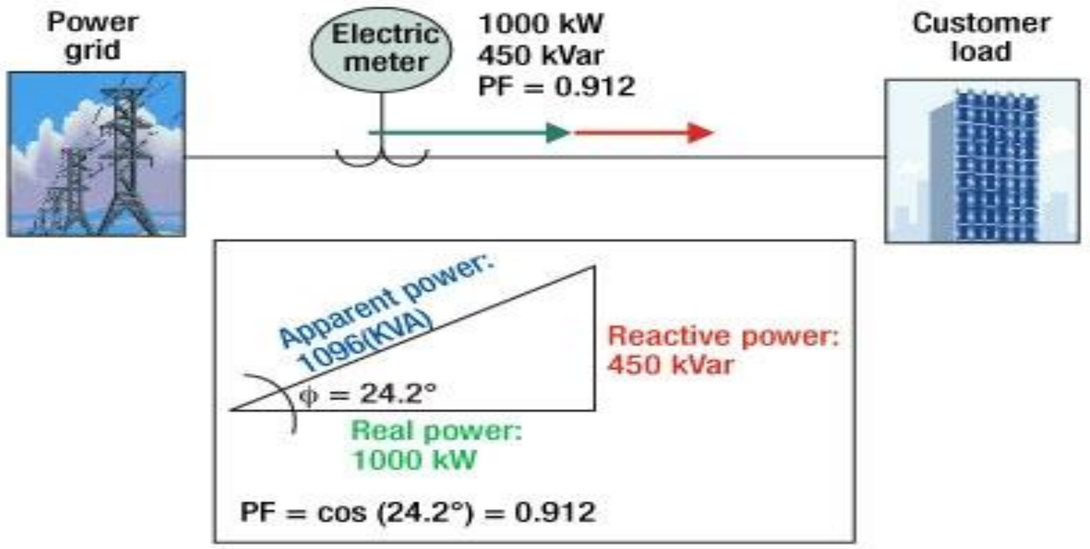

Figure (3.6): Utility power factor without grid-tie inverter (GTI) [54]

In figure (3.7), we have the same configuration except this time a large GTI unit displaces 50% of utility real power. In other words, the grid and GTI each feed 500kW to the load [54]. The meter now registers 500kW of real power and the full 450kVars of reactive power as well.

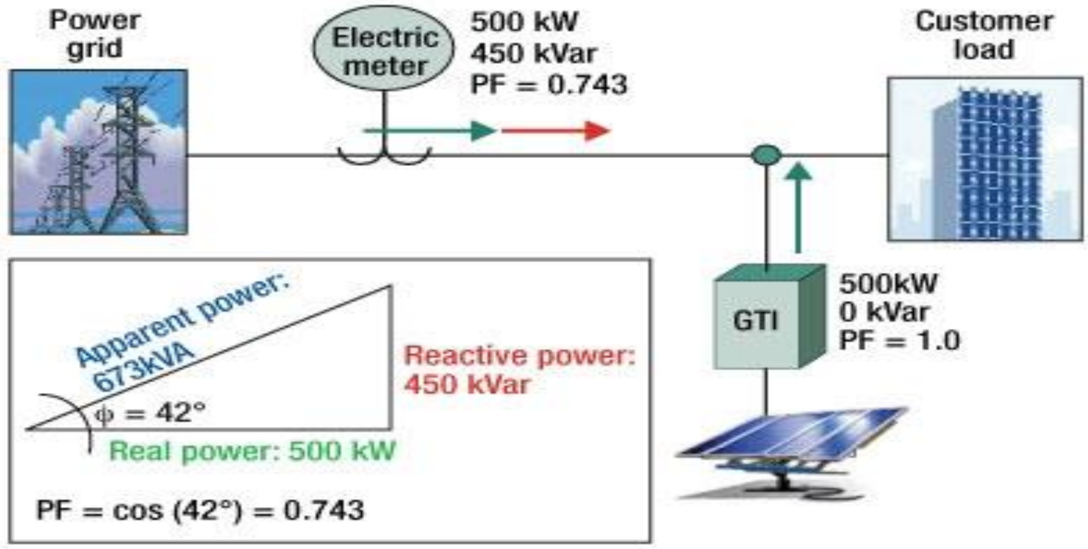

Figure (3.7): Utility power factor with grid-tie inverter (GTI) [54]

The power factor will affect directly with installing PV systems to the grid, due to the active power injected from the PV which has a unity power factor. As the installed PV is increased the power factor will decrease [50].

The majority of PV system inverters can only supply real power, which can be beneficial as it means the network doesn't have to supply this power. However the load still has a reactive component which must be supplied in total by the network. Thus with a large amount of PV systems the network is seen to be providing only reactive power .The effect of this poor power factor is mainly in grid losses in equipment such as transformers. Core losses in the transformer become significant due to the high proportion of the magnetizing current compared to the load current. This can cause an increase in transformer temperature and thus increase network loss. [57-59]

When PV system works with high power values close to rated ones, most active power demanded by the customers is supplied by the PV plant, reducing the demand of active power from the grid, but reactive power demand is the same, so it causes a low power factor measured at the substation [55].

3.3.3 Harmonics Consideration

The harmonics refer to the quality of the sinusoidal wave of both current and voltage. Harmonics occur at multiples of the fundamental frequency by the inverter when converting the DC power from the PV to AC power. The inverter injects harmonics which sometimes seem to be acceptable. However, when the number of harmonics increases, problems occur in the distribution grid.

Utilities have standards to minimize harmonics in the network as they can cause heating in equipment and can disrupt the operation of equipment connected to the network [56-59]. Harmonics are measured by total harmonic distortion .There are many nonlinear loads in the network which can be sources of harmonic distortion. Of particular interest is the potential for inverters (especially pulse width modulated (PWM) driven inverters) to produce current harmonics. Current harmonics are also caused by inverters as they try to synchronies their output voltage with the system voltage. The inverters may need to supply extra current to certain parts of the waveform to make the voltages synchronized, thus introducing current harmonics.

The harmonics are mainly negated due to harmonic filters on the output of the inverters, which can actually assist the network in absorbing harmful harmonics. However many older style inverters have poor harmonic filtering and can contribute significant harmonics to the network.

Additionally when similar converters are connected to the same feeder they have the potential to add, thus making the harmonics on the feeder quite large. This occurs mainly with the triple harmonics (defined as fundamental frequency multiplied by three); luckily the delta winding in most MV to LV transformers tend to attenuate the third harmonic. Harmonics in the grid can be either on the voltage waveform or on the current waveform. Harmonics on the voltage waveform have more potential to cause damage on the network and are more tightly regulated in the standards. They can cause disruption of sensitive equipment like audio and computer hardware. [56-59]

On the other hand current harmonics are also a major cause of voltage harmonics. Moreover, current harmonics cause extra system losses in equipment like transformers. This loss can be significant, causing excessive winding loss and abnormal temperature rise, potentially lowering the life expectancy of the transformer. The triple harmonics also cause excess current to flow in the system neutral wire which may be significantly underrated for this current to be flowing. This can cause damage to the network and will certainly result in extra system losses [57-59].

3.3.4 Solar Irradiance and Power Quality

One of the demands presented in all standards with regard to grid-tied PV systems is the quality of the distributed power. According to the standards in this field which will be discussed in the last section of this chapter, the injected current in the grid should not have a total harmonic distortion larger than 5%. [44]

Good power quality translates into obtaining a sinusoidal voltage and current output from a photovoltaic system in order to avoid harmonics, inter harmonics and eventually voltage distortion [43]. The efficiency and good operation of the grid connected PV systems are depending on many factors; the environmental conditions as well as the design of the PV system are the most important factors to the reliability of PV system. Moreover, these factors have significant effects to the power quality of the PV outputs. We can see that the variability in the output power of the PV systems depends on the variability of the solar irradiance, the temperature and the PV module's type of material. For example, the thin film (amorphous silicon) module has less response to the variation in temperature than the mono and poly crystalline modules.

With large amount of PV systems connected to the distribution grid and with low irradiance condition, there will be undesirable variations of the output power from the PV in both power components (voltage and current) at the point where the PV system is connected to the distribution feeder. These variations might exceed the limits of the grid.

The inverter's output has an effect on the power quality, when converting the DC power to AC power in low voltage networks the inverter increases the power quality problems due to the internal circuit of the inverter, even when the inverter works within the acceptable limits. The high sensitive electronic devices in the inverter might be damaged due to the low power quality condition.

In order to improve the performance of PV systems, many maximum power point tracking (MPPT) techniques have been developed. In most of these articles, the main goal was to supply the maximum available active power from PV to a grid without compensating the harmonic current and reactive power demanded by the load. Today, non-linear loads are widely used in residential and office buildings. These include computers, modern electrical products, variable speed drives and even normal fluorescent lamps. As a result, the power quality of the grid has been reduced (poor power factor and increasing total harmonic distortion (THD)). Conventional grid-connected PV systems require additional active filters to reduce THD and compensate reactive power [46].

There is a study to the power quality due to the low irradiance condition in [44] to a grid connected PV systems in Cyprus, figure (3.8) shows the circuit diagram of this system.

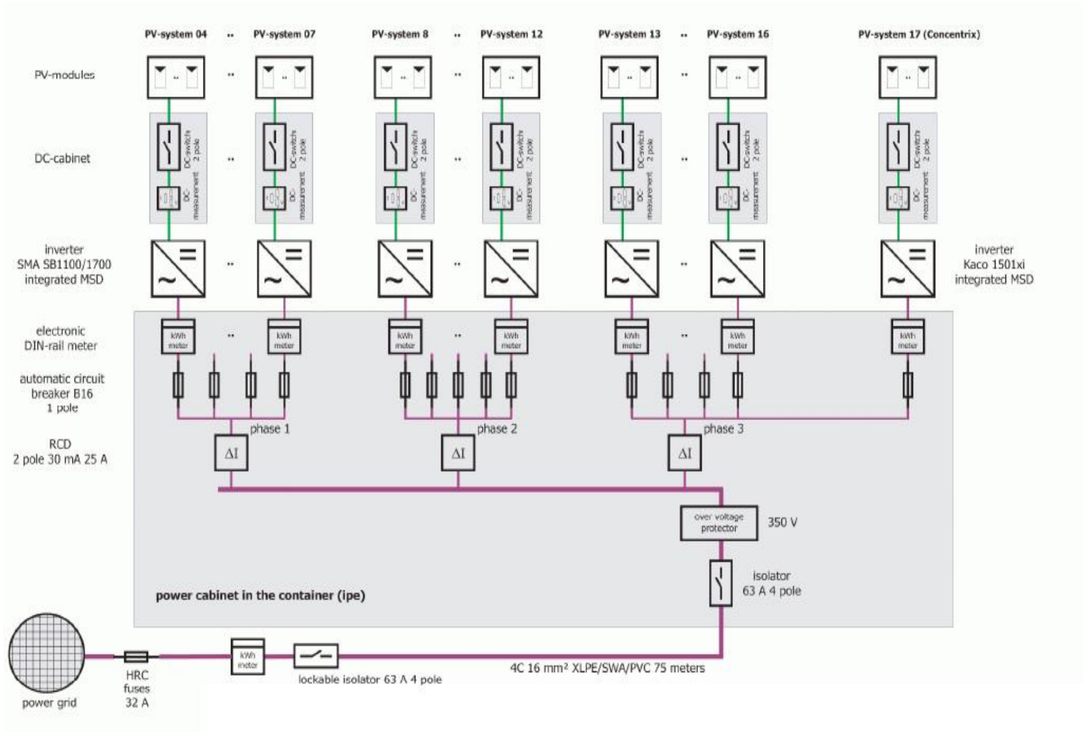

Figure (3.8): Circuit Diagram of Power System with Grid-Tied PV Systems [35]

The power quality quantities were correlated with instantaneous solar irradiance measured during a two week period. The results are shown in figure (3.9.a) and figure (3.9.e). The Voltage and Current THD are shown in figure (3.9.a) and figure (3.9.b) respectively. The results confirm the high harmonic content in the current waveform. The total voltage harmonic distortion THD measured at the output of the system is not strongly dependent on the fluctuations of solar irradiance (figure (3.9.a)), but the current harmonics, are very sensitive to changes of incident radiation. The total voltage harmonic distortion ranges from 1.5 % to 2.2 %, confirming the existence of an accurate control mechanism for voltage as shown in figure (3.9.a).

The current total harmonic distortion has a larger range of values, from 6% to 65% (figure (3.9.b)). The active power delivered to the distribution network has been found to vary linearly with changes of the solar irradiance incident on the PV modules as shown in figure (3.9.c). In contrast, the reactive power produced depends non-linearly on solar irradiance having higher values at low solar irradiance (figure (3.9.d)). Finally, the power factor behavior due to changes of solar irradiance is shown in figure (3.9.e). The power factor acts linearly for values of solar irradiance lower than 200 W/m² and stays close to unity for higher values.

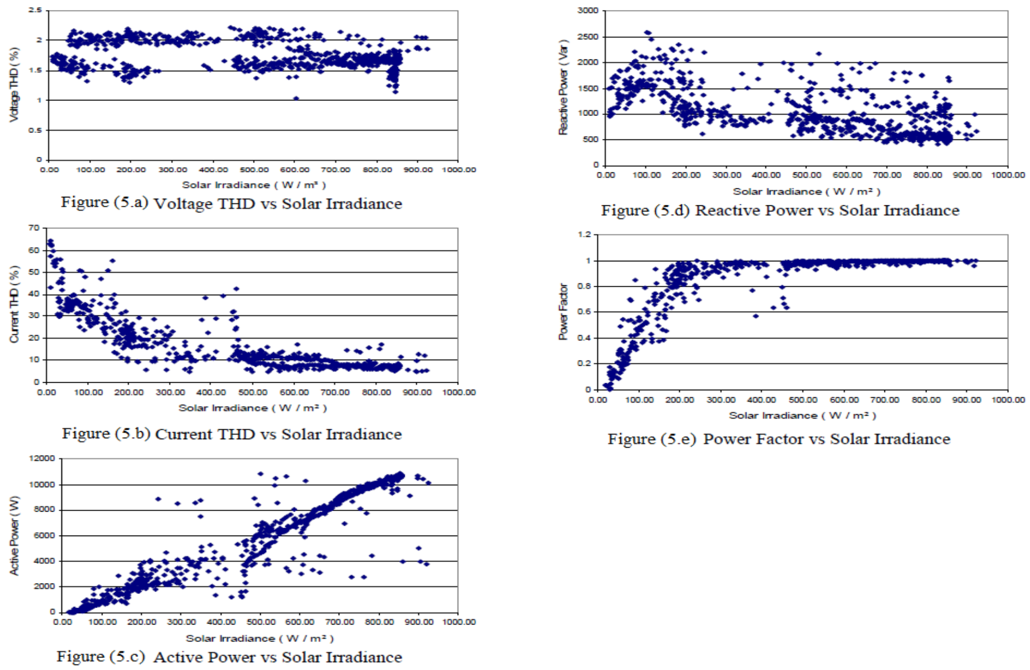

Figure (3.9): The results of Above Study [45]

3.3.5 Protection

The first protection problems related to the grid connected PV is the islanding. Islanding is a situation that happens when the centralized power plant is shut down and the grid voltage is maintained by the distributed generation connected to it.

Inverters have quite good islanding protection. The second protection issue associated with PV systems is the masking of short circuit faults. When a short circuit fault occurs in a distribution network a large current is seen by the protection devices. This current then activates the protection measures and the short circuit is isolated, unable to cause any more damage to people or equipment. [53]

When a fault occurs PV systems also respond to the short circuit fault current. Their individual respond is very limited as the inverter protection circuits only allow them to supply limited levels of current; however with high penetration their combined respond can be significant. In this situation the network protection process here can cause damage to the consumer's equipment.

Two islanding protection situations related to the inverter; passive if no voltage is detected outside the inverter, power is switched off and active by attempting to shift the frequency .If this is possible the grid is down. So a single line to ground fault is founded as it has the smallest fault current of all fault types. [53]

3.3.6 Conditions Affect the Outputs for Grid-Tied PV Systems

The unpredictable outputs of the PV system that could be according to the design mistakes or to the weather conditions are explained in these points below:

- Orientation of the panel: Ideally each solar panel should be oriented in Palestine to the south in order to align peak production with the peak solar radiation. Additionally, the panel should be titled at the correct angle according to the latitude. In Palestine, it must be around 32° as the latitude in Palestine. If these conditions are not met, the output of the panels will be restricted. This is entirely possible if the roof of the house is unsuited to PV installation.

- Shading over the PV system may be unavoidable on certain roofs and this will limit PV panel output.

- Many systems have underrated panels to make optimum use of the inverter

- Cloud cover will also limit PV output

- Solar potential is also different between seasons as the sun is father distance changes with the earth’s rotation. Thus in the winter months PV output tends to be less than in the summer.

- PV output is sometimes lowered in order to comply with limitations, due to stability conditions when the voltage decreased in the grid, the output voltage from the PV system must be decreased.

- The high ambient temperature, which will strongly affect the output of the PV if the difference in temperature is huge.

Chapter Four

Impacts of PV Penetration Levels on Distribution Networks

Chapter Four

Impacts of PV Penetration Levels on Distribution Networks

Introduction

Installing grid-tied PV systems to the national electricity grid is good and recommended to assist the self-electricity generation and exploiting the available renewable energy sources, especially the solar energy in electricity generation.

In the other hand, the installed PV systems must be restricted under conditions and standards to avoid the problems that could happen if a large amount of these systems are installed to the grid. The previous chapter mentioned some international standards about installing distributed generation systems to the grid. The literature review at the end of this chapter will talk about experiments worldwide with the high PV penetration.

The high penetration levels of on grid PV may have some negative impacts on the electricity grid; throw affecting the voltage, frequency and the power factor. To avoid these problems we have to investigate these impacts and find solutions such as: control the penetration levels according to acceptability of the grid and the related standards.

This chapter will discuss and investigate these impacts on the grid and integration issues, and present a literature review to the penetration of the distributed generation systems, the best penetration levels that will be suitable to the grid, how to control the penetration levels, how to synchronize the installed grid-tied PV systems with the grid and some experiments of dealing with penetration problems from countries have these experiments.

4.1 PV Penetration and Operations of On Grid PV Systems

4.1.1 Definition of PV Penetration

Photovoltaic (PV) system capacity penetration, or simply “penetration,” is often defined as the rated power output of the aggregate PV systems on a distribution circuit segment divided by the peak load of that circuit segment. See this equation of penetration.

$$PV_{penetration} = \frac{PV_{peakpower}}{PeakLoad_{apparentpower}} \qquad \text{(Equation 4.1)}$$

It is generally agreed that a conservative value to designate high penetration is the condition when the ratio of aggregate PV systems ratings to peak load exceeds 15% [47].The Penetration on the distribution network differs from one country to another, because of the differences in quality of the distribution network, the variation of peak demand, the network's ability to withstand with this penetration and as the PV system depends on the sun, also the network will take in consideration the variation of solar potential. The PV systems provide just real power which will affect the power factor in different degrees depending on the amount of penetration of the PV systems.

The penetration of PV systems could be in the low voltage level or in the medium voltage level. At the low voltage level the PV can be installed separately at different sides of the feeder, so the effects of PV on this feeder will be more effective and hard to deal with, because the PV installed in different places on the feeder, which means we must take in consideration each PV according to where it is installed. In addition, at low voltage level the PV will be close to the load which means that the impacts of PV will affect directly the load. On the other hand, installing PV at medium voltage level is more efficient, lower losses and we can deal with it as one block and the impacts will be limited at the connection point of this PV system to the grid.

4.1.2 Grid Operation with PV Penetration

The distribution grid suffers from the high PV penetration. So, the main challenge is to limit the impacts of the high penetration which is the current and future challenge worldwide.

Today, the energy from PV systems is difficult to predict, offers less controllability from the perspective of the grid operator and cannot be sufficiently buffered in existing storages. Since the existing distribution system was constructed to serve the local load demand, it can be considered insufficient when it comes to high amounts of local PV energy feed-in [48]. The increase of the number of grid connected PV systems which inject active power to the grid, this will affect the power factor and the PV systems could cause an overvoltage which makes a reverse power flow in the grid due to the high penetration and the high solar potential times.

The high PV penetration causes many problems to distribution networks. So, it affects the electrical companies. These problems could make reverse flow of the power, decreasing the power factor when installing large amount of PV systems, faults in the transformers and inverters, injecting harmonics and the islanding. All of these are costly to the electrical utilities, so the main goal of these utilities is to avoid or to reduce or to limit the impacts of high PV penetration levels through developing strategies and facilitate the grid by control systems and by convert to the smart grid.

Technical issues associated with high levels of PV do not differ significantly from country to country. While specific details may vary depending on circuit design characteristics, most challenges are associated with voltage and frequency effects, islanding, and fault detection.

4.2 Impacts of High PV Penetration Levels on the Grid

The variation of the solar radiation changes the output of the PV system and this affects the distribution system. The distribution system stability is the most important challenge when we talk about installing PV systems to the grid. There are many issues that affect the system stability and sometimes lead to fault in the system. So, we need to understand these issues and their impacts on the grid in order to find ways to eliminate or reduce their impacts to improve the system stability.

The high and somewhat uncertain variability in PV system output also have implications for power system planning. This variability introduces difficulties in forecasting peak system loads and designing the network accordingly. In addition to this, there is a desire by PV installers to be able to connect large commercial PV systems to the network. There are particular challenges when introducing such systems to the network because of the significant network investigation that is often required to determine the suitability of the system and proposed network connection point. Also, applications of this type often currently require a large amount of administrative procedures and there has been a concern over the lack of a standardized process amongst all utilities to facilitate the connection of commercial PV systems. The current process and potential network augmentation costs introduce a large level of commercial risk to these projects and the current lack of uniform procedure is a deterrent to a large scale system business case. [49]

4.2.1 Voltage Rise and Fluctuation Issues

The problems associated with the voltage rise on the grid can be counted as an independent impact from other high PV penetration impacts. The traditional power system sets the voltage at high levels in order to avoid the voltage drops effects on the load. The installed PV systems have already high voltage levels which can cause over voltages in the load side. There are inverters disconnect the PV system if the output voltage of the PV system is higher than the nominal voltage of the distribution grid. But the drop voltage due to the losses along the distribution feeders makes the output voltage from the PV system seems higher than the distributed voltage which can lead to an over voltage.

The voltage variation due to installing PV is the most important issue in the low voltage distribution system. The rise of the voltage can be explained as; when installing the PV at the end of the distribution system closed to the load with high penetration there is a reverse voltage flow. In the normal voltage flow, from the start point to the end point there is a voltage drop due to the losses along the distribution feeders. As the output voltage of the grid connected PV system limited to the rated distributed grid voltage, so the output PV voltage is higher than the received voltage to the load. As a result there is a reverse voltage flow, see figure (4.1).

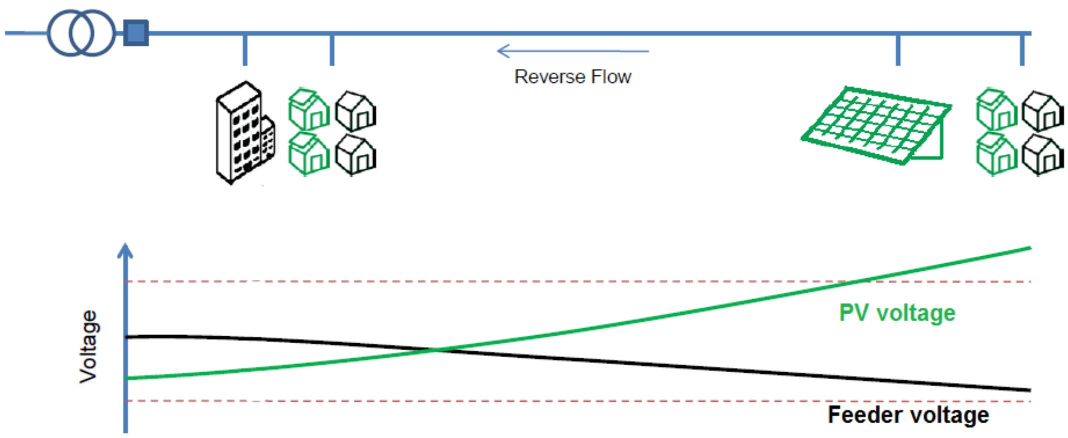

Figure (4.1): Reverse Voltage Flow [48]

In an American study, which was done for 115 houses with 2 KW of PV panels and a total capacity of 230 KW, there is only 0.6% of voltage rise on the low voltage distribution network [48]. In the low load condition at the previous system shown in the figure (4.1) and high PV generation, there is an over power which means that the power provided by the distribution grid in addition to the power provided from the PV system is more than the power needed by the load.

Due to the lack of standards for the high PV penetration in Palestine, this European standard EN-50160 which says that a 5% overvoltage of a week is acceptable will be previewed. Voltage variations have much less problems in short feeders, even at very high penetration. The impacts of overvoltage depend on the location of the PV on the feeder.

In Palestine, the medium voltage feeders which are up to 33 KV and all of them are between transformers means not close to the loads. So, the small rise in voltage will not affect the loads. The installed PV systems to medium voltage distribution network as the PV station in Jericho which has 300 KWp and is connected to the 33 KV feeders, is considered as low PV power generation system and has no significant effect to the medium voltage feeder. So, the voltage rise effect has significant impact on the low voltage feeders.

Voltage fluctuation is a change or swing in voltage, and can be problematic if it moves outside specified values. It affects the performance of many household appliances and can consist of variations in the peak or RMS (root mean square) voltage on the line. Supply authorities or government regulators stipulate the maximum acceptable deviation from the nominal voltage. Effects on loads are usually noticed when the voltage fluctuates more than 10% above or below the nominal voltage, and the severity of the effects depend upon the duration of the change. Extended overvoltage decreases the life of most equipment and can damage sensitive electronic equipment [51].

Voltage level variations are relatively variable in distribution networks (being partly caused by load variations), to avoid variations exceeding acceptable limits many different regulation techniques are used depending on the network's characteristics: automatic step up transformers and voltage regulators at medium voltage (MV) levels, manual tap changers in MV/LV transformers and other techniques. This regulation is important, since distribution system operators must take in to consideration to fulfill certain obligations regarding the power quality supplied to consumers. For example, for public LV networks voltage variations within 10% of the nominal values are normally considered acceptable in Europe, with stricter limits for over voltages typically applied in many countries.

4.2.2 Frequency Regulation Issue

The frequency is an important or one of the most important factors in the power quality. So, it must be uniform throughout an interconnected grid. The way to control the frequency is by maintaining a balance between the generation part of the grid and the load which is connected to the grid. The frequency is controlled within a small deviation.

There are some examples taken from Japan and Europe about the deviation to control the frequency in their networks. In Japan the standard is 0.2-0.3 Hz; in the U.S. it is 0.018-0.0228 Hz and in the European UCTE it is 0.04-0.06 Hz. The state of unbalance between the generation and the demand of electricity could lead to what we can call a frequency fluctuation.

The fluctuation will fall when the demand exceeds the generation and it will rise when the generation exceeds the demand. With the increasing penetration of grid connected PV systems, frequency control becomes more difficult. As the number of grid-tied PV systems increases, the impacts of frequency fluctuation will become more significant. Inverters can provide frequency control in short time, sometimes milliseconds, which is significantly faster than conventional generation. Moreover, the inverter may cause harmonics and inject it to the distribution network which makes losses and disturbance in the power (voltage and current).

The frequency regulations affect the distribution system stability, so it’s important to avoid this issue. In some grid connected PV systems, the inverter must disconnect the PV system from the grid when the output frequency breaks the limits to avoid the instability of the distribution system.

Sometimes the output frequency of the PV system is in the standard range, but the passive component of this protection requires the inverter to disconnect from the network to avoid some technical problems. For example, a frequency of 51Hz would be within power quality standards and would therefore cause inverter disconnection during normal network operation. In addition, if a system disturbance occurs, such as a fault on the network, it is likely that an excursion in frequency or voltage will occur, resulting in disconnection of PV systems from the network.

4.2.3 Power Issue

The effects on the voltage or the current affect the power, because the power is defined as the product of voltage and current.

Fluctuations in power output as short-term fluctuations (seconds) can cause problems with power quality (both voltage and power factor), while longer term fluctuations require back-up generation to maintain power supply. Short-term fluctuations can also result in tap-changers and capacitor switches continually ‘hunting’ as they attempt to maintain power quality, which results in increased wear of these devices, as well as an increased number of switching surges [51].

The low power factor due to the PV penetration will affect the load and the equipment that is connected to the feeder. Moreover, some machines or other equipment which is connected to the grid and they depend on reactive power will have instability due to the lack of the reactive power as a result of huge amount of active power penetrated to the grid from the PV systems. Installing of capacitor banks is desirable to improve the power factor to be acceptable and to feed the machines and equipment with reactive power. So, the grid will be more stable regarding the other issues of high PV penetration levels.

4.2.4 Current Swings Issue

The current swings happen when the inverter disconnects the PV system from the grid. The current swings have impacts on the consumer as it has impacts on the distribution network. Switch off in periods of potential high generation impacts on the customers tariff incentives and can possibly leave the utility liable for the damages incurred if the voltage is outside of acceptable limits.

In the distribution networks we can measure the current swings at the secondary terminal of the transformer when there is a high PV penetration. This is compared to the current at the secondary terminal when none of the systems are generating. Thus, the net current swing is calculated by taking the generating current away from the non-generating current. When we measure the current at different penetration levels and compare them to the current when no PV generation we can find how the current swings are increased as the penetration levels increase.

Current Swing which occurs when systems are shutoff, this parameter is taking into consideration because of the protection requirements of the inverters.

This paragraph is taken from study of [52] on Endeavour network which has some results about the current swings. These results are from the PV systems generating at full capacity (modeled as 70% of quoted values) and then all simultaneously shutting off due to an event such as increased voltage triggering the inverter islanding protection. It is definitely feasible for a scenario such as this to occur in a distribution system with high penetration as the PV systems are likely to cause back feeding and thus high voltages in the system. Compounding the problem is the fact that inverter islanding protection voltage levels are generally set to lower than the utility accepted voltage levels, for example in Endeavour Energy accepted single phase voltage is up to 262.2V. Figure (4.2) shows the current swing in the network from the results above.

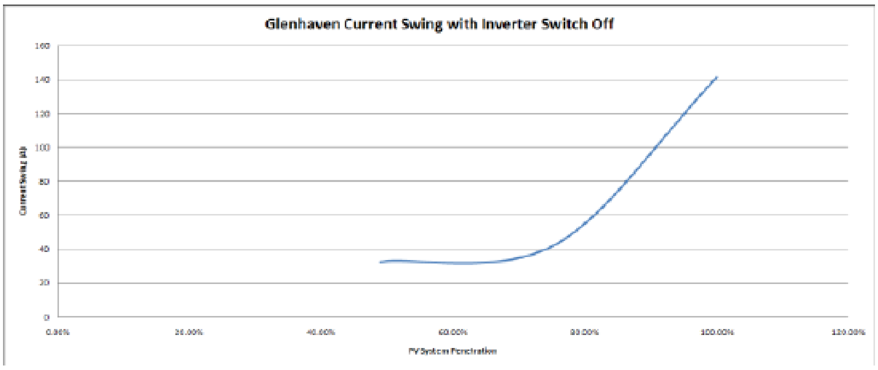

Figure (4.2): Current Swing Graph [52]

The major problem associated with current swings of this size is that they would appear to the network to be similar to switching surges and such appearance could affect the voltage stability of the system and possibly cause faults. Additionally the current swings would be extremely unpredictable as they are a factor of dynamic generation and individual feeder load levels.

4.3 The Relation between Distribution Network and PV Penetration Level

The feeder either low voltage or medium voltage (there is no high voltage levels transmission in Palestine yet) is the most affected from the high PV penetration, because the PV systems are injected directly or through transformer to the feeder. The voltage rise is the biggest problem to the feeder, because it causes the reverse flow in the feeder. The other problems on the feeder are the feeder layout, transformer short circuit resistance and feeder impedance; these other problems lead in somewhat to the voltage variation on the feeder.

Some of the feeders where PV systems are installed in urban areas close to the consumers (any change in the feeder will affect directly the load) as Rooftop systems that are causing the voltage rise problems on the various LV networks in the area. This is a problem because over voltage on the network can impact the utility stability, cause problems with some equipment (both for the network and the customer), increase equipment power consumption and cause the PV inverters to disconnect from the network. This section will study the main problems that affect the feeder due to the high penetration levels of the PV systems.

4.3.1 Feeder Impedance Effect

The feeder impedance is the main player in the voltage rising in the feeder, because it affects the voltage drop along the feeder. As the impedance value increases due to the increasing of the long of the feeder the voltage drop will be increased directly and the voltage increasing by the PV systems is more significant.

For example, if there is a feeder of 11 KV at the start point of the feeder, 2 MW, 0.9 PF and the impedance as 0.5 Ohm per Km, so:

If the feeder has a length of 1 Km, the voltage at the end of the feeder is:

$Vend\ of\ feeder = V_{start} - I_{feeder}xR$........... (Equation 4.3)

$$V_{endoffeeder} = 11\ KV - \left(\frac{2000\ K}{11x0.9}x0.5x1\ Km\right) = 10.9\ KV.$$

If the feeder has a length of 2 Km, then the voltage at the end of the feeder is:

$$V_{endoffeeder} = 11\ KV - \left(\frac{2000\ K}{11x0.9}x0.5x2\ Kmx\right) = 10.8\ KV.$$

From this example we can see that as the impedance of feeder is increased, the voltage drop will be decreased.

The effect of feeder impedance, an example taken from [50], feeder impedance varies and the second where the feeder impedance characteristics (*K = R/XL*) vary. This study has this condition: all the values chosen are based on the typical cables and conductor configuration found in LV feeders. For instance, a two fold increase in the impedance has a similar effect of the LV feeder, the range used in these simulations takes into consideration different conductor configurations like spacing and type of material, which could result in a variety of absolute values of the feeder impedance and feeder impedance characteristics.

Figure (4.3) presents the voltage at the last customer while varying the absolute value of the feeder impedance. The feeder experiences a higher voltage rise when the line has higher impedance. The voltage rise rate for the last customer in the LV part of the feeder, when the feeder impedance is twice the value used in the base case, was 0.93%/kW/house, which is almost 55% above the base case value (0.60%/kW/house). Also, for lower net generation values, the voltage exceeds the CAN3-C235 NR limits. As a reference, when you double the feeder impedance value, the maximum export limit to avoid exceeding the normal threshold is reduced to1.10 kW/house, which is about 41% below the maximum export limit for the base case with low load.

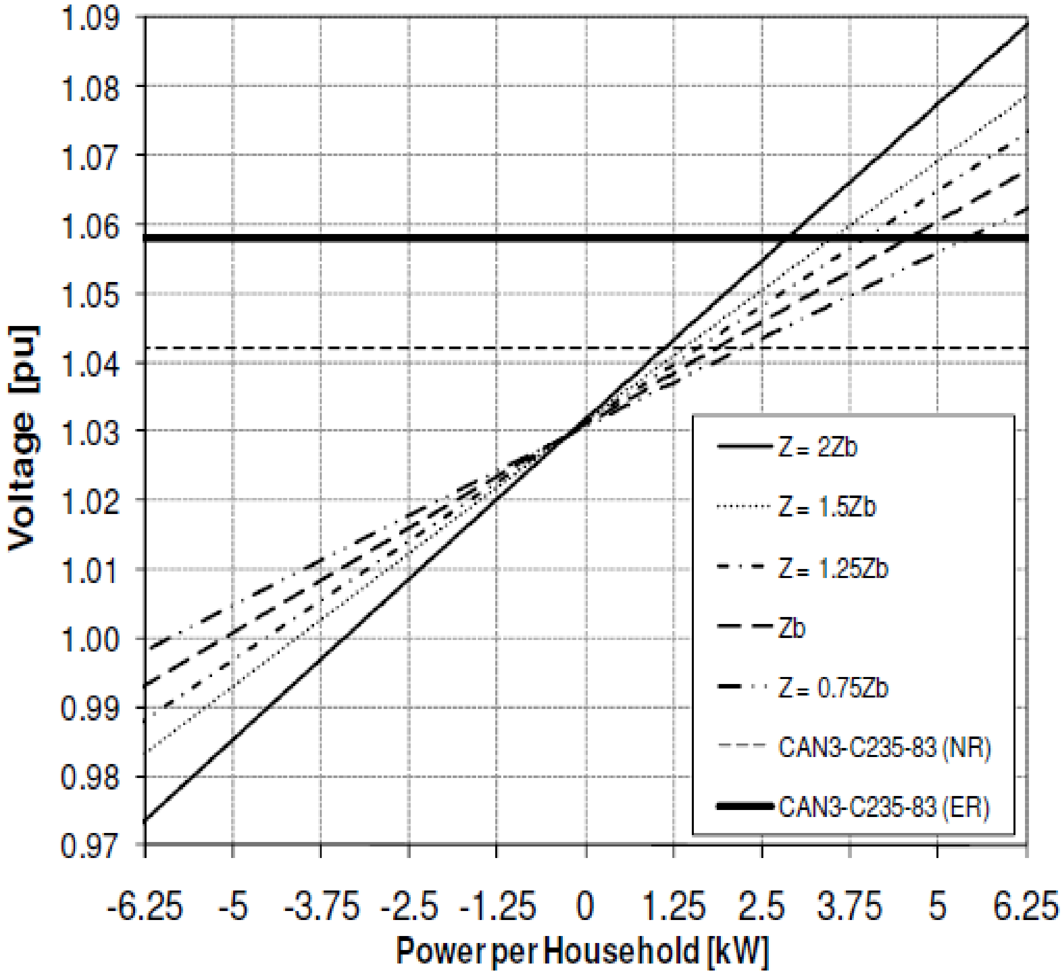

Figure (4.3): Voltage level at the last customer node for different LV feeder impedances (|Z|) (LV) [50]

4.3.2 Feeder Layout Effect

The layout of the feeder affects the impedance of this feeder, as the feeder becomes longer, the impedance will increase and as a result the voltage drop will increase causing voltage fall at the end of the feeder. The increase of number of PV systems (Rooftops) on the feeder will affect the voltage of this feeder, as mentioned earlier. The voltage will increase as the number of PV Rooftops increased, and due to the larger voltage drop the voltage increasing by the PV systems which connected at the end of the feeder will be more effective and the reverse voltage flow will occur. The system in the following figure (4.4) shows a 12 Rooftops from study in [50] connected to the feeder with a net load/generation ratio of $\pm$ 6.25 KW/house at different feeder layout levels of (0m, 40m, 80m, 120m, 160m and 180m) between the Rooftops. The circuit diagram is shown in figure (4.5).

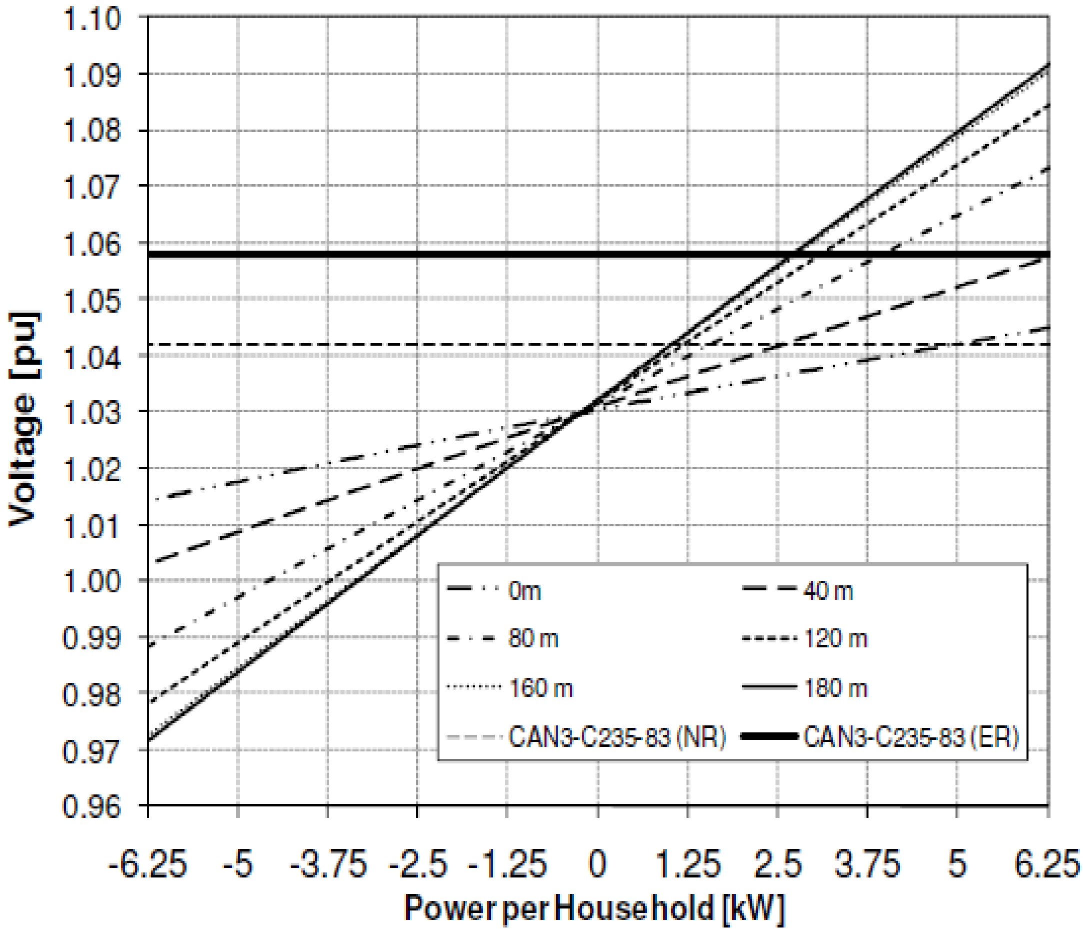

Figure (4.4): A 12 Rooftops connected to the feeder with a net load/generation ratio of ± 6.25 KW/house at different feeder layout levels [50]

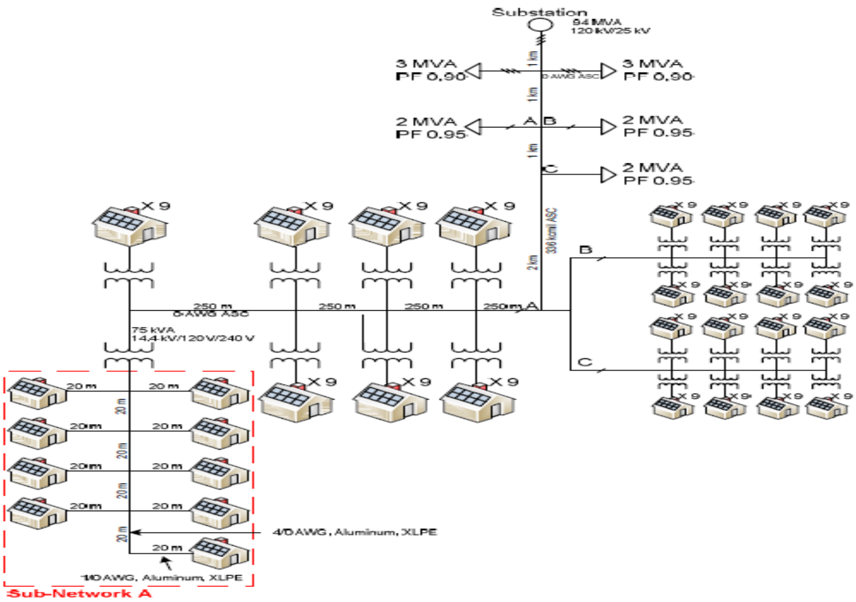

Figure (4.5): The One Line Diagram of the System above [50]

4.3.3 Transformer Short Circuit Resistance Effect

As the previous effects, the transformer resistance has a significant effect to the voltage rise in the feeder.

To clarify the effect of transformer short circuit impedance, an example taken from [50] using transformers with different short circuit resistance. The feeder impedance values are assumed the same as those used for the base case. As transformers are mostly custom ordered to meet utilities requirements, the values chosen consider a wide range used by utilities.

Figure (4.6) presents the voltage at the last customer. The voltage rise rate is higher when the transformer has larger resistance (0.70%/kW/house). Besides increasing the losses, having transformers with larger short circuit resistance also reduces the capacity of the grid to absorb power. Compared to the base case, for a 50% increase on the transformer resistance, the maximum net generation limit to avoid exceeding the normal threshold is reduced by 20% (1.49 kW per house). On the other hand, if the transformer resistance is reduced by 50%, the capacity is increased by 28% (2.40 kW per house) and the voltage rise rate is reduced to 0.49%/kW/house.

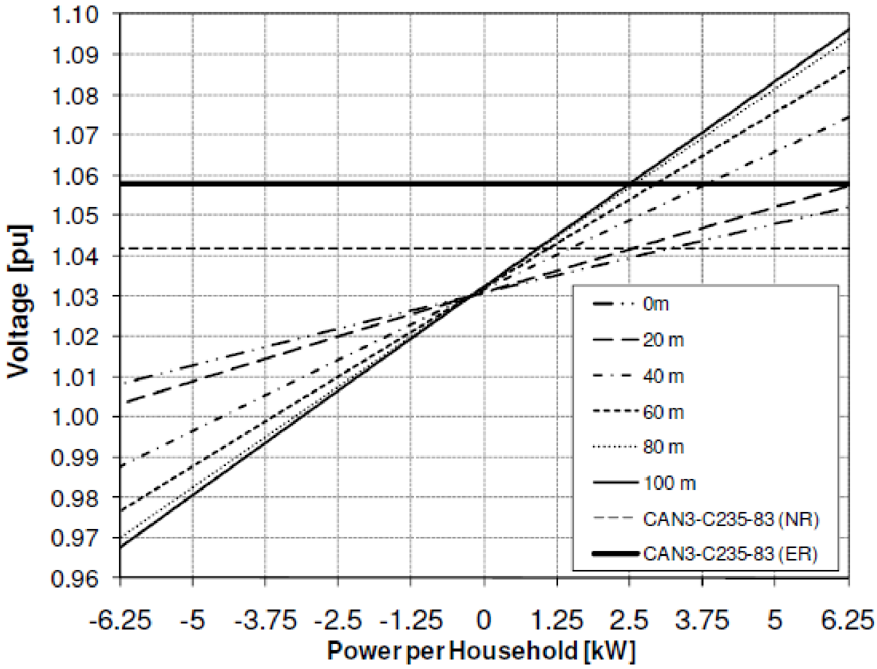

Figure (4.6): Voltage profile for the worst case scenario (LV) [50]

4.4 The Impacts of PV Penetration Level on Protection of Distribution Network

The protection is related to the equipment of the grid and PV system in case of preventing damage and fault. The main equipment that is affected by the high PV penetration issues are; the transformer and the inverter.

The management from the utilities must do limiting of the amount of PV systems on distribution transformers, implementation of network design to limit potential efficiency problems, standardization of inverter protection processes and the inclusion of PV system impact when designing protection systems. Although, In the case of PV system shutoff due to voltage protection process, current swings exceeds the acceptable limit might be observed in the network.

The biggest integration issues predicted by the previous literature are voltage levels, power factor, harmonics, and protection.

There is also an issue with the voltage protection process of the inverters. If this protection system changes its state while the grid is still active, the inverters will switch off and cause current swings in the network. This is really a problem because increased voltage levels due to a high PV system penetration mean the inverters are likely to be switched off, and the larger the number of inverters the larger the current swings are when they switch off. The inverter must switched off when the grid falls down and when the frequency output from the PV system exceeds the limits as mentioned in 4.2.2.

4.5 Acceptable International Levels of PV Penetration

There are many researches done about the impacts of high penetration levels on the distribution grid. This literature review will represent some researches done by experts worldwide to find the suitable or the acceptable penetration level on the networks they had tested.

The penetration level is defined as the ratio of nameplate PV power rating (W_p) to the maximum load seen on the distribution feeder (W). The results of that literature survey are presented below. The first study (Appendix B) examined cloud transient effects if the PV were deployed as a central-station plant, and it was found that the maximum tolerable system level penetration level of PV was approximately 5%,the limit being imposed by the transient following capabilities (ramp rates) of the conventional generators. The second study (Appendix B) focuses on the operating experience of the Southern California Edison central-station PV plant at Hesperia, CA, which reported no such problems, but suggests that this plant had a very ‘‘stiff’’ connection to the grid and represented a very low PV penetration level at its point of interconnection.

The third one (Appendix B) dealt with voltage regulation issues on the Public Service Company of Oklahoma system during the passage of clouds over an area with high PV penetration levels, if the PV were distributed over a wide area. At penetration levels of 15%, cloud transients were found to cause significant but solvable power swing issues at the system level, and thus 15% was deemed to be the maximum system level penetration level.

The fourth study in (Appendix B) describes the harmonics at the Gardner, MA PV project. The 56 kW of PV at Gardner represented a PV penetration level of 37%, and the inverters (APCC SunSines) were among the first generation of ‘‘true sine wave ’’PWM inverters. All of the PV homes were placed on the end of a single phase of a 13.8 kV feeder. The

PV contribution to voltage distortion at Gardner was found to be about 0.2%, which was far less than the contributions made by many customer loads. It was thus concluded that harmonics were not a problem as long as the PV inverters were ‘‘well designed’’. This paper also mentions the potential value of PV systems being able to provide reactive power to keep the power factor of a feeder approximately constant. The Gardner, MA PV project (Appendix B) looked at four areas: the effect on the system in steady state and during slow transients (including cloud transients); how the concentrated PV responded under fast transients, such as switching events, islanding, faults, and lightning surges; how the concentrated PV affected harmonics on the system; and the ‘‘overall performance of distribution systems’’, in which the total impact of high-penetration PV was evaluated. The final conclusion is that the 37% penetration of PV at Gardner was achieved with no observable problems in any of the four areas studied.

The last study (Appendix B) attempted to quantify the impact of geographic distribution of PV on allowable PV penetration level, at the system level, using a utility in Kansas. The study concluded that under the conditions studied, the utility’s load-following capability limited PV penetration to only 1.3% if the PV were in central-station mode, with the limitation being caused by unscheduled tie-line flows that unacceptably harmed the utility’s economics. However, the allowable penetration rose to 36% if the PV is scattered over a1000 km2 area, because of the ‘‘smoothing’’ effect of geographic diversity.

From the previous literature review, some of the studies found a low penetration level which is below or equal to 15%. One of the studies found that there is no penetration limit, they found just harmonics. Another study found a variable penetration limits as from 1.3% up to 37%. Unacceptable unscheduled tie-line flows, the variation is caused by the geographical extent of the PV (1.3% for central-station PV), results particular to the studied utility because of the specific mix of thermal generation technologies in use. There is a study found that the penetration limit equals the minimum load on the feeder, due to the rising in the voltage and also assuming no tap changing in the MV/LV transformer. The last study found that there are two limits for the penetration, the first one is 33% and the other one is 50% because the excursion beyond the 50% is extremely small. See (Appendix B).

Chapter Five

The Impact of Penetration Level of Grid Tied PV Systems on Law Voltage Distribution Network of Al-Jeep Village (Case Study)

Chapter Five

The Impact of Penetration Level of Grid Tied PV Systems on Law Voltage Distribution Network of Al-Jeeb Village (Case Study)

5.1 Description of Al-Jeeb Electrical Distribution Network.

5.1.1 Al-Jeeb Village Introduction (Statistical, Geographical, Historical Data)

Al-Jeeb is a Palestinian Village part of Jerusalem District, located 10 km to the northwest of the city of Jerusalem and rising from the sea about 710 m, see figure (5.1). The village is on the location of the city (Gibeon) which means a hill; a city's main tribes were Hivites Canaanite. The total land area is 8205 acres and it is surrounded by villages of Prophet Samuel, House parts, Bir Nabala, Bedouins, and deserve. Estimated population in 1922 was about (465) people. In the year 1945 it was (830) people, in 1967 it was about (1173) people, in 1987 (2111) people, and in 1996 the number has increased to reach (2550) people. There are archaeological sites in the village of rooms carved into the rock, and the Church, and landfills. The occupation authorities confiscated as part of its territory, and established the settlement (Jfot) in it in 1977. [60]

The population in 2007 was about (3800) people according to the population, housing and establishment census that was conducted by the Palestinian central bureau of statistics in 2007. The village was divided into two regions by the apartheid wall in the recent years.

Al-Khalayleh Neighborhood which is the case study for this thesis is located outside the wall, outside Jerusalem in the west bank.

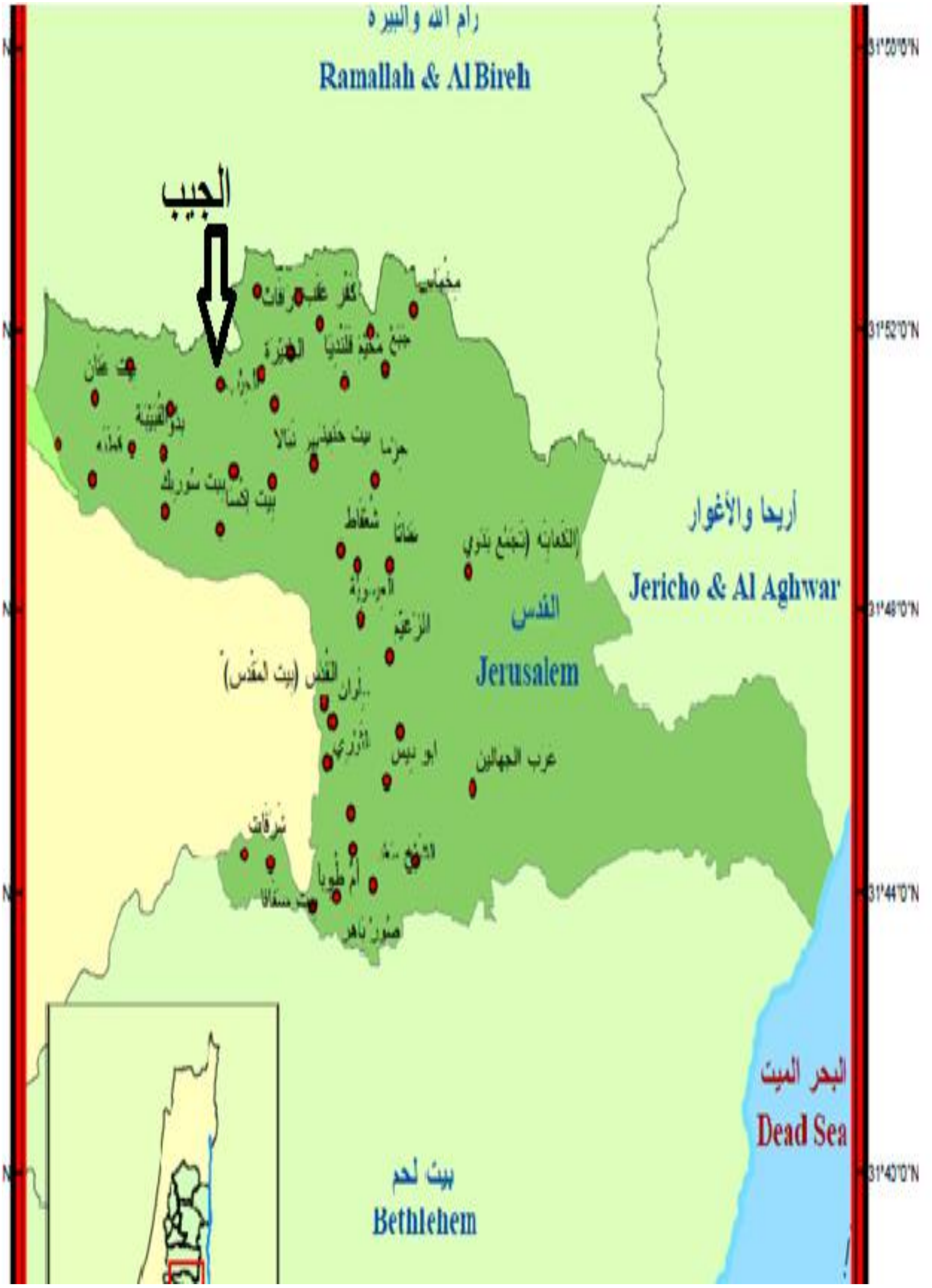

Figure (5.1): West Bank – Jerusalem Map, Al-Jeeb Location [61]

5.1.2 Al-Jeeb Electrical Network (Al-Khalayleh Feeders)

Al-Khalayleh Lane feeds from JDECO Electricity network, through 33KV line that supplies one 160 KVA transformer 33/0.4 KV, see figure (5.2). The distribution transformer feeds two main feeders (CR5, CR6).The total electrical services that are feeding from this transformer are approximately 80 services (Meters), according to JDECO data base and GIS department. The network consists of different types and sizes of conductors, two main185 mm^2 Aluminum cables from the transformer that are feeding the two overhead lines. Each overhead line network represents a feeder and consists of multiple branches and different types of conductors like insulated (ABC), not insulated Aluminum conductors with different cross section dimensions (25, 50) mm^2. The maximum length of the network from the transformer to the farthest end point in the grid = 350 m for CR6 and equal 500 m for CR5, according to GIS information from GIS departments at JDECO, note the next table (5.1) and the attached tables (1, 2) in appendix (A) which describe in details the type and the length and sizes of each segments of the network form pole to pole in addition to the resistance and reactance of each segments in Ohms.

Figure (5.2): Al-Jeeb Google Earth Map, with Grid Projection [61]

Table (5.1): Type, Length and Sizes of Each of Al-Jeeb network Lines [61]

TR1034-3 160KVA OVER HEAD LINE		
Conductor Type	**Length (m)**	**Feeder Name**
AL 1X50	330 m	CR5
AL 1X25	355 m	
AL 1X50	271 m	CR6
AL 1X25	572 m	
ABC		
Conductor Type	**Length (m)**	**Feeder Name**
ABC 25	429 m	CR5
ABC 50	291 m	
ABC 25	291 m	CR6
ABC 50	633 m	
CABLE		
Conductor Type	**Length (m)**	**Feeder Name**
3X10 CU	187 m	CR5
4X16 CU	137m	
3X10 CU	615 m	CR6
4X16 CU	183 m	

Al- Jeeb electrical GIS map, showing the feeders and services, see figure (5.3).

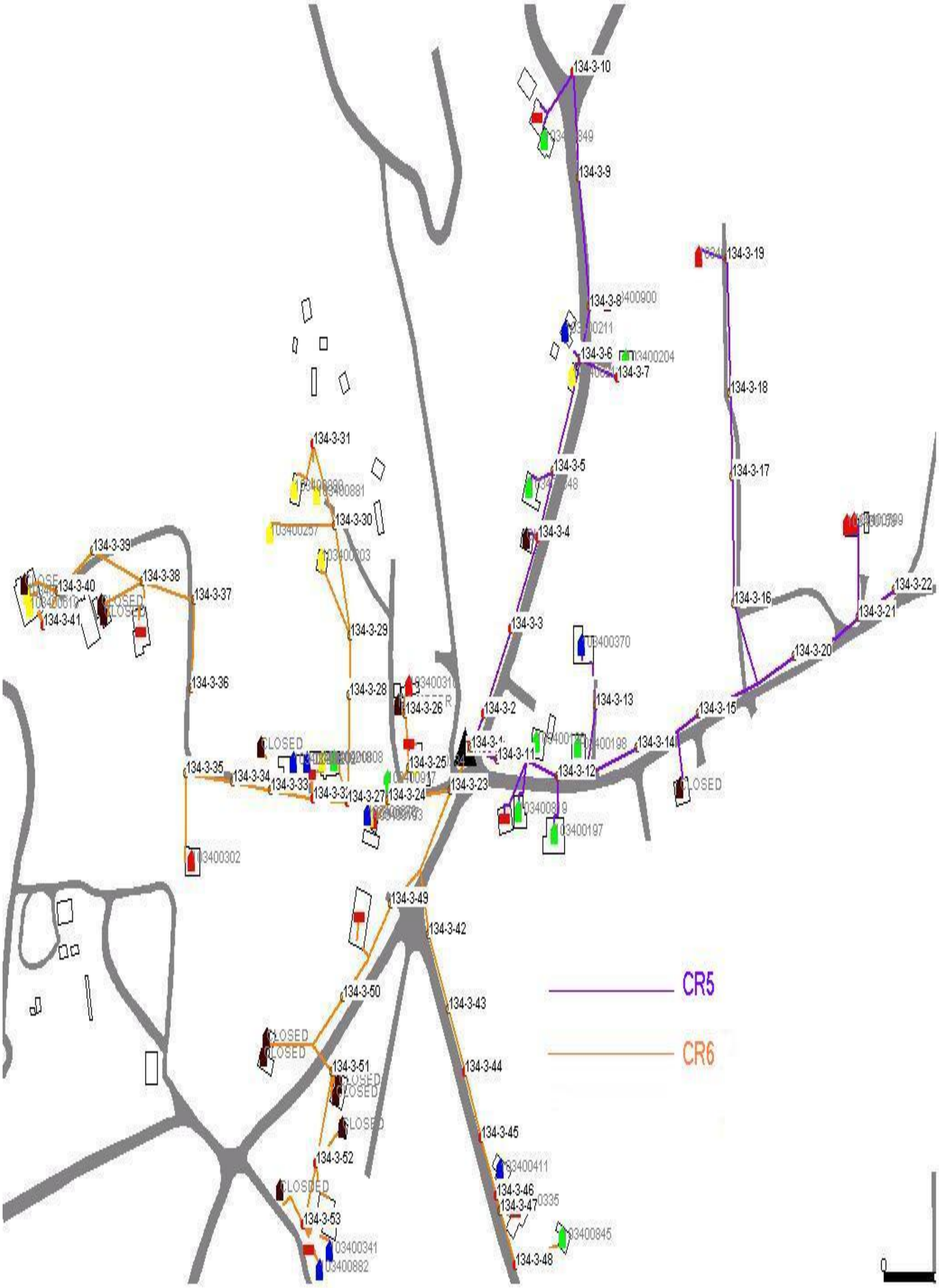

Figure (5.3): Al-Jeeb Electrical GIS Map, Showing the Feeders and Services [61]

5.1.3 Al-Jeeb Smart Grid System (AMI, MMI)

The new pilot electrical system project in Al-Jeeb is a Smart Grid and Metering System by JDECO, see figure (5.4). It is an automatic metering reading and management system that allows JDECO to gather the meters reading remotely instantaneously, which include all the smart meter data (KWh hourly-monthly records, PF, THD, tampering cases, load profile, voltage and frequency) and control and also managing it. Another important feature for this system is the losses calculation and fraud detection which is a major priority for the NSP’s.

Smart Grid: any electricity grid without adequate communications is simply a power “broadcaster”. It is through the addition of two-way communications that the power grid is made “smart”. Different types of communication methods are used to transfer the data from and to the meters (GPRS, WIFI, Ethernet, and finally the revolution of PLC technology).

Power Line Communications (PLC) or Power Line Carrier collectively refers to technologies that use existing power lines for data communications at frequencies (far) beyond the 50 Hz (or 60 Hz) mains frequency. The main advantage of PLC over other wired communications solutions is that the wire infrastructure is already in place.

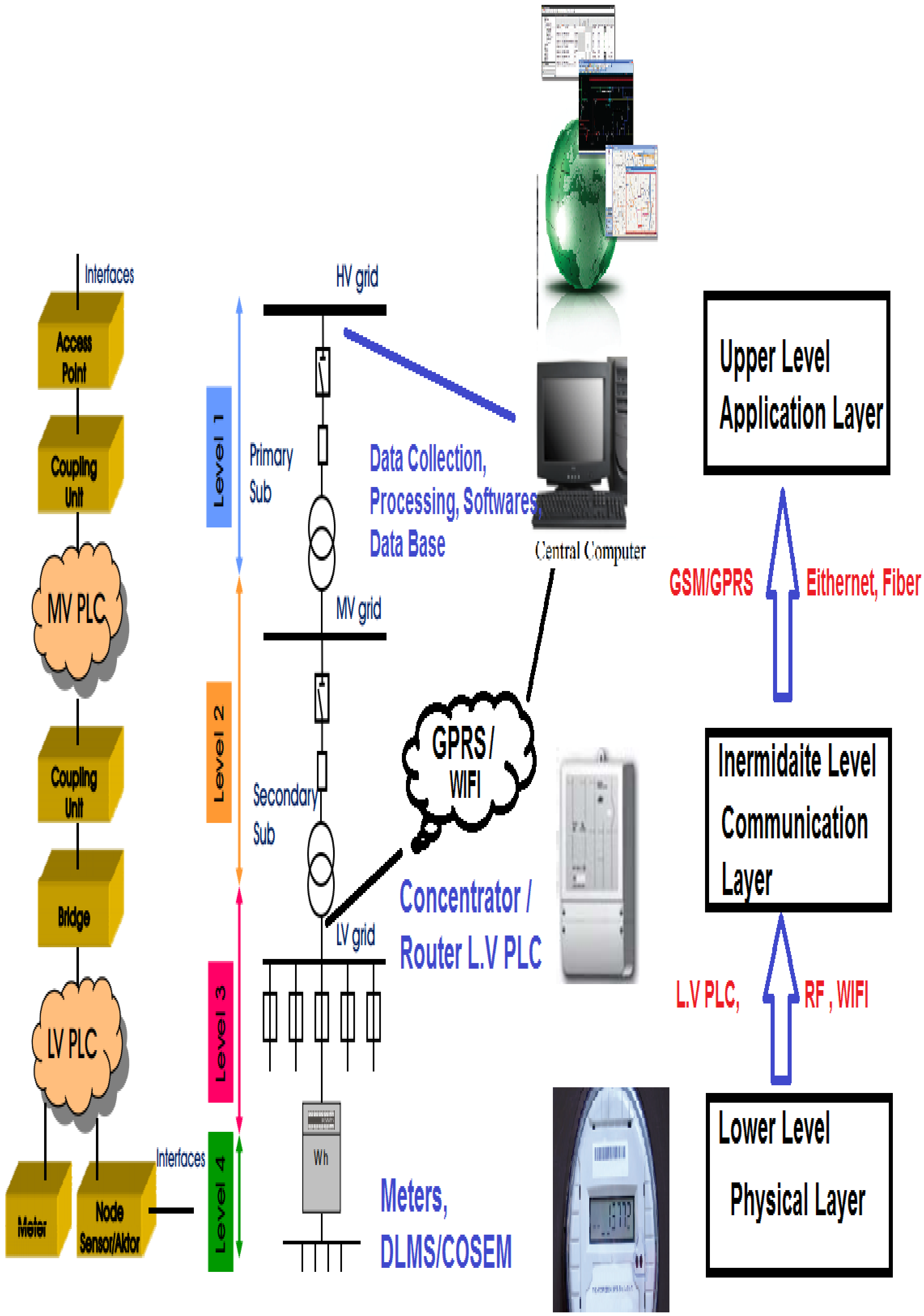

Figure (5.4): Smart Grid System Layers [61]

The following diagram in figure (5.5) shows the structure of smart metering grid that is being used at JDECO.

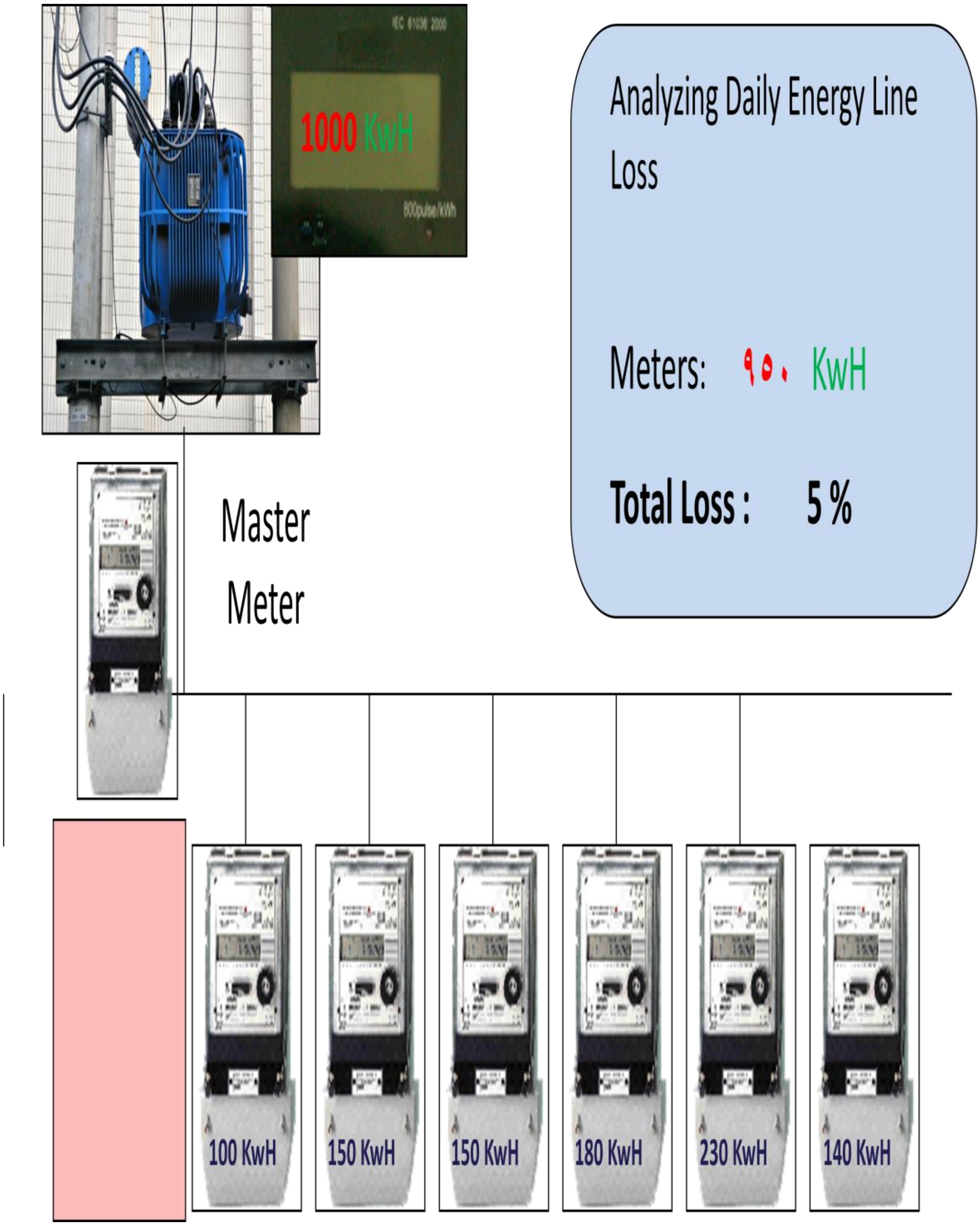

Figure (5.5): JDECO Smart Grid Structure [61]

The following charts from figure (5.6) to figure (5.9) and diagrams show some of JDECO smart metering system features: (Curves and Information Tables, Alerts and Alarms).

1) Table (5.2) shows the daily losses on the feeders of a transformer in Jerusalem- Bethanina

Table (5.2): Daily Losses on the Feeders of A Transformer in Jerusalem- Bethanina [61]

Losses (%) 15/10/2011	**Losses (%)** 03/10/2011	**Feeder**	**Transformer**
12.4	13.3	CR3	Al-Shwykeh
25.8	10	CR4	
13.1	8	CR6	

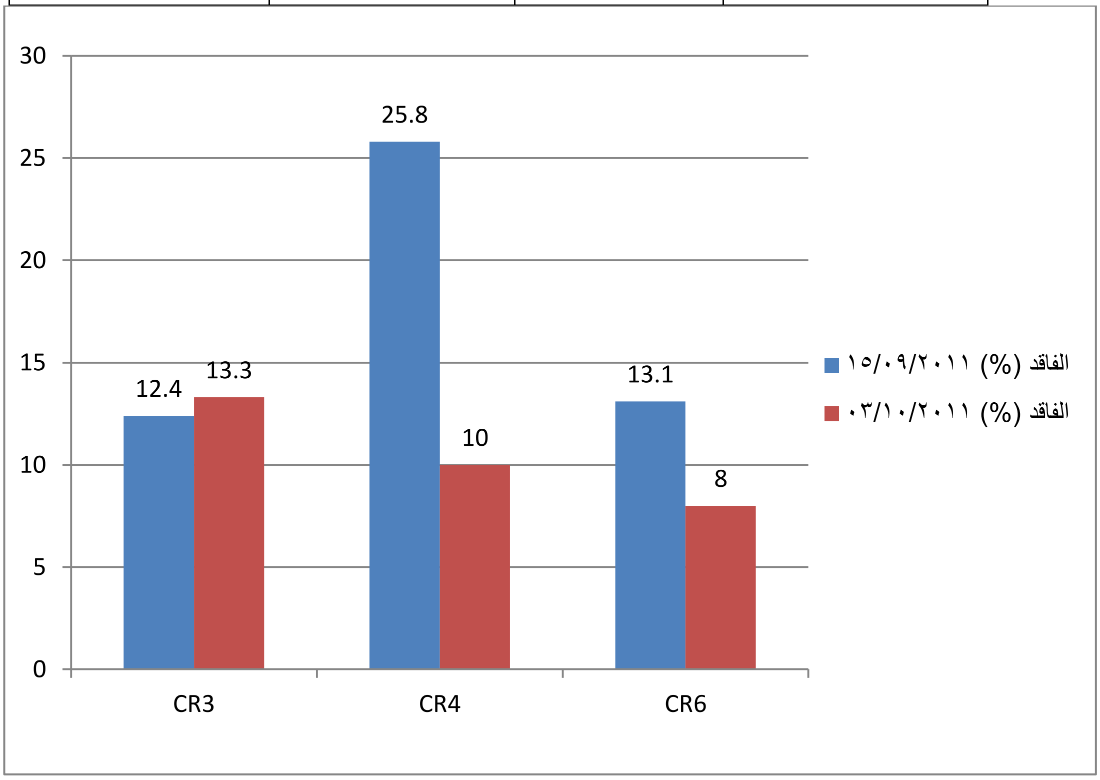

Figure (5.6): Losses Percentage on Bethanina Feeders [61]

2) The following pictures show some instantaneous alerts and alarms that are delivered by the system if there is any theft detection on any of the meters.

3) The following Chart shows daily load curve for a Transformer:

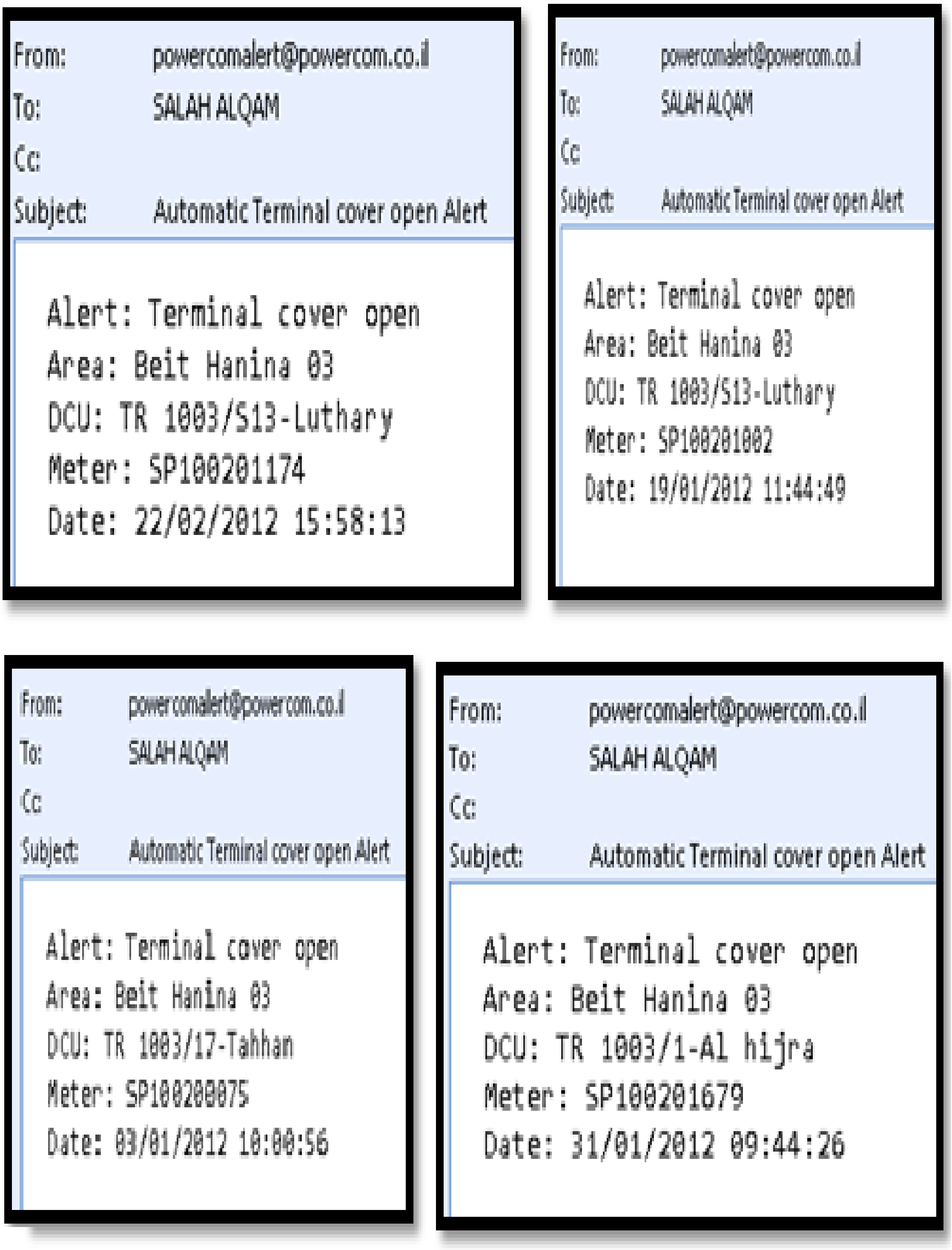

Figure (5.7): Alerts and Alarms Messages from Smart System [61]

Figure (5.8): Transformer Daily Load Curve Charts [61]

4) The following chart shows, the monthly consumption reports:

5) All of these features of the smart grid system at Al- Jeeb grid help to make a real case study with real time data and real network parameters, instantaneous and cumulative data base were available.

6) Detailed data for Al-Jeeb meters and grid will be in the appendix (A) and in the next section.

POWERCOM

Single Tariff Meters Cumulative Consumption Report

From Date 2/1/2012 To Date 2/25/2012

TR 1003/18-Shweki

Meter	From	Reading	To	Reading	Consumption
SP100201115	2/1/2012	1236.980	2/25/2012	1582.220	345.240
SP100201100	2/1/2012	1401.580	2/25/2012	1977.520	575.940
SP100201088	2/1/2012	2635.190	2/25/2012	3066.690	431.500
SP100201120	2/1/2012	4697.780	2/25/2012	5608.140	910.360
SP100201116	2/1/2012	2365.470	2/25/2012	3064.580	699.110
SP100201090	2/1/2012	2182.490	2/25/2012	2615.030	432.540
SP100201114	2/1/2012	3749.220	2/25/2012	4618.860	869.640
SP100201085	2/1/2012	3218.630	2/25/2012	4083.020	864.390
SP100201095	2/1/2012	225.690	2/25/2012	251.030	25.340
SP100201117	2/1/2012	2025.780	2/25/2012	2388.570	362.790
SP100201097	2/1/2012	1375.980	2/25/2012	1700.610	324.630

Figure (5.9): Monthly Consumption Reports [61]

5.2 Analysis of Al-Jeeb Electrical Network.

5.2.1 Identifying the case study

Al- Jeeb data were gathered and collected from JDECO remotely systems and physical data from the technical sites team.

The systems that were used to collect data:

1- SCADA System, (Supervisory Control and Data Acquisition System)

2- GIS System,

3- AMR, Smart Grid and Metering System. (Powercom System)

Al-Jeeb village was chosen for the study and simulation due to the existence of this smart metering system firstly, which allowed us to gather real time and accurate data. Secondly, it consists of two small feeders that facilitate examining the effects of the PV generation on grid and investigate the risk of it. Although there is no PV penetration yet on the grid, not only in Al-Jeeb or east Jerusalem but in all of Palestine, since the law was recently approved, however some of the installed PV systems were recently installed in the same area which has (Middle of West Bank) which has the same weather conditions, radiation, metrological data and geographical position, and it will be used to be installed and projected in Al-Jeeb grid for simulation purposes.

5.2.2 Data Collection

The attached reports that were used for analysis in the appendixes are:

1- 31 days readings in May, 2013 for each customer service in Al-Jeeb and for the transformer meters on its feeders were collected from the system, the readings were taken hourly for 24 hour each day, the total records are more than 50,000 records. Appendix (A) from Powercom system at JDECO

2- Monthly consumption from July, 2012 to July, 2013, for each customer service and for the transformer’s 0.4 KV feeders. More than 10,000 records. Appendix (A) from Powercom system at JDECO.

3- GIS maps and tables for Al- Jeeb Village (Al-Khalayleh Feeders), that shows the geographical position of the transformer and the services and the poles, also the grids lengths and cross section sizes and type of it. From GIS System Department at JDECO.

4- Instantaneous and live data reading for some chosen services in Al – Jeeb from 11:00 AM – 02:00 PM in July, 2013. Appendix (A) from Powercom system at JDECO.

5- Readings for residential 5 KW PV systems in Ramallah, Jerusalem and Tubas areas that were installed recently after announcing the PV Law (PSI).

5.2.3 Data Processing and Filtering

The case study that was identified for these sections is Al-Jeeb network. Large numbers of data were gathered and collected for the network equipment parameters. consumption and load profile and other parameters (voltages, PF, ..) at the end users, all these physical data were gathered from different sections in JDECO, (GIS, SCADA, Smart Grid System, Customer Services..), and these large amounts of data need to be filtered , sorted and averaged for purposes of this study.

Processing works were applied on these data for some missing data due to communication problems or other issues. So, interpolation and extrapolation were conducted on these numbers. Other irrelevant data were omitted.

The following diagrams and tables are Daily Load Curves for different one phase meters in Al-Jeeb, those were chosen randomly. The records were taken from Appendix (A) which has hourly consumption data for all the meters in Al-Jeeb in May, 2013 for 31 days.

These different types of daily load curves of multiple household in Al-Jeeb will help us to understand the trends of power demand in this village in the middle of West Bank near Jerusalem and Ramallah, which have typical building, household and consumption behavior and life style for residential and domestic demand in Palestine.

Two days were chosen, 3/5/2013 which was a vacation day (Weekend), and 15/5/2013 which was a typical work day.

The analysis and simulation will focus on a day period of time from 11:00 AM to 2:00 PM, taking the average data in this period for the individual services, the main transformer meter and the output generation of the PV systems, since the PV systems are assumed to generate at their peak, and the goal is to study at this max generation and investigate any effects.

5.2.4 Modeling Daily Load Curve for residential use

To build up and model the most accurate (Optimum) and relevant load curve for the whole household customer services in Al-Jeeb, all the data records were aggregated for each meter in 31 days and then the data for all the meters were also aggregated together and the result were averaged to get the average daily load curve for residential (Domestic) one phase meter.

Many factors affect the shape of such model like, for example:

- Behavior and lifestyle of people
- End-uses appliances (Washing Machines, Lighting, Cooling and Heating)
- Diversity factor of the power demand for a large number of household

Moreover weather condition and time of use factors: season, works day, weekend day, holiday, cold or rainy or hot weather condition.

Daily Load Curves for different households in Al-Jeeb on May-2013 were gathered and studied. The next diagrams show some of these curves for different randomly chosen houses. The first household's daily load curves are shown in figure (5.10) and figure (5.11) where they show the daily load curves in 3/5/2013 and 15/5/2013 respectively. The identity of this household is SP880.

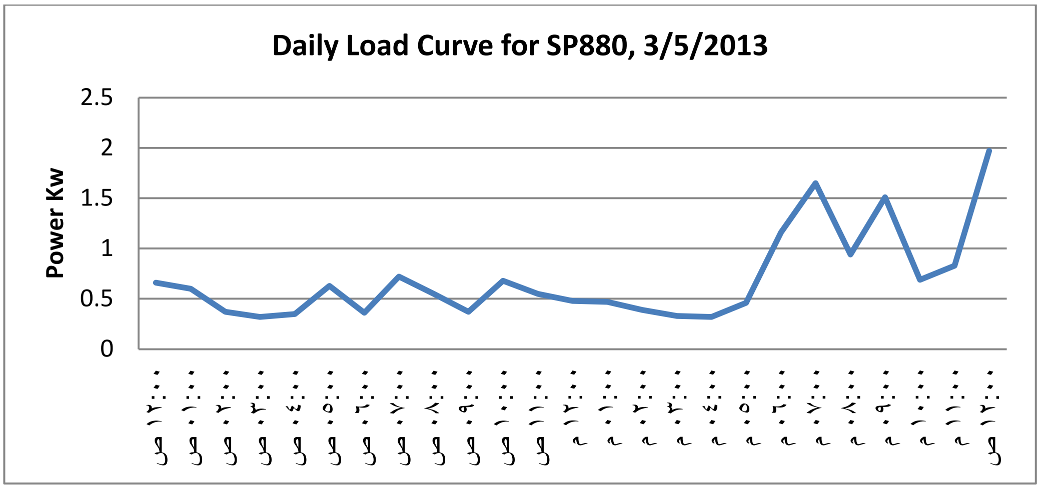

Figure (5.10): Daily Load Curve in 3/5/2013 for SP880

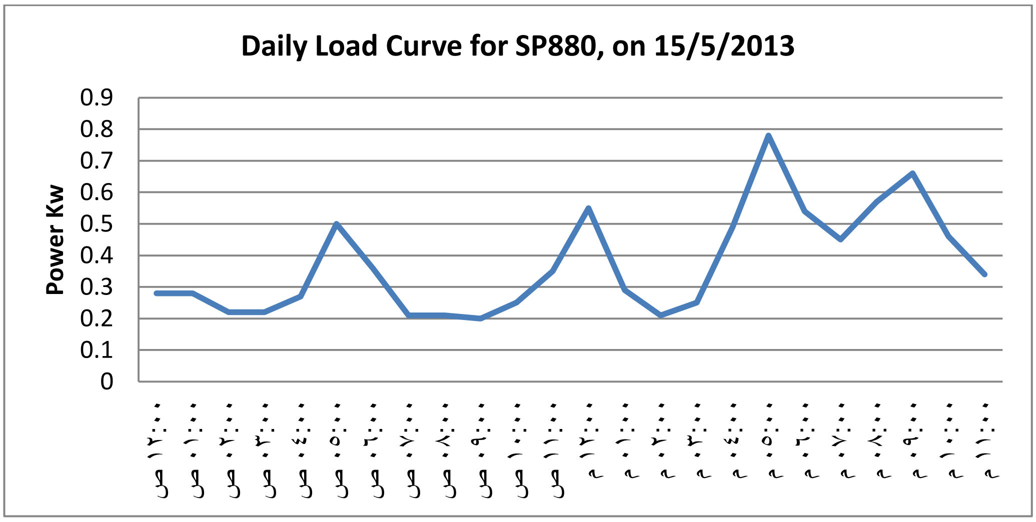

Figure (5.11): Daily Load Curve in 15/5/2013 for SP880

The second household's daily load curves are shown in figure (5.12) and figure (5.13) where they show the daily load curves in 15/5/2013 and the average daily load curve for 5 days in May respectively. The identity of this household is SP938. For this household the maximum load power, the average power and the daily consumption will be calculated.

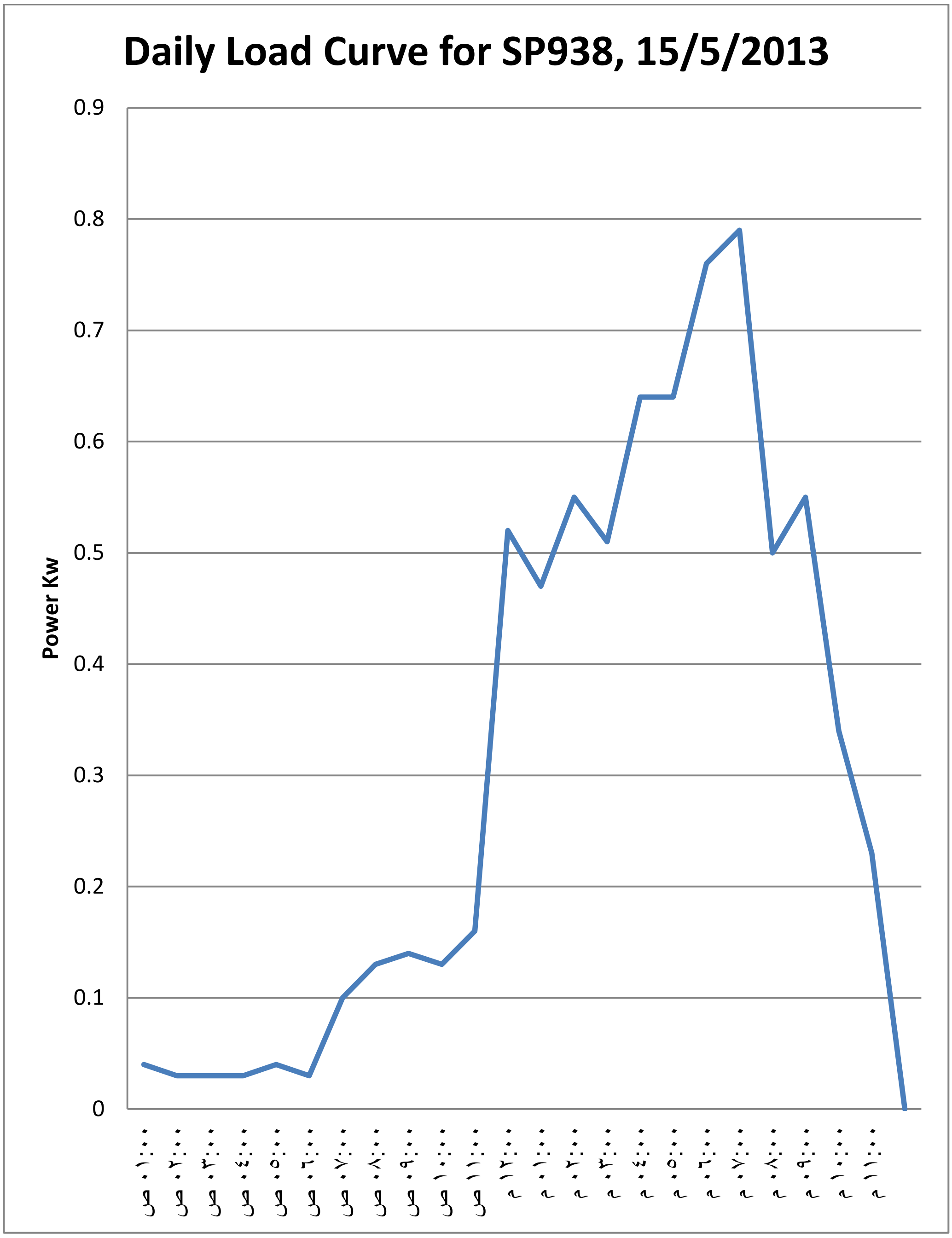

Figure (5.12): Daily Load Curve in 15/5/2013 for SP938

- Max Load Power = 0.8 KW
- Average Power (11:00 Am – 2:00 PM) = 0.41 KW
- Daily Consumption = 0.32x24= 7.68 KWh

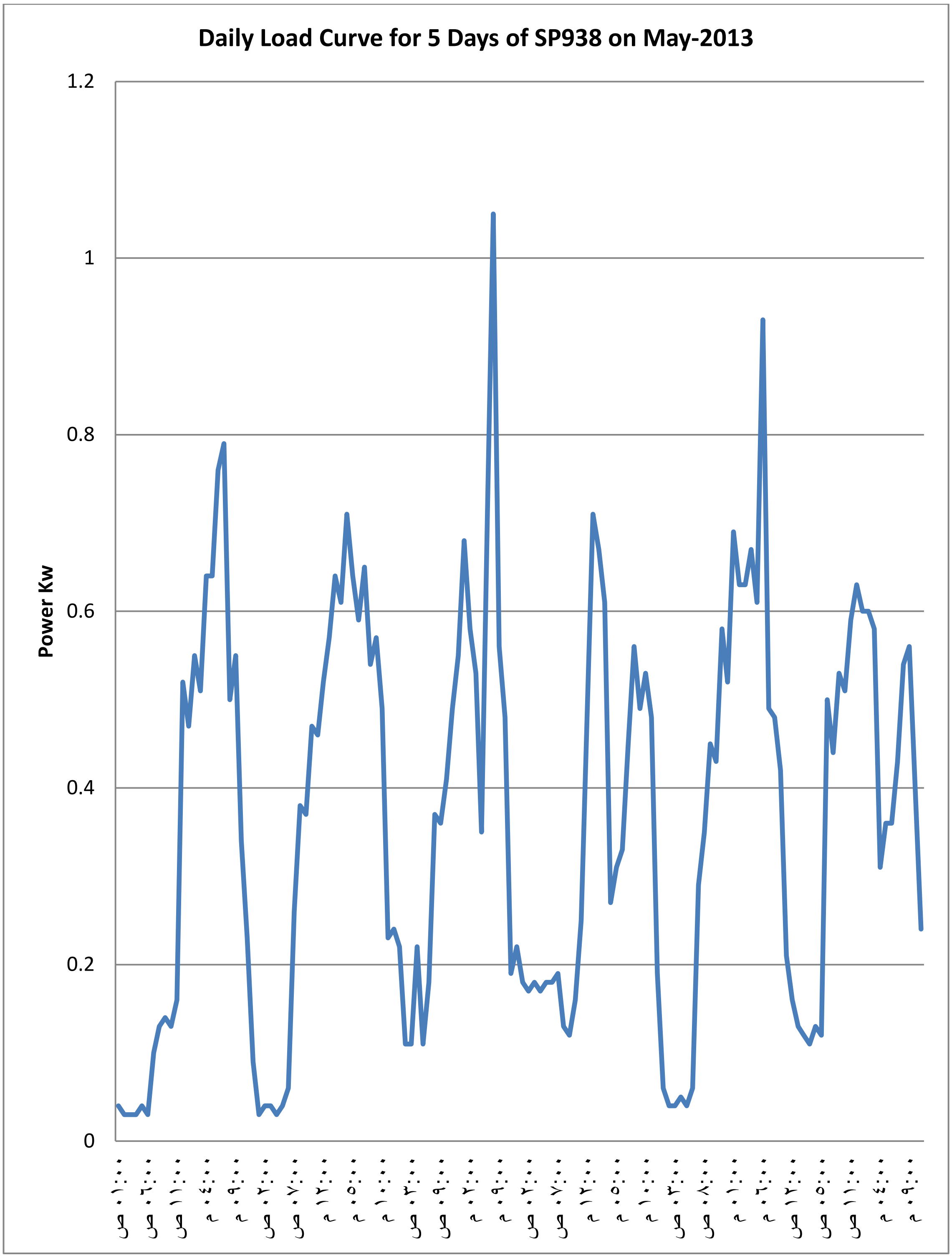

Figure (5. 13): Average Daily Load Curve For 5 Days for SP938

The Third household's daily load curves are shown in figure (5.14) which shows the daily load curve in 15/5/2013. The identity of this household is SP203. For this household the maximum load power, the average power and the daily consumption will be calculated.

- Max Load = 1.84 KW
- Average Power (11:00 Am – 2:00 PM) = 0.7 KW
- Daily Consumption = 0.5x24= 12 KWh

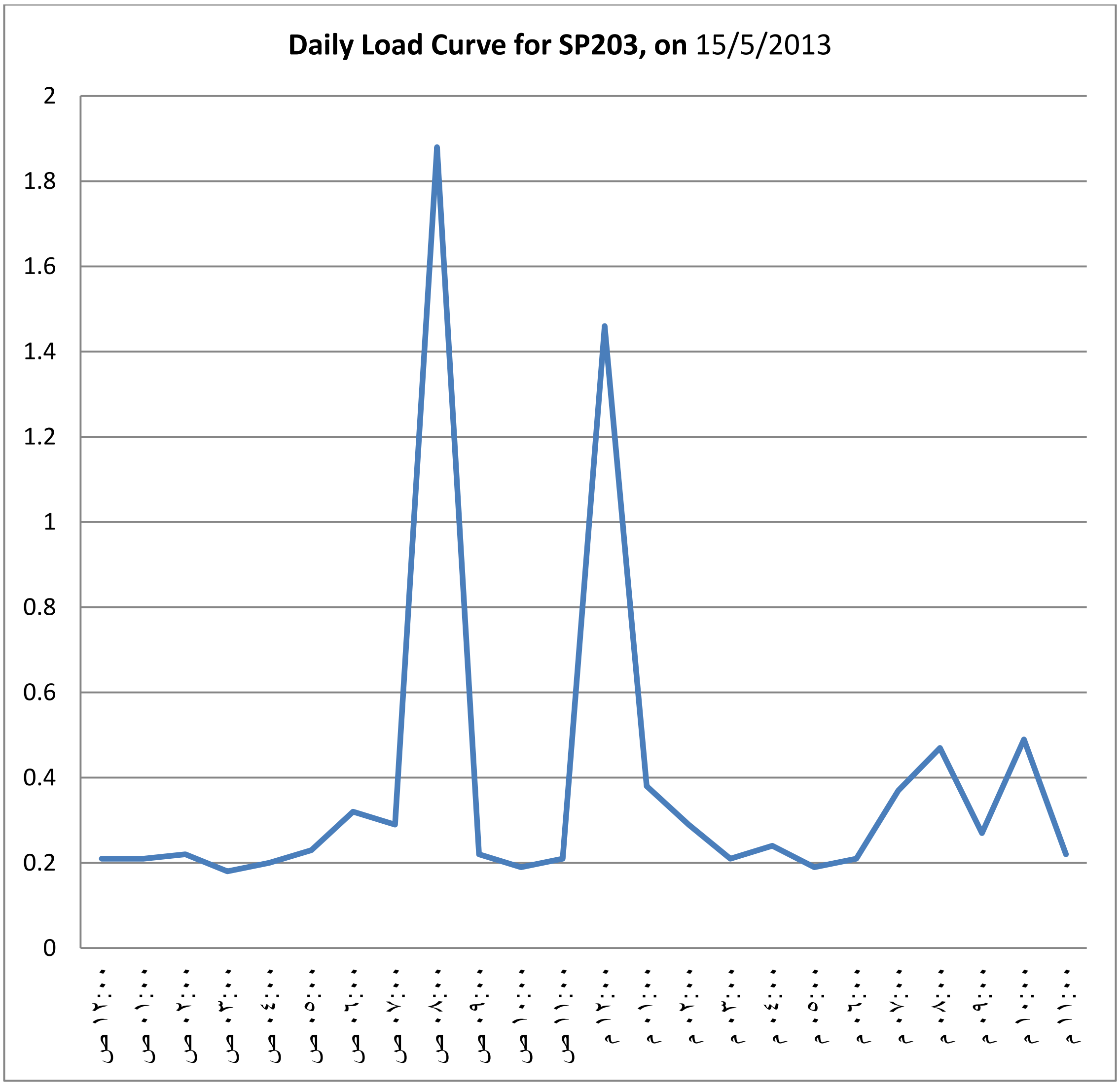

Figure (5.14): Daily Load Curve in 15/5/2013 for SP203

The house load behavior could vary with various definite parameters and no overall control on each consumer’s habit and loads. It’s a very chaotic load and has no standard or global generic model for residential load. Therefore the load for all houses will be considered equal, to simplify the study, and one important period is well studied.

Finally the main load curve was built using aggregating criteria, and the load average between 11:00AM – 2:00 PM was calculated for simulation analysis, since the maximum generations of the PV systems are predicted to generate at these time periods, which may have the extreme effect on the grid.

The final daily load curve, as mentioned before when the data for the whole single phase meters in Al-Jeeb network were aggregated and averaged together, we get the next diagram which can be described as typical residential daily load curve. Figure (5.15) show the average for the whole services on 31 days of May, 2013. In addition, Table (5.3) shows the hourly average power for the whole services on 31 days of May, 2013.

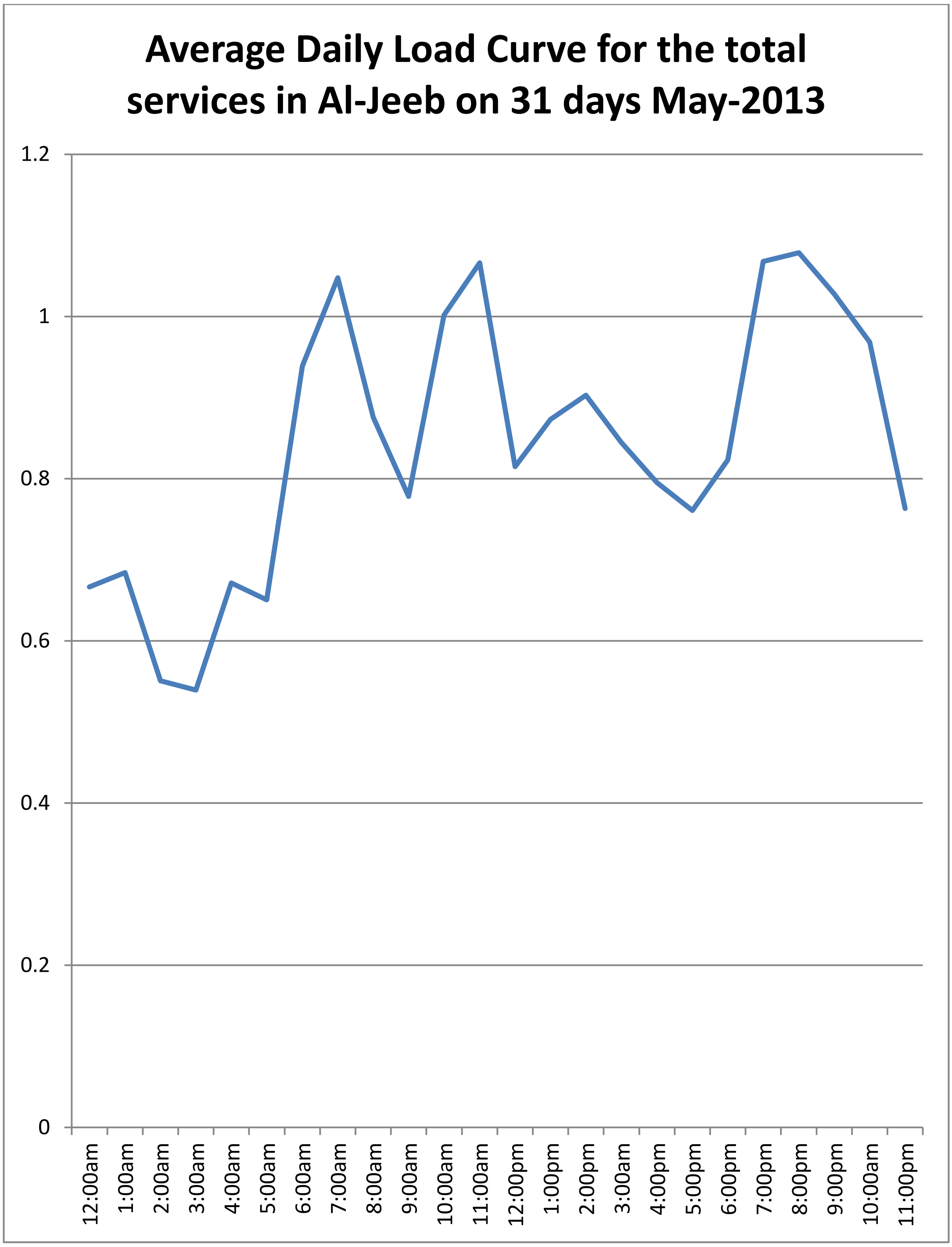

Figure (5.15): The Average for the Whole Services on 31 Days of May, 2013

5.2.5 Real Time Data

Table (5.3): Hourly Average Power for the Whole Services on 31 Days of May, 2013

time (h)	Power (KW)	time (h)	Power (KW)
12:00 AM	0.67	1:00 PM	0.87
1:00 AM	0.68	2:00 PM	0.90
2:00 AM	0.55	3:00 PM	0.84
3:00 AM	0.54	4:00 PM	0.79
4:00 AM	0.67	5:00 PM	0.76
5:00 AM	0.65	6:00 PM	0.82
6:00 AM	0.94	7:00 PM	1.07
7:00 AM	1.04	8:00 PM	1.08
8:00 AM	0.88	9:00 PM	1.03
9:00 AM	0.78	10:00 PM	0.97
10:00 AM	1.00	11:00 PM	0.76

- Max Load = 1.07 KW

- Average Power (11:00 Am – 2:00 PM) = 0.923 KW

- Daily Consumption = 18.29 KWh

The actual physical data had taken instantly (Live Data), Jul-2013 from JDECO smart meter section. The following tables show the actual data, they are numbered from table (5.4) to table (5.9).

Table (5.4): CR5 Feeder's Data

CR5	11:00 AM	12:00 PM	1:00 PM	2:00 PM	Average
Voltage	247	248	248	248	247.75
PF	0.69	0.65	0.68	0.68	0.675
Power	43.2	46.2	39	39	41.85
Frequency	49.95	50	49.95	49.95	49.9625

Table (5.5): CR6 Feeder's Data

CR6	11:00 AM	12:00 PM	1:00 PM	2:00 PM	Average
Voltage	248	248	247	247	247.5
PF	0.96	0.96	0.92	0.92	0.94
Power	41.4	48.6	43.5	43.5	44.25
Frequency	50.02	49.95	50	50	49.9925

Table (5.6): Service TP197's Data

TP197	11:00 AM	12:00 PM	1:00 PM	2:00 PM	Average
Voltage	245	245	245	245	245
PF	0.5	0.25	0.62	0.62	0.4975
Power	0.64	5	5.5	5.5	4.16
Frequency	49.95	49.95	49.95	49.95	49.95

Table (5.7): Service SP938's Data

SP938	11:00 AM	12:00 PM	1:00 PM	2:00 PM	Average
Voltage	244	246	243	243	244
PF	0.71	0.8	0.75	0.75	0.7525
Power	0.33	0.44	0.47	0.47	0.4275
Frequency		49.98	94.93	94.93	79.94667

Table (5.8): Service TP204's Data

TP204	11:00 AM	12:00 PM	1:00 PM	2:00 PM	Average
Voltage	240	244	242	242	242
PF	0.47	0.77	0.77	0.77	0.695
Power	9.8	5.8	9.1	9.1	8.45
Frequency		49.95	49.95	49.95	49.95

Table (5.9): Service SP879's Data

SP879	11:00 AM	12:00 PM	1:00 PM	2:00 PM	Average
Voltage	244	225	220	220	227.25
PF	0.96	0.97	0.98	0.98	0.9725
Power	0.26	0.33	0.48	0.48	0.3875
Frequency		49.99	49.9	49.9	49.93

Note: the services TP197 and TP204 are three phase services from the previous data processing and the attached appendixes, it can be concluded that the maximum load/house during the test period is around 1 KW, and the maximum total load of the transformer is around 90 KW and the maximum PV generation/system is 4.3 KWp as you will see in the next section.

5.2.6 GIS Information:

The next information was collected from GIS section at JDECO. They include all the geographical data needed for real simulation and the parameters of the network like: length of the lines and the grid, type of conductors, impedance and reactance of all elements in the grid. This information was used to build my case in a single line diagram that was used in simulation using Power World Simulator. Figure (5.16) shows the GIS map of Al-Khalayleh Neighborhood.

The following tables that are numbered from table (5.10) to table (5.13) are showing the length, resistance and reactance of each segment on feeder CR6.

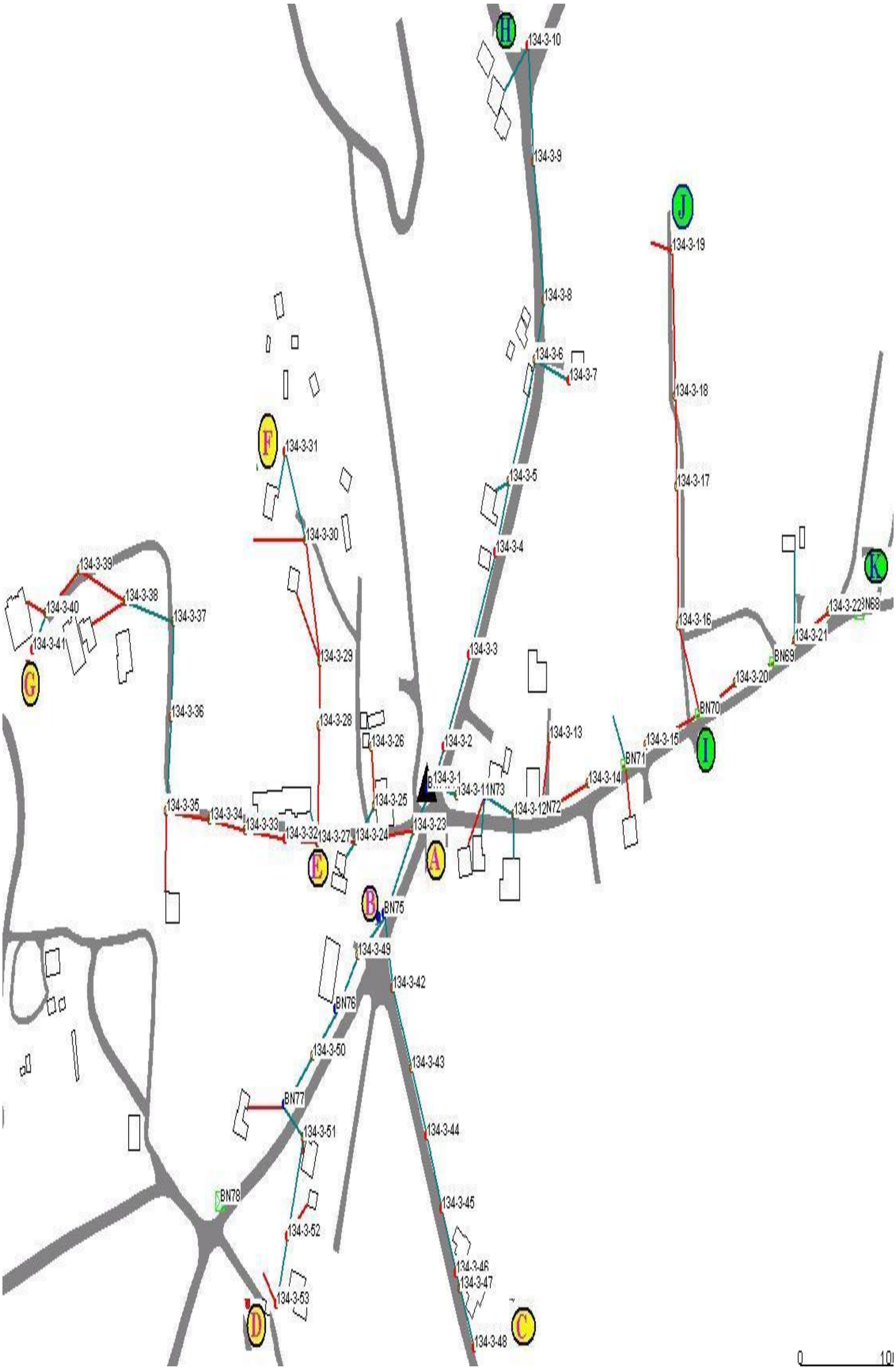

Figure (5.16): Al-Khalayla Neighborhood's GIS Map [61]

Table (5.10): CR6 Feeder (1) segments A- B , A- E

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (Ohm)
134-3-1	134-3-23	31	0.019871	0.002387
134-3-23	BN75	53	0.033973	0.004081
TOTAL		84	0.053844	0.006468
134-3-1	134-3-23	31	0.019871	0.002387
134-3-23	134-3-24	63	0.022617	0.020349
134-3-24	134-3-27	42	0.015078	0.013566
TOTAL		136	0.057566	0.036302

Table (5.11): CR6 Feeder (2) segment B- D

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (Ohm)
BN75	134-3-49	35	0.022435	0.002695
134-3-49	BN76	37	0.023717	0.002849
BN76	134-3-50	34	0.021794	0.002618
134-3-50	BN77	4	0.02564	0.00308
BN77	134-3-51	25	0.016025	0.001925
134-3-51	134-3-52	52	0.033332	0.004004
134-3-52	134-2-53	36	0.023076	0.002772
TOTAL		259	0.166019	0.019943

Table (5.12): CR6 Feeder (3) segment E – F

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (Ohm)
134-3-27	134-3-28	57	0.040869	0.019665
134-3-28	134-3-29	32	0.022944	0.01104
134-3-29	134-3-30	61	0.043737	0.021045
134-3-30	134-3-31	49	0.0588	0.004018
TOTAL		199	0.16635	0.055768

Table (5.13): CR6 Feeder (4) segment E – G

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (1/Ohm)
134-3-27	134-3-32	35	0.012565	0.011305
134-3-32	134-3-33	44	0.015796	0.014212
134-3-33	134-3-34	39	0.014001	0.012597
134-3-34	134-3-35	48	0.017232	0.015504
134-3-35	134-3-36	46	0.029486	0.003542
134-3-36	134-3-37	96	0.061536	0.007392
134-3-37	134-3-38	53	0.033973	0.004081
134-3-38	134-3-39	53	0.038001	0.018285
134-3-39	134-3-40	42	0.030114	0.01449
134-3-40	134-3-41	24	0.015384	0.001848
TOTAL		480	0.268088	0.103256

The following tables that numbered from table (5.14) to table (5.16) are showing the length, resistance and reactance of the feeder CR5.

Table (5.14): CR5 Feeder (1) Segment A–I

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (1/Ohm)
134-3-1	134-3-11	27	0.017307	0.002079
134-3-11	BN73	30	0.01923	0.00231
BN73	134-3-12	33	0.021153	0.002541
134-3-12	BN72	29	0.018589	0.002233
BN72	134-3-14	54	0.019386	0.017442
134-3-14	BN71	42	0.015078	0.013566
BN71	134-3-15	24	0.008616	0.007752
134-3-15	BN70	61	0.021899	0.019703
TOTAL		300	0.14126	0.067626

Table (5.15): CR5 Feeder (2) Segment I–K

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (1/Ohm)
134-3-16	134-3-17	68	0.048756	0.02346
134-3-17	134-3-18	45	0.032265	0.015525
134-3-18	134-3-19	73	0.052341	0.025185
BN70	134-3-16	49	0.035133	0.016905
TOTAL		235	0.1685	0.081075
BN70	134-3-20	41	0.014719	0.013243
134-3-20	BN69	43	0.015437	0.013889
BN69	134-3-21	25	0.008975	0.008075
134-3-21	134-3-22	40	0.01436	0.01292
TOTAL		149	0.05349	0.048127

Table (5.16): CR5 Feeder (3) Segment A-H

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (1/Ohm)
134-3-1	134-3-2	22	0.014102	0.001694
134-3-2	134-3-3	54	0.034614	0.004158
134-3-3	134-3-4	58	0.037178	0.004466
134-3-4	134-3-5	38	0.024358	0.002926
134-3-5	134-3-6	67	0.08040001	0.005494
134-3-6	134-3-8	30	0.036	0.00246
134-3-8	134-3-9	70	0.084	0.00574
134-3-9	134-3-10	58	0.0696	0.004756
TOTAL Segment A - H		**397**	**0.38025**	**0.031694**

For simulation & calculation purposes, per unit resistances and reactances must be calculated, all values were calculated in per unit for each line segment in the grid and inputted to the simulator.

S_{base}= 100 MVA, V_{base}=0.4 KV

For the Segment from A-H at Feeder CR5, Length= 397 meter,

R/Length = 0.38025 Ω, X/Length= 0.031694 Ω

Per unit calculation: $Z_{Base} = \frac{V^2}{Sbase} = 0.0016\ \Omega$

$R = \frac{R}{Zbase} = 237.65625$ p.u, $X = \frac{X}{Zbase} = 19.80875$ p.u

The same calculation were performed to all segments for the two feeders CR5,Cr6

5.3 Load Flow Simulation for the Current Case using Power World Simulator.

5.3.1 Preface of Power World Simulator.

Power World Simulator is a registered trade mark of Power World Corporation; it is an interactive power systems simulation package designed to simulate high voltage power systems operation on a time frame ranging from several minutes to several days. The software contains a highly effective power flow analysis package capable of efficiently solving systems with up to 100,000 buses. [62]

Version 17 of Power World Simulator was used to build the one line diagram and to perform the simulation.

5.3.2 Inputting Grid Information.

The data that collected in the previous sections were used to execute the simulation, loads, network parameters, all data were examined and aggregated and averaged and then filtered by eliminating the inconsistent data. The desired periods between 11:00 – 02:00PM were the maximum output of the PV system assumed to generate, and so the extreme effect of these systems can be tested.

- Inputting Bus Information

The Slack Bus is chosen which is the transformer bus, and the nominal voltage 0.4 KV, see figure (5.17).

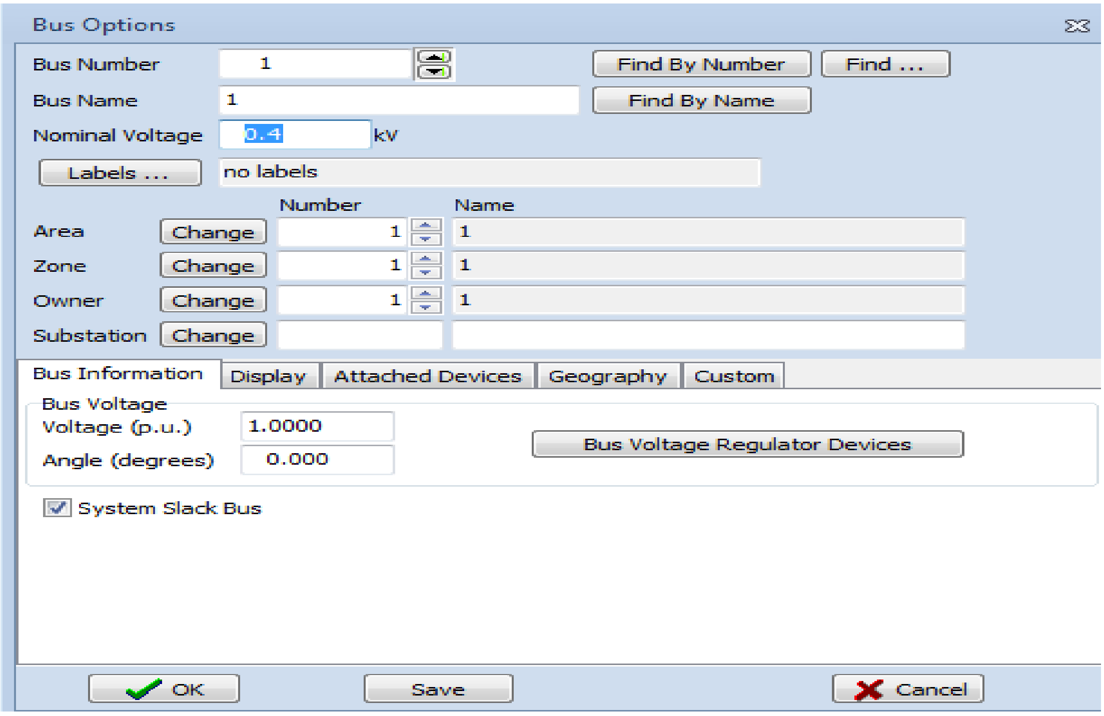

Figure (5.17): Bus Information Dialog Box

- Inputting Transformer Information

S= 160 MVA , PF= 0.85, $S = \sqrt{3}VI$, $P = \sqrt{3}VI\cos\theta$ → P= 136 KW

$Q = S * \sin(\theta)$ → Q= 70 KVAR

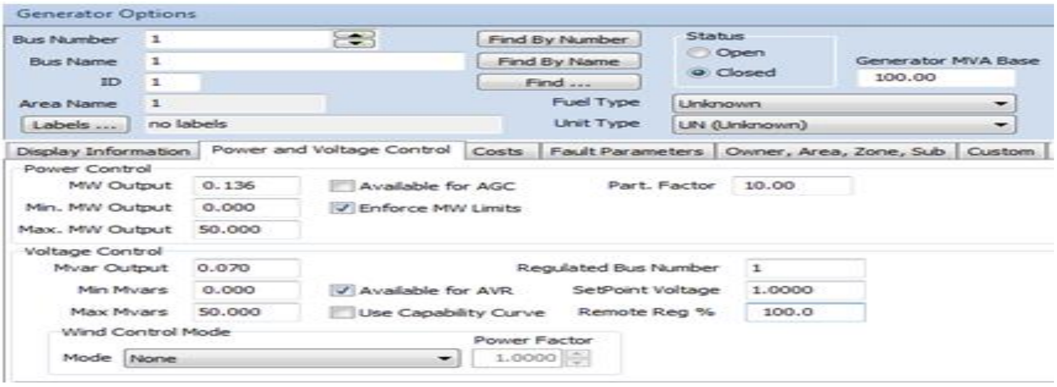

Figure (5.18): Transformer Information Dialog Box

- Inputting Line Information, Note that R, X are in per unit

S_{base}= 100 MVA, V_{base}=0.4 KV, Segment A-H at Feeder CR5, Length= 397 meter, R/Length = 0.38025 Ω, X/Length= 0.031694 Ω.

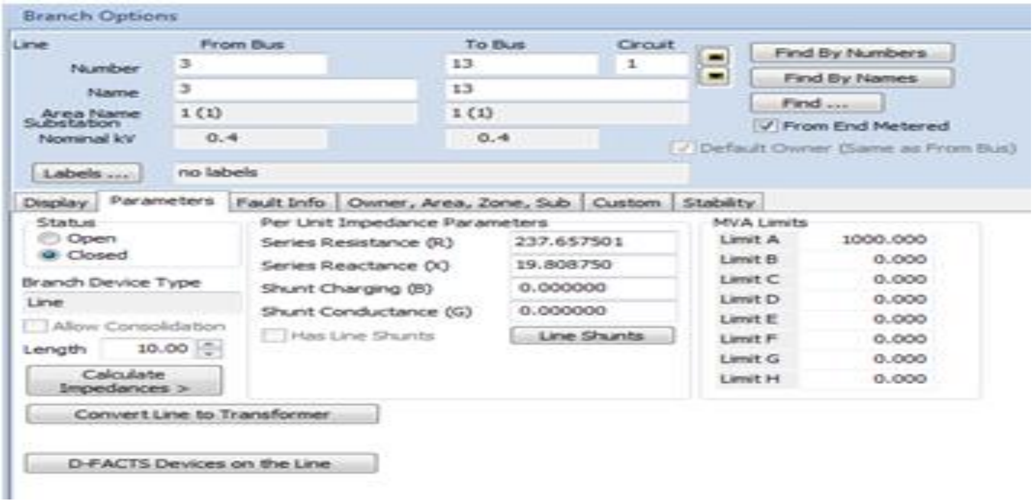

Figure (5.19): Line Information Dialog Box

Per unit calculation:

Z_{Base}= $\frac{V2}{\text{Sbase}}$ = 0.0016 Ω, R= $\frac{R}{\text{Zbase}}$ = 237.65625p.u, X= $\frac{X}{\text{Zbase}}$ = 19.80875p.u

The same calculations were performed to all segments for the two feeders CR5, CR6.

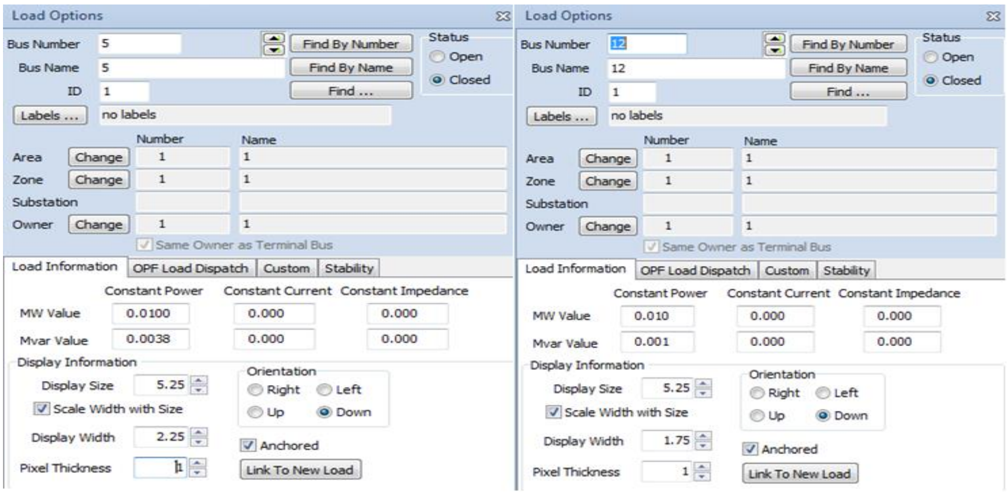

Figure (5.20): Load inputting options dialog box

- Inputting Load Information

$S = \sqrt{3}VI,\ P = \sqrt{3}VI\cos\theta,\ Q = S * \sin(\theta)$

$Power\ Factor = \cos\theta = \frac{P}{S}$, The Loads were Lumped into 8 Groups of 5, 10, 20 KW.

- Feeder 1 (CR5), PF= 0.67

- At P = 5 KW ➔ Q = 5.54 KVAR
- At P = 10 KW ➔ Q= 11.08 KVAR
- At P = 20 KW ➔ Q = 22.16 KVAR

- Feeder 2 (CR6), PF = 0.94

- At P = 5 KW ➔ Q = 1.8 KVAR
- At P = 10 KW ➔ Q = 3.6 KVAR
- At P = 20 KW ➔ Q = 7.3 KVAR

5.3.3 Al-Jeeb's Single Line Diagram Simulation

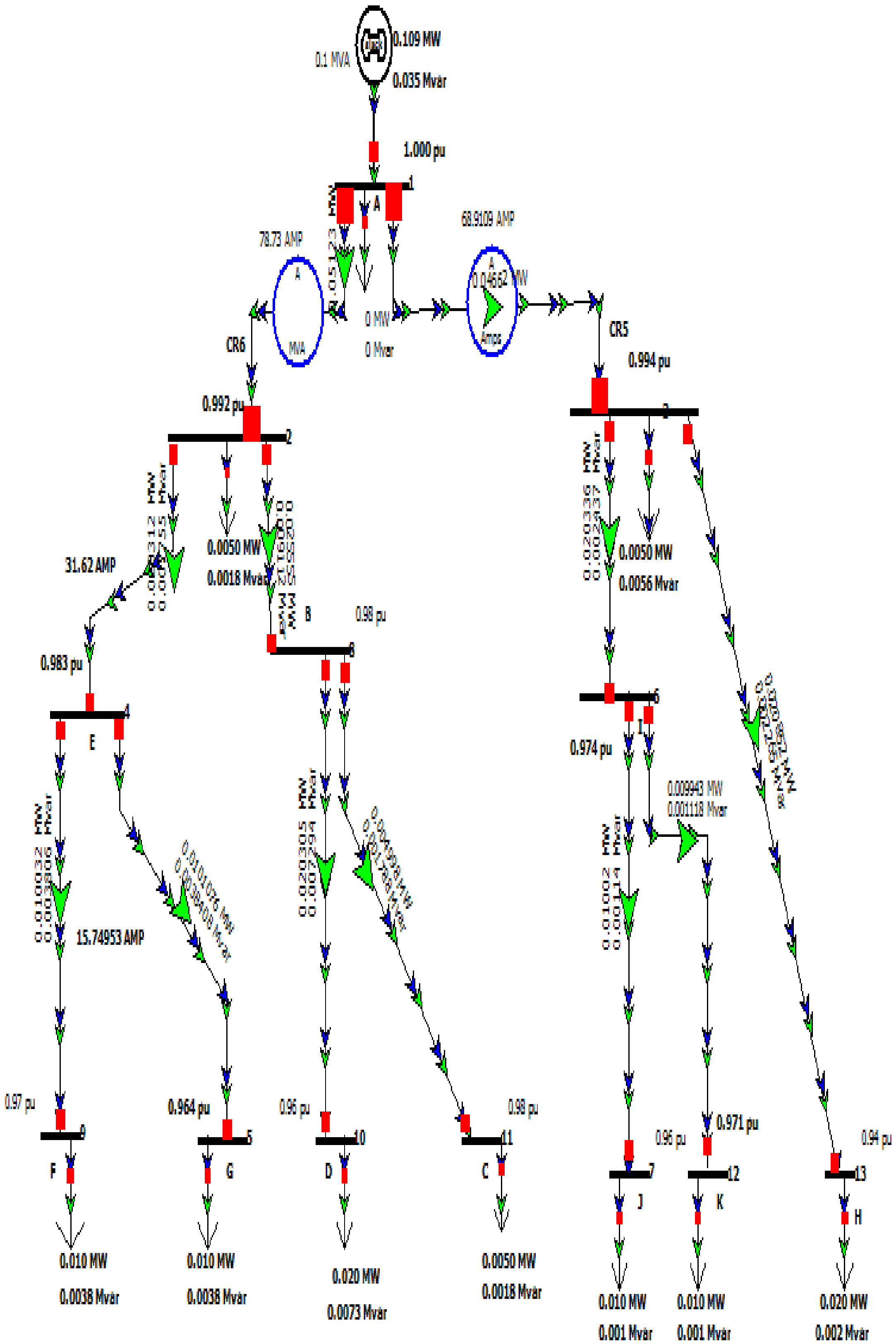

Figure (5.21): AL–Jeeb's One Line Diagram Simulation

5.3.4 Simulation Results

1- The Power Factor of the Transformer = 0.95 at the desired period.

2- At the desired period all the loads values were taken at the midday average between 11:00 – 02:00 PM.

3- The loads were lumped into 8 groups to facilitate the simulation.

4- The Total Losses of the Area = 3.5 KW, at the examined moment which is 3.25%, see figure (5.21).

	Area Num	Gen MW	Load MW	Loss MW	Gen Q/P Ratio	BG Gen PF	Gen Mvar	Loss Mvar	Load Mvar	PU Volt (min)	PU Volt (max)	BG Load PF
1	1	0.108850	0.106000	0.0035334	0.31804	0.95296	0.03462	0.00100	0.03410	0.94320	1.00000	0.95195

Figure (5.22): Area Load Flow Simulation, Solutions

6- Voltage Levels at the Buses varying between 377 – 400 Volt, 0.94 – 1 PU, which are acceptable values according to the Grid Code and IEC Standard, see figure (5.22) and figure (5.23).

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	1	1	1	0.40	1.00000	0.400	0.01100	0.005600	0.108850	0.034619
2	2	2	1	0.40	0.99243	0.397	0.00500	0.001800		
3	3	3	1	0.40	0.99353	0.397	0.00500	0.005600		
4	4	4	1	0.40	0.98329	0.393				
5	5	5	1	0.40	0.96355	0.385	0.01000	0.003800		
6	6	6	1	0.40	0.97445	0.390				
7	7	7	1	0.40	0.96304	0.385	0.01000	0.001100		
8	8	8	1	0.40	0.98339	0.393				
9	9	9	1	0.40	0.97134	0.389	0.01000	0.003800		
10	10	10	1	0.40	0.96106	0.384	0.02000	0.007300		
11	11	11	1	0.40	0.97548	0.390	0.00500	0.001800		
12	12	12	1	0.40	0.97069	0.388	0.01000	0.001100		
13	13	13	1	0.40	0.94320	0.377	0.02000	0.002200		

Figure (5.23): Buses Load Flow Simulation, Solutions

	Number of Bus	Name of Bus	ID	Status	MW	Mvar	MVA	S MW	S Mvar
1	1	1	1	Closed	0.01100	0.005600	0.01234	0.01100	0.005600
2	2	2	1	Closed	0.00500	0.001800	0.00531	0.00500	0.001800
3	3	3	1	Closed	0.00500	0.005600	0.00751	0.00500	0.005600
4	5	5	1	Closed	0.01000	0.003800	0.01070	0.01000	0.003800
5	7	7	1	Closed	0.01000	0.001100	0.01006	0.01000	0.001100
6	9	9	1	Closed	0.01000	0.003800	0.01070	0.01000	0.003800
7	10	10	1	Closed	0.02000	0.007300	0.02129	0.02000	0.007300
8	11	11	1	Closed	0.00500	0.001800	0.00531	0.00500	0.001800
9	12	12	1	Closed	0.01000	0.001100	0.01006	0.01000	0.001100
10	13	13	1	Closed	0.02000	0.002200	0.02012	0.02000	0.002200

Figure (5.24): Loads Flow Analysis

5.4 PSI for Grid Tied PV Systems on Dist. Network (PV Output).

5.4.1 PV Output of 5Kw System:

The next diagram and information is for daily 5KW, PV generation output of a system which was recently installed in Ramallah near Al-Jeeb. The full information and data is in the appendix (A). The output data of the system will be used in the simulation of grid tie impacts on al-Jeeb network, since no PV system available yet in this village and it has the same weather condition and geographical and Metrological circumstances.

From the online webpage for PV system of SMA Inverter Company, the following data of the inverter instantly can be shown. Note that for 5 KW system the max generation power at approximately 11:00 – 2:00PM is around 4.5 KW at peak, and the total KWh generation per day = 35 KWh. See figures; figure (5.24), figure (5.25).

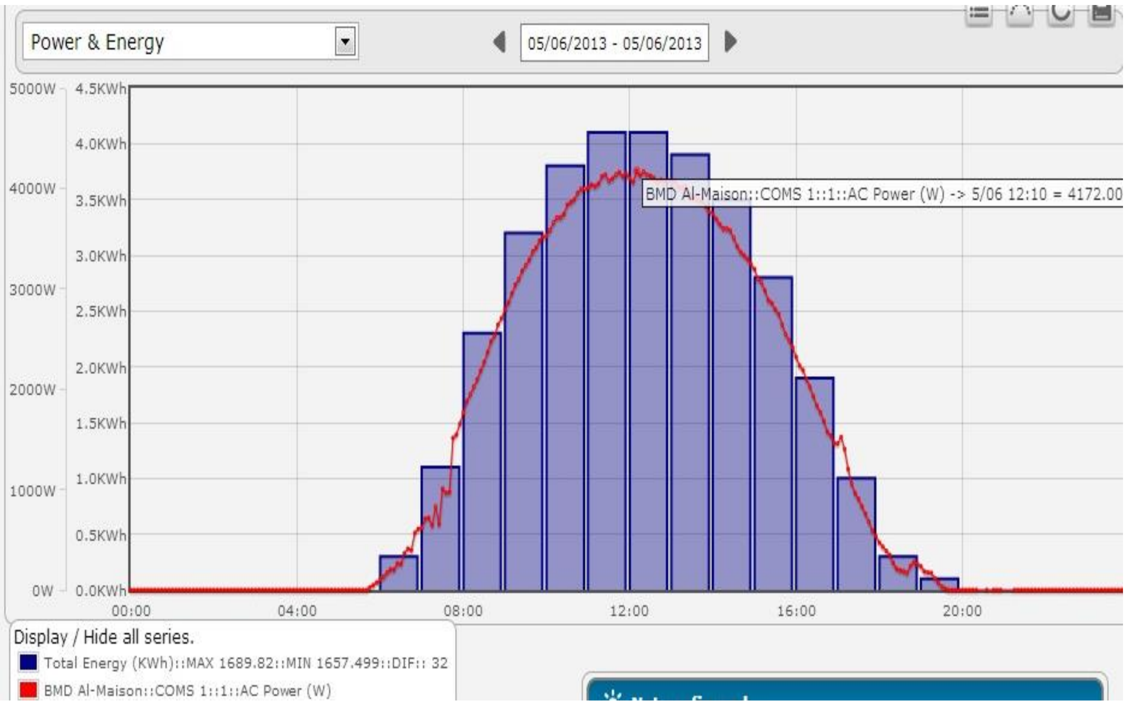

Figure (5.25): Live PV Power Output in 5-6-2013

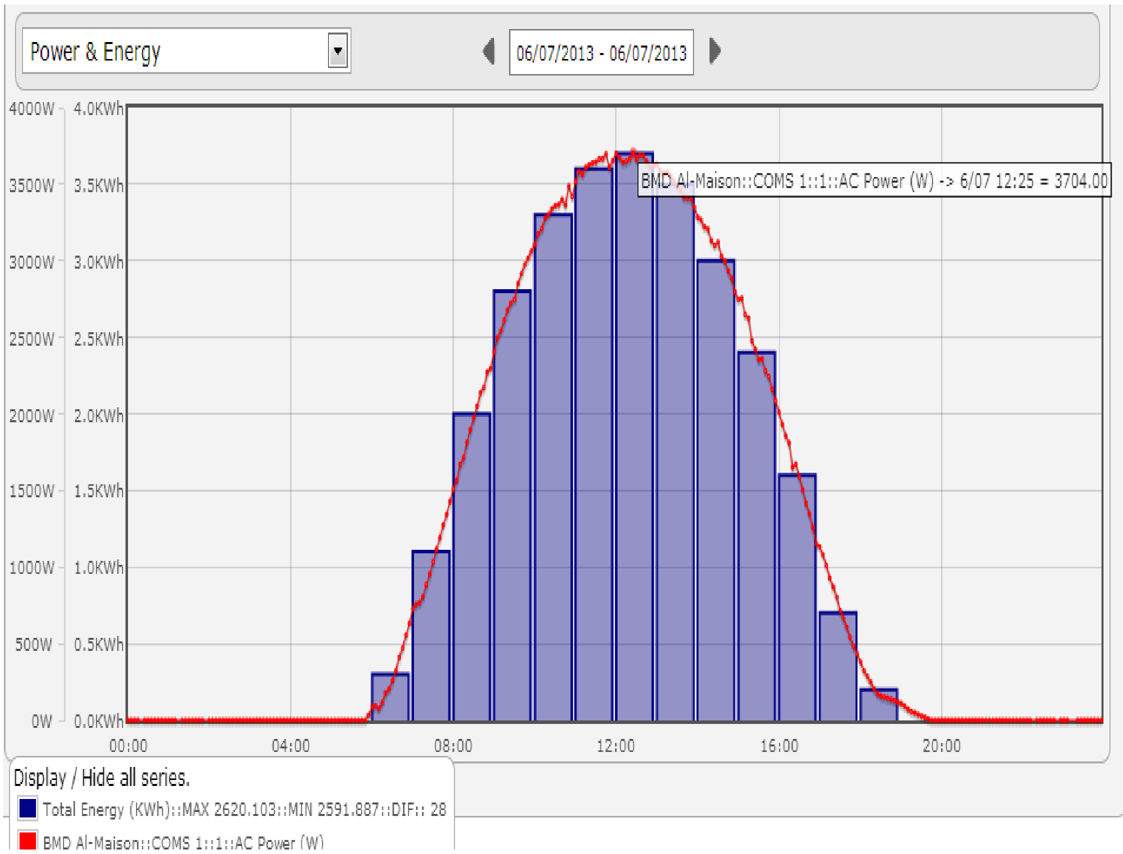

Figure (5.26): Live PV Power Output in 6-7-2013

5.4.2 Simulation of 5Kw PV System using Simulink

A simple simulation on grid connected PV system using MATLAB/SIMULINK program. In this simulation the grid were lumped of Scopes (not real grid) and the metrological data were gathered from Salfit which shown in Table (5.17).

Table (5.17): The Daily Solar Radiation from Jan. to Dec in Ramallah District (from ERC)

Item	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Average Solar Radiation (W/m^2)	609.52	740	955.56	110.2	117	1272
Item	Jul	Aug	Sep	Oct	Nov	Dec
Average Solar Radiation (W/m^2)	1301	1030	940	733.28	521	326.09

5.4.2.1 Design of 5 KWp PV System

The module that was used in this simulation is mono crystalline of 96 cells with 0.6 V as Open Circuit Voltage and 3.4 A as Short Circuit Current. The outputs of this module are:

V_{mpp}=96x0.6x0.8=46.08 V.

I_{mpp}=3.4x0.9=3.06 A.

P_{mpp}=46.08x3.06=141 W.

The following figures (figure (5.26) and figure (5.27)) represent the PV module and its internal connections respectively.

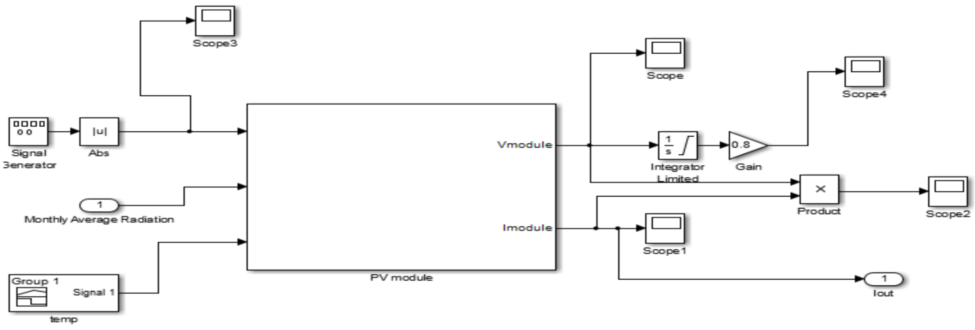

Figure (5.27): PV Module

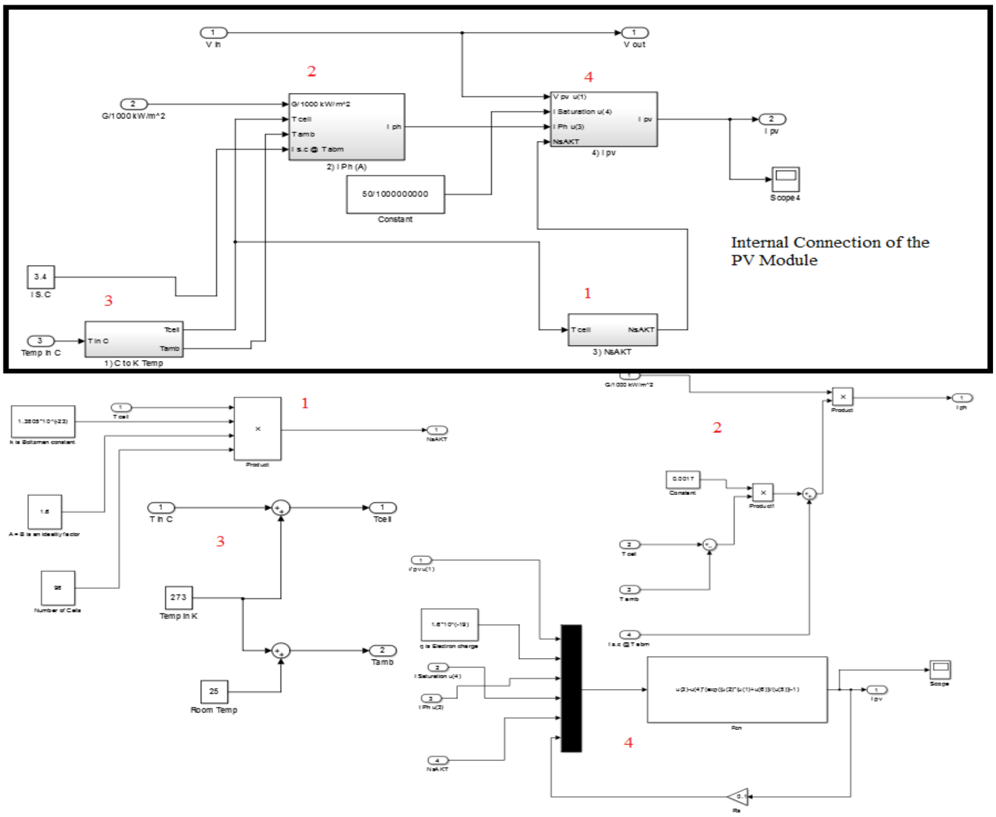

Figure (5.28): Internal Connections of the PV Module

To get the 5 KWp, the peak power divided on P_{mpp}. The number of required modules is:

No. of Modules=5000/141=35.46 Modules.

By multiplying this number with safety factor of 1.15, then the number will be: 35.46x1.15=40 Modules.

The input voltage of the inverter is 200 V. so the number of series modules is:

No. of Series Modules=200/46.08= 4.34, but approximate this number to 5 modules in series. The parallel string of modules is:

No. of Parallel Modules=40/5=8 Strings. The series and parallel connection of the modules shows in figure (5.28).

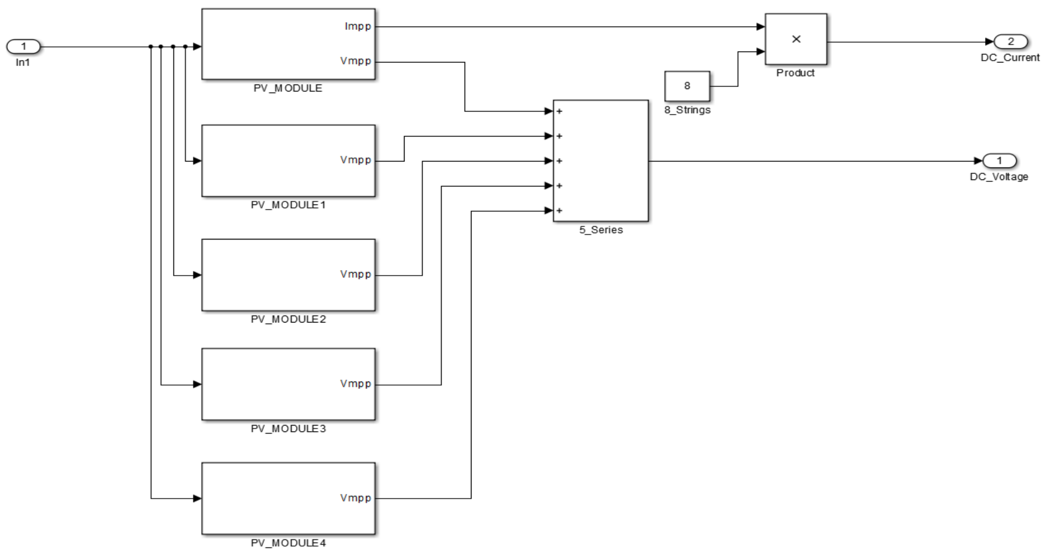

Figure (5.29): Series and Parallel Connection

The inverter which used in this simulation converts the 200 V (DC) to 400 V (Three Phase AC) and its shows in figure (5.29).

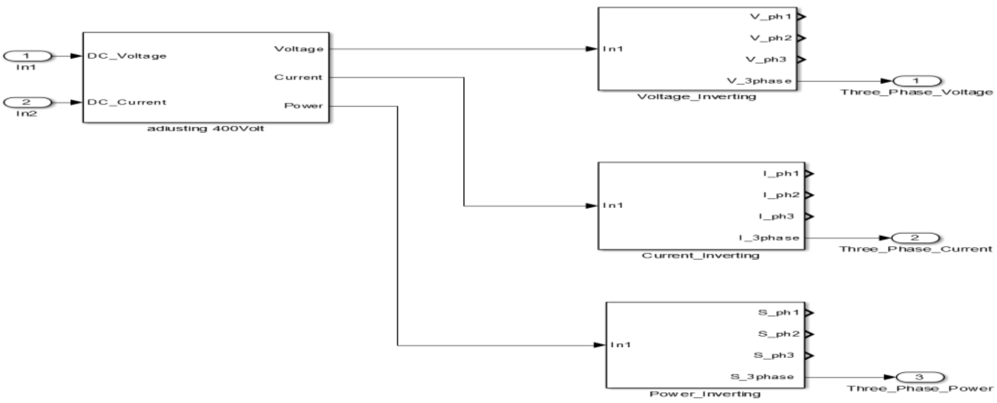

Figure (5.30): Inverter Diagram

The whole system shows in figure (5.30).

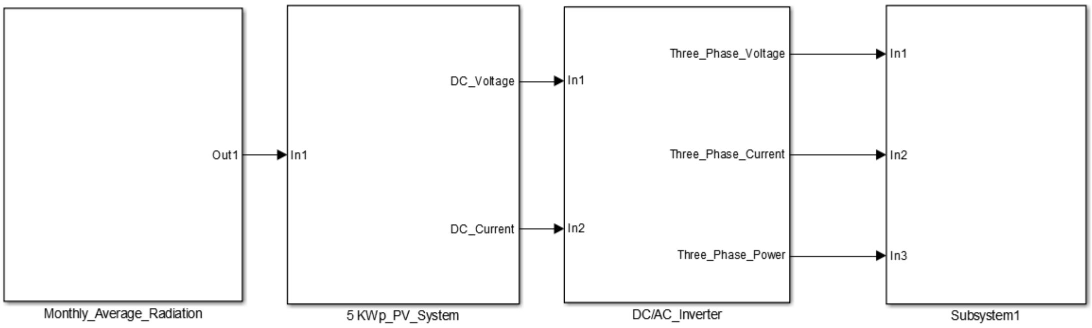

Figure (5.31): The Whole System Diagram

5.4.2.2 Results

As the radiation is monthly average, so the output will be also monthly average. The next figures show the AC output voltage, current and power per month, each figure represents the output in its month.

- January, Power (peak) = 3886.84 W, figure (5.32) shows the output.

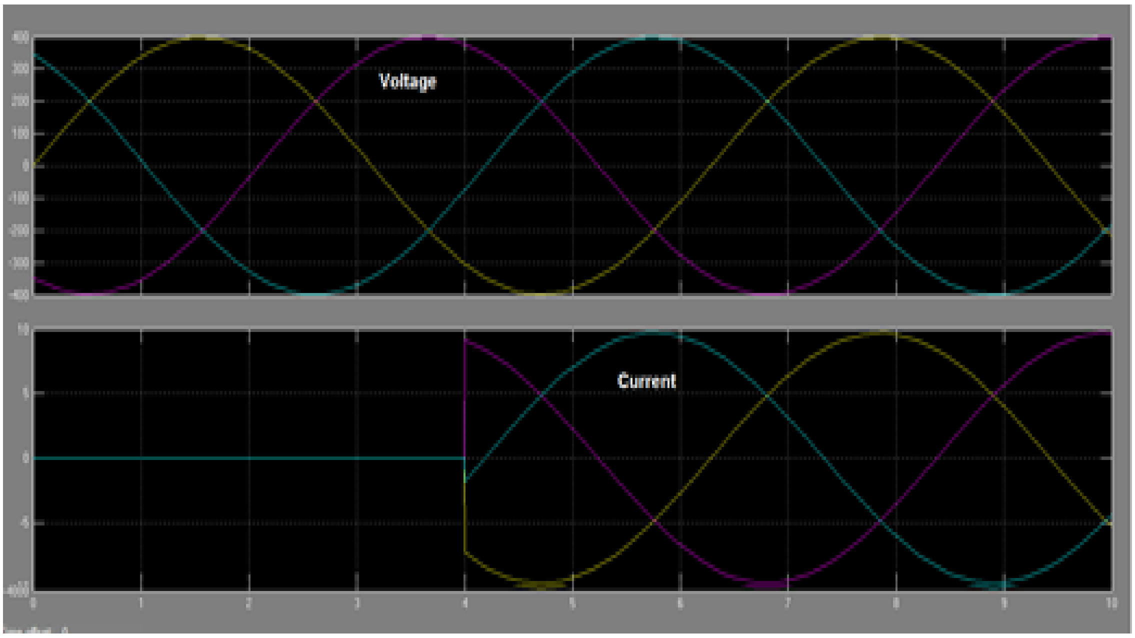

Figure (5.32): January

- March, Power (peak) = 6090 W, figure (5.33) shows the output.

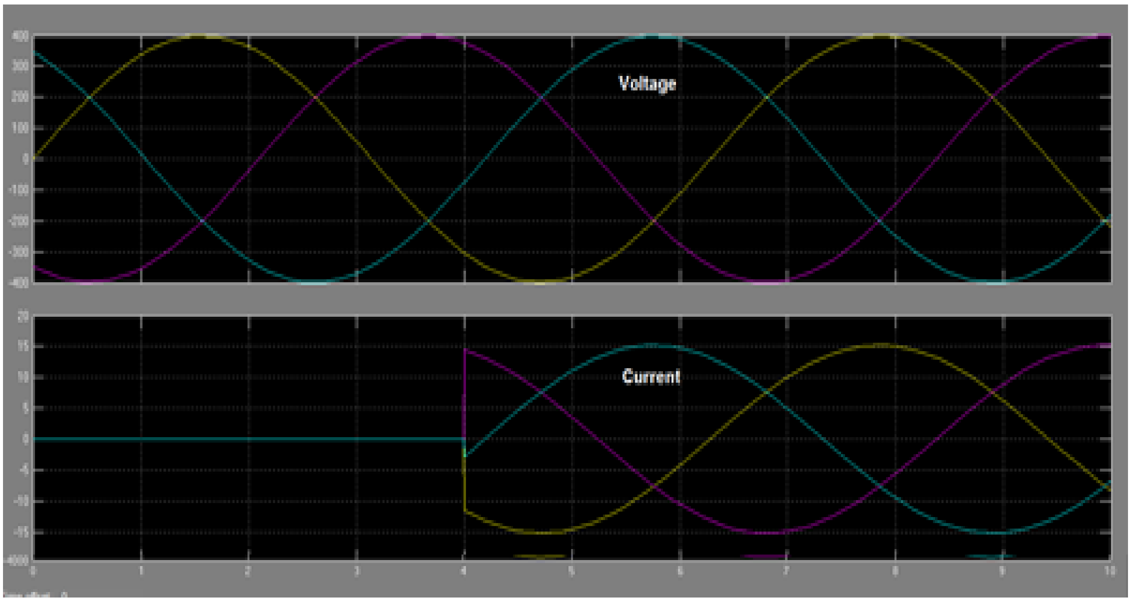

Figure (5.33): March

- June, Power (peak) = 8111 W, figure (5.34) shows the output.

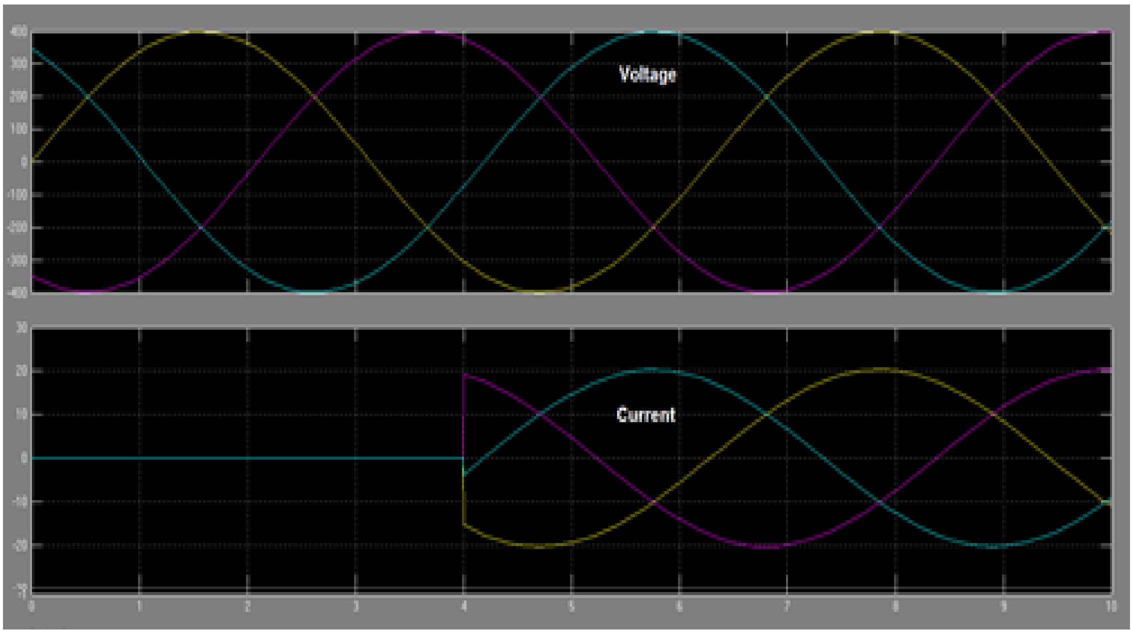

Figure (5.34): June

- September, Power (peak) = 5708 W, figure (5.35) shows the output.

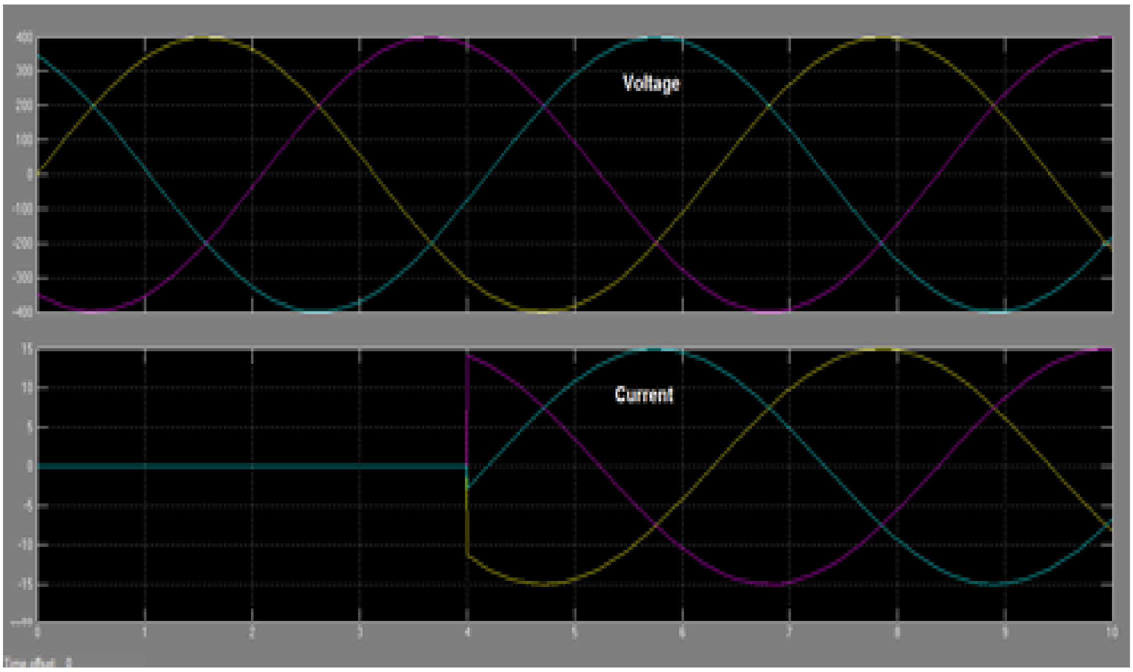

Figure (5. 35): September

- December, Power (peak) = 2078 W, figure (5.35) shows the output.

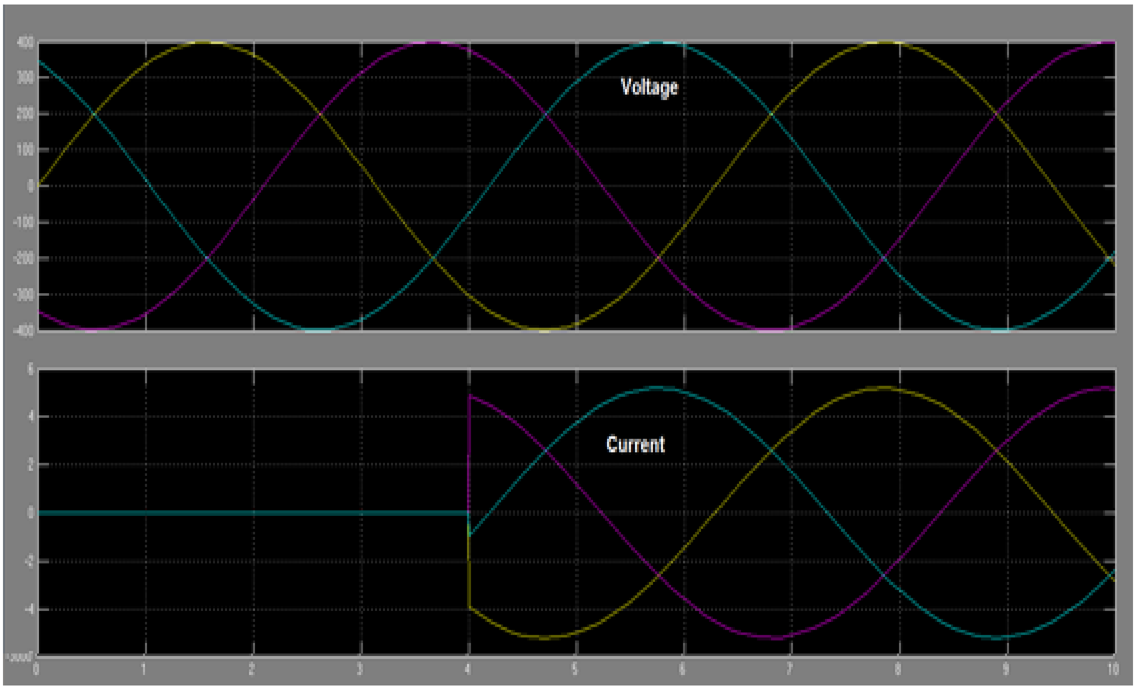

Figure (5.36): December

Notation: the zero value of current and power until the 4 second is due to offset time to the inverter.

In the previous section the output power seems to be like sinusoidal. But actually the AC power isn't sinusoidal. The simulation depends on some configuration of multipliers that cannot do a mathematical multiplication. The following figure (5.37) shows the actual output draw of the AC power.

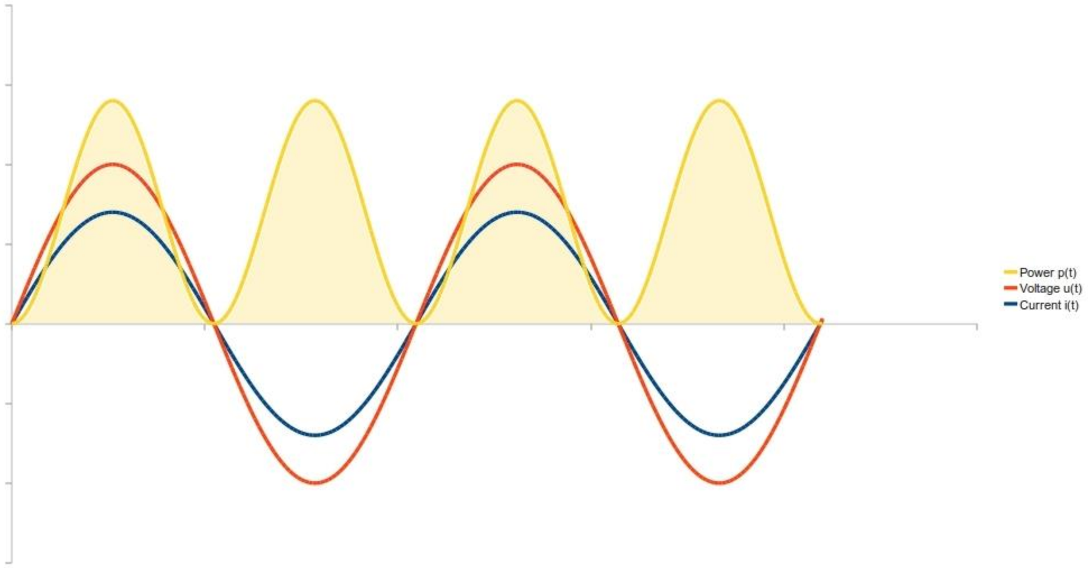

Figure (5.37): Draw of the Output AC Power (Yellow Line is for Power)

5.5 The Impacts of PSI Penetration Levels on Al-Jeeb Electrical Network Using Power World Simulator.

The main purposes of such simulation and analysis are to analyze the expected output from the PV systems that may connect in future to the grid. And to investigate how the PV systems output combined to network, and measure the effect of group of PV systems aggregated together appeared on the grid.

Analysis Assumptions:

1- The total loads and services were lumped and grouped into 8-10 groups, in order to simplify and facilitate the simulation.

2- The PV systems are assumed to generate at their peaks between 11.00 AM – 2:00 PM, and so all the data and parameters were averaged at this period.

3- The previous load profiles data in the previous sections (5.2) in this chapter were averaged, and the PV systems output were taken in sunny days to calculate the extreme effect of PV system on the grid.

4- The PV systems were modeled on the simulator as negative loads since its acting as a current source and not voltage sources (imbedded generators).

5- All the values that were used in simulation based on a real and physical data and information that were used in simulation and analysis of the current case of Al-Jeeb grid in (5.3), (5.3.3).

6- The effects that studied in these simulations: voltage level, power factor, line losses and current swing, at PV penetration levels: 25%, 50%, 75%, 85%, 95% and 100%.

5.5.1 Al-Jeeb's one line Simulation with 25% PV Penetration.

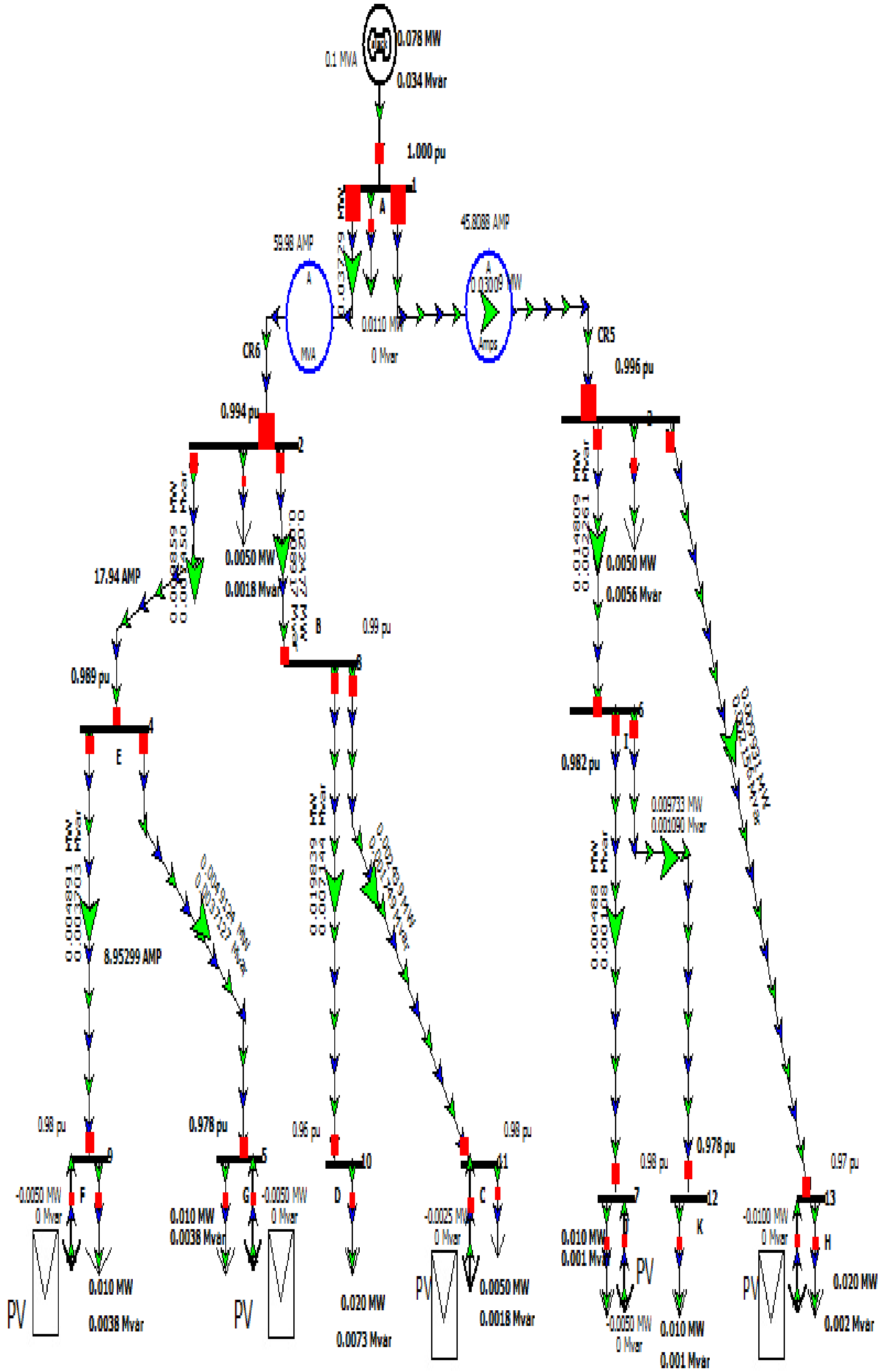

Figure (5.38): Al-Jeeb One Line Diagram at 25% Penetration

	Area Num	Gen MW	Load MW	Loss MW	Gen Q/P Ratio	BG Gen PF	Gen Mvar	Loss Mvar	Load Mvar	PU Volt (min)	PU Volt (max)	BG Load PF
1	1	0.078383	0.078500	0.0016977	0.43407	0.91731	0.03402	0.00049	0.03410	0.96446	1.00000	0.91720

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Load MW	Load Mvar
1	1	1	1	0.40	1.00000	0.400	0.01100	0.005600
2	2	2	1	0.40	0.99419	0.398	0.00500	0.001800
3	3	3	1	0.40	0.99561	0.398	0.00500	0.005600
4	4	4	1	0.40	0.98892	0.396		
5	5	5	1	0.40	0.97818	0.391	0.00500	0.003800
6	6	6	1	0.40	0.98153	0.393		
7	7	7	1	0.40	0.97574	0.390	0.00500	0.001100
8	8	8	1	0.40	0.98622	0.394		
9	9	9	1	0.40	0.98248	0.393	0.00500	0.003800
10	10	10	1	0.40	0.96446	0.386	0.02000	0.007300
11	11	11	1	0.40	0.98227	0.393	0.00250	0.001800
12	12	12	1	0.40	0.97788	0.391	0.01000	0.001100
13	13	13	1	0.40	0.97148	0.389	0.01000	0.002200

Figure (5.39): Results at 25% Penetration

Results of 25% Penetration Analysis:

1- No evidence of back feedings occurs on the lines or on the transformer.

2- Power on Transformer Decrease to = 78.38 KW

3- Losses on the Grid Decrease to = 1.7 KW, 2.2%

4- Power Factor Decrease to = 0.92

5- Voltage Levels on the Buses Improved and Varying between 0.96 – 1 PU.

5.5.2 Al-Jeeb's one line Simulation with 50% PV Penetration.

	Area Num	Gen MW	Load MW	Loss MW	Gen Q/P Ratio	BG Gen PF	Gen Mvar	Loss Mvar	Load Mvar	PU Volt (min)	PU Volt (max)	BG Load PF
1	1	0.050740	0.051000	0.0009929	0.67761	0.82784	0.03438	0.00026	0.03410	0.96692	1.00000	0.83130

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Load MW	Load Mvar
1	1	1	1	0.40	1.00000	0.400	0.01100	0.005600
2	2	2	1	0.40	0.99576	0.398	0.00500	0.001800
3	3	3	1	0.40	0.99748	0.399	0.00500	0.005600
4	4	4	1	0.40	0.99405	0.398		
5	5	5	1	0.40	0.99164	0.397	0.00000	0.003800
6	6	6	1	0.40	0.98784	0.395		
7	7	7	1	0.40	0.98730	0.395	0.00000	0.001100
8	8	8	1	0.40	0.98864	0.395		
9	9	9	1	0.40	0.99275	0.397	0.00000	0.003800
10	10	10	1	0.40	0.96692	0.387	0.02000	0.007300
11	11	11	1	0.40	0.98842	0.395	0.00000	0.001800
12	12	12	1	0.40	0.98422	0.394	0.01000	0.001100
13	13	13	1	0.40	0.99704	0.399	0.00000	0.002200

Figure (5.40): Results at 50% Penetration

50% Penetration, one line simulation results:

1- No evidence of back feedings occurs on the lines or on the transformer.

2- Power on Transformer Decrease to = 51 KW

3- Losses on the Grid Decrease to = 1 KW, 2%

4- Power Factor Decrease to = 0.83

5- Voltage Levels on the Buses Improved and Varying between 0.97 – 1 PU.

5.5.3 Al-Jeeb's one line Simulation with 75%, 85% and 95% PV Penetration

75% Penetration, one line simulation results:

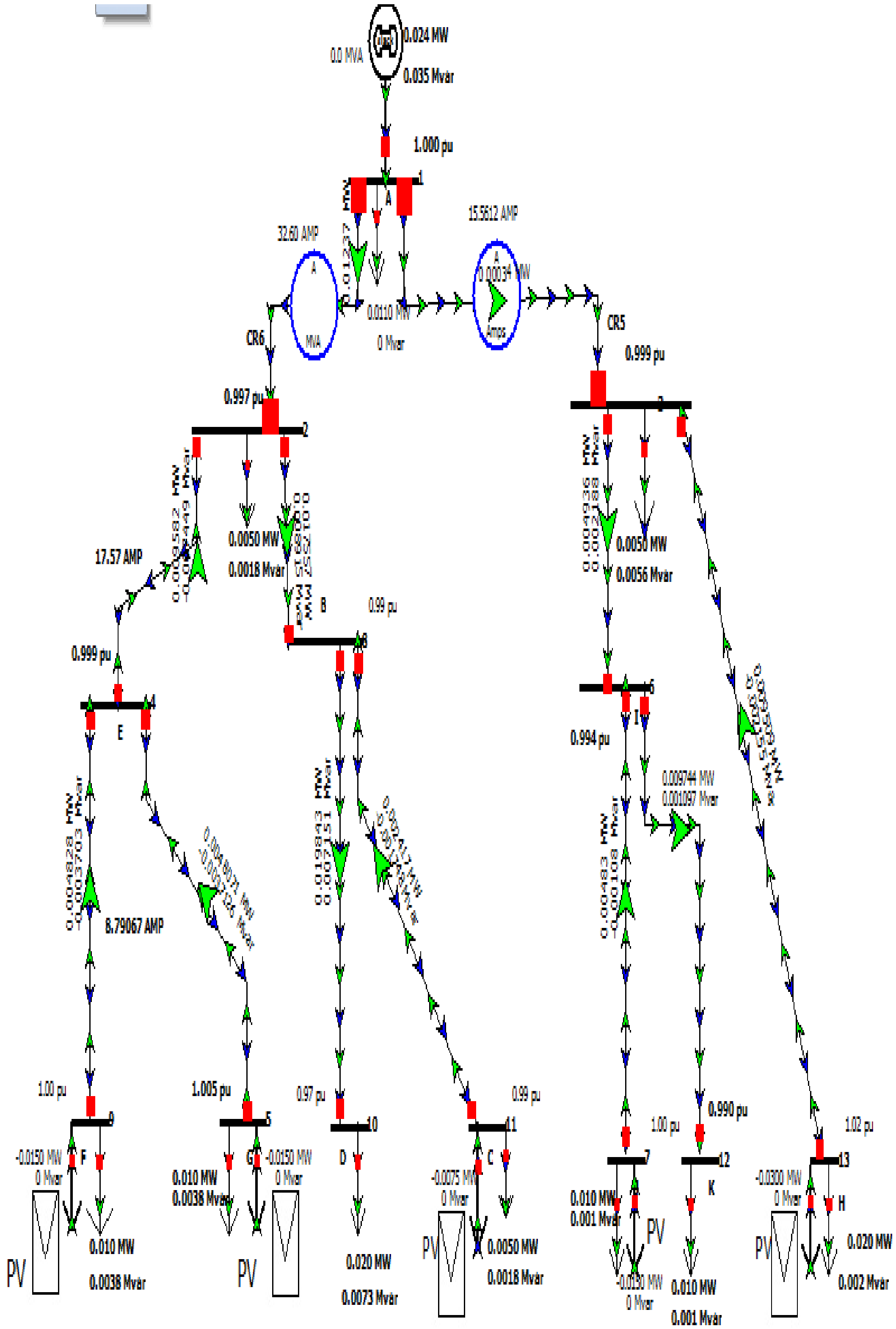

Figure (5.41): Al-Jeeb One Line Diagram at 75% PV Penetration

	Area Num	Gen MW	Load MW	Loss MW	Gen Q/P Ratio	BG Gen PF	Gen Mvar	Loss Mvar	Load Mvar	PU Volt (min)	PU Volt (max)	BG Load PF
1	1	0.023709	0.023500	0.0011578	1.48769	0.55787	0.03527	0.00026	0.03410	0.96933	1.02150	0.56745

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Load MW	Load Mvar
1	1	1	1	0.40	1.00000	0.400	0.01100	0.005600
2	2	2	1	0.40	0.99727	0.399	0.00500	0.001800
3	3	3	1	0.40	0.99929	0.400	0.00500	0.005600
4	4	4	1	0.40	0.99905	0.400		
5	5	5	1	0.40	1.00476	0.402	-0.00500	0.003800
6	6	6	1	0.40	0.99400	0.398		
7	7	7	1	0.40	0.99858	0.399	-0.00500	0.001100
8	8	8	1	0.40	0.99099	0.396		
9	9	9	1	0.40	1.00280	0.401	-0.00500	0.003800
10	10	10	1	0.40	0.96933	0.388	0.02000	0.007300
11	11	11	1	0.40	0.99448	0.398	-0.00250	0.001800
12	12	12	1	0.40	0.99039	0.396	0.01000	0.001100
13	13	13	1	0.40	1.02150	0.409	-0.01000	0.002200

Figure (5.42): Results at 75% Penetration

1- Most of the lines start to back feeding.

2- Power on Transformer Decrease to = 23 KW

3- Losses on the Grid Decrease to = 1.2 KW

4- Power Factor Decrease to = 0.56

5- Voltage Levels on the Buses Varying between 0.97 – 1.02 PU.

6- The Transformer Point star to being Reactive Power Source.

85% Penetration, one line simulation results:

	Area Num	Gen MW	Load MW	Loss MW	Gen Q/P Ratio	BG Gen PF	Gen Mvar	Loss Mvar	Load Mvar	PU Volt (min)	PU Volt (max)	BG Load PF
1	1	0.009764	0.008500	0.0017291	3.61652	0.26651	0.03531	0.00058	0.03410	0.97171	1.02948	0.24187

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Load MW	Load Mvar
1	10	10	1	0.40	0.97171	0.389	0.02000	0.007300
2	12	12	1	0.40	0.98981	0.396	0.01000	0.001100
3	8	8	1	0.40	0.99333	0.397		
4	6	6	1	0.40	0.99342	0.397		
5	11	11	1	0.40	0.99681	0.399	-0.00250	0.001800
6	7	7	1	0.40	0.99800	0.399	-0.00500	0.001100
7	3	3	1	0.40	0.99871	0.399	0.00500	0.005600
8	2	2	1	0.40	0.99959	0.400	0.00500	0.001800
9	1	1	1	0.40	1.00000	0.400	0.01100	0.005600
10	4	4	1	0.40	1.00808	0.403		
11	13	13	1	0.40	1.00972	0.404	-0.00500	0.002200
12	9	9	1	0.40	1.02167	0.409	-0.01500	0.003800
13	5	5	1	0.40	1.02948	0.412	-0.01500	0.003800

Figure (5.43): Results at 85% Penetration

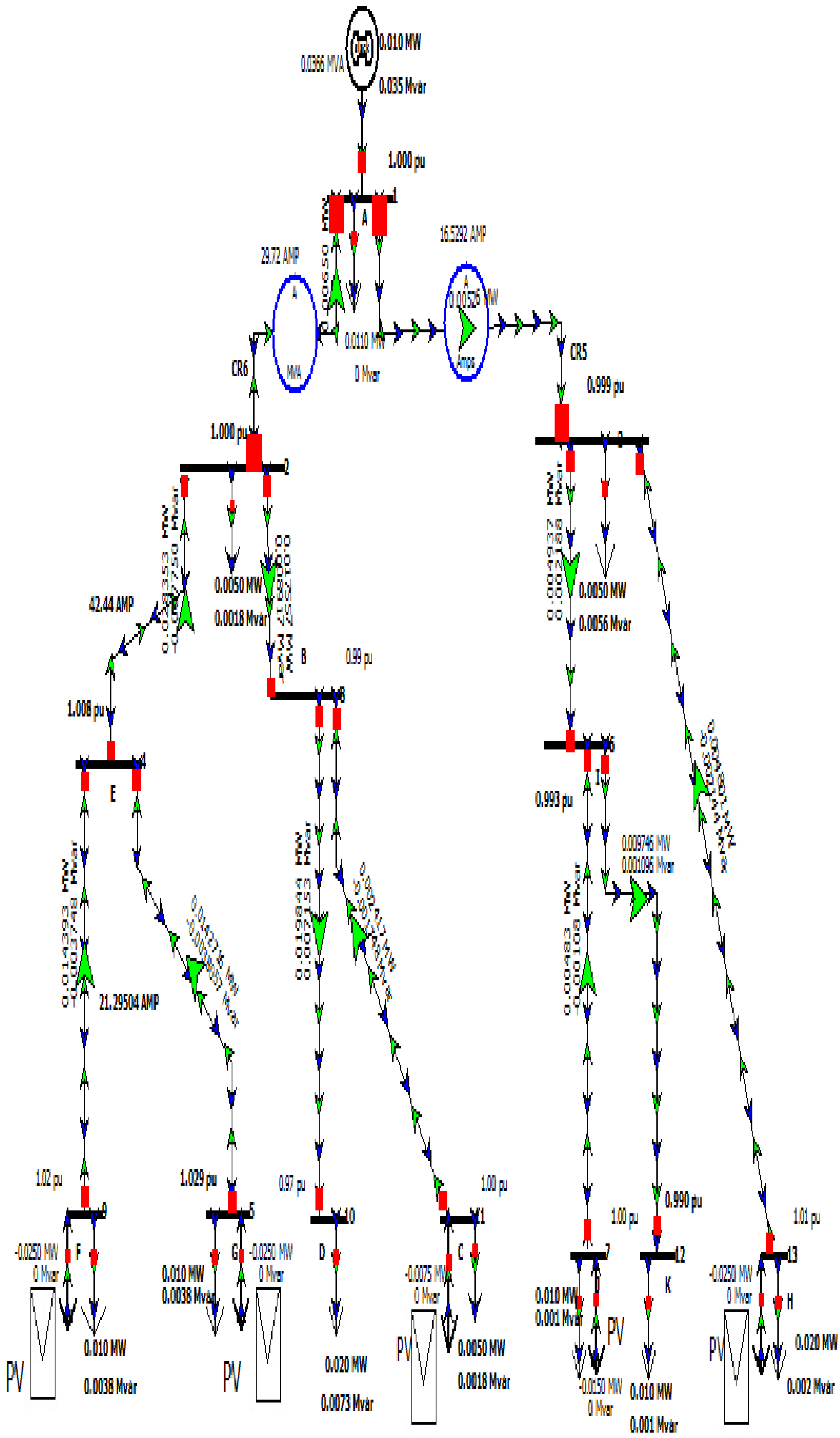

Figure (5.44): Al-Jeeb one Line Simulation With 85 % Penetration

Note that: the green arrows are real power flow, and the blue arrows are reactive power flows

1- Most of the lines start to back feeding.

2- Power on Transformer Decrease to = 10 KW

3- Losses on the Grid = 1.7 KW

4- Power Factor Decrease to = 0.27

5- Voltage Levels on the Buses Varying between 0.97 – 1.03 PU. Note that all busses voltages around 1 per unit.

6- The Transformer Point star to being Reactive Power Source only.

95% Penetration, one line simulation results:

	Area Num	Gen MW	Load MW	Loss MW	Gen Q/P Ratio	BG Gen PF	Gen Mvar	Loss Mvar	Load Mvar	PU Volt (min)	PU Volt (max)	BG Load PF
1	1	0.000357	-0.001500	0.0021578	99.55494	0.01004	0.03558	0.00071	0.03410	0.97224	1.03161	-0.04395

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Load MW	Load Mvar
1	10	10	1	0.40	0.97224	0.389	0.02000	0.007300
2	12	12	1	0.40	0.99046	0.396	0.01000	0.001100
3	8	8	1	0.40	0.99385	0.398		
4	6	6	1	0.40	0.99406	0.398		
5	11	11	1	0.40	0.99733	0.399	-0.00250	0.001800
6	7	7	1	0.40	0.99864	0.399	-0.00500	0.001100
7	3	3	1	0.40	0.99935	0.400	0.00500	0.005600
8	1	1	1	0.40	1.00000	0.400	0.01100	0.005600
9	2	2	1	0.40	1.00011	0.400	0.00500	0.001800
10	4	4	1	0.40	1.01025	0.404		
11	13	13	1	0.40	1.02158	0.409	-0.01000	0.002200
12	9	9	1	0.40	1.02867	0.411	-0.02000	0.003800
13	5	5	1	0.40	1.03161	0.413	-0.01500	0.003800

Figure (5.45): Results at 85% Penetration

5.5.4 Al-Jeeb's one line Simulation with 100% PV Penetration.

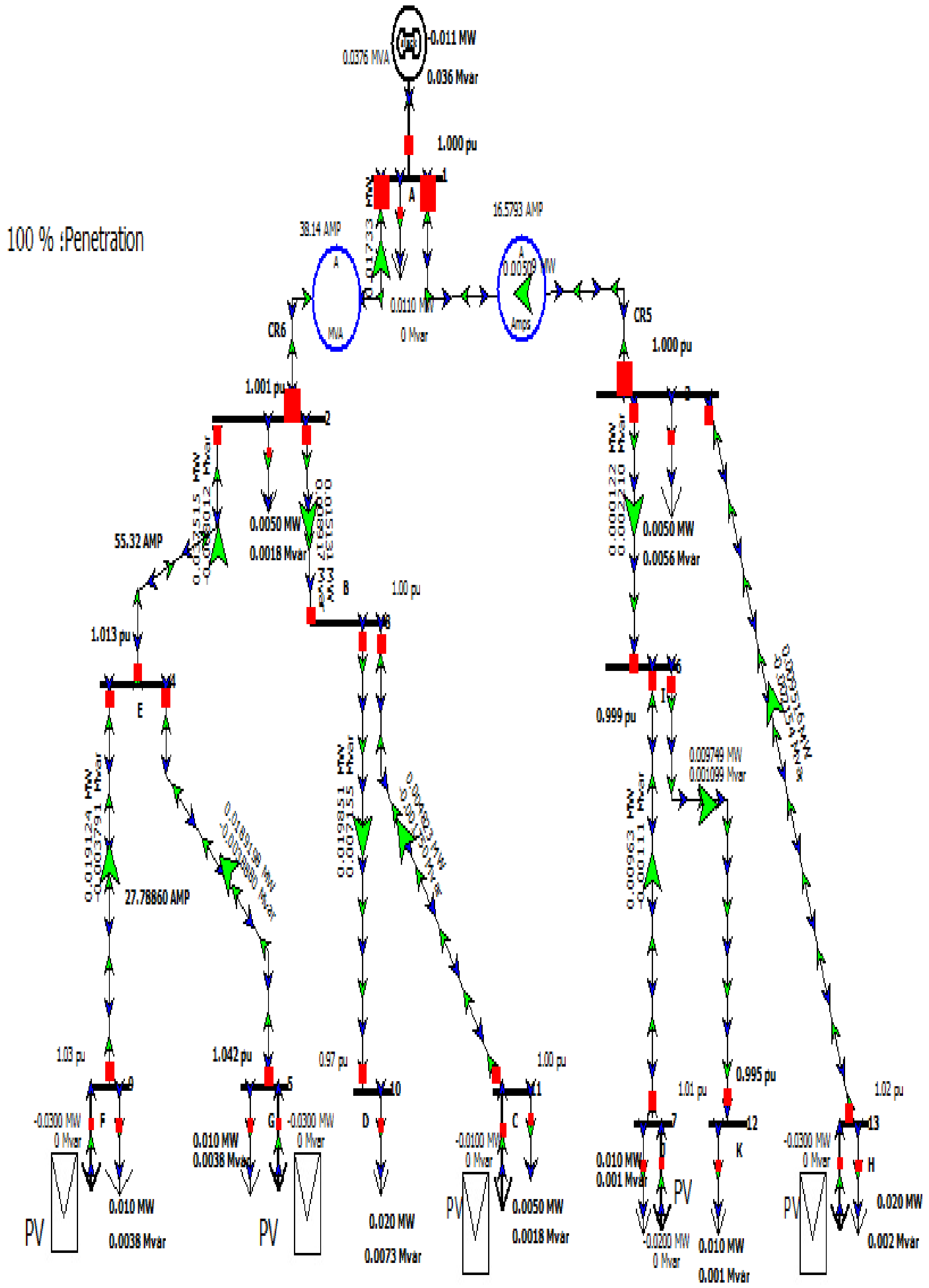

Figure (5. 46): Al-Jeeb One Line Simulation with 100 % PV Penetration

Note that: the green arrows are real power flow, and the blue arrows are reactive power flows

	Area Num	Gen MW	Load MW	Loss MW	Gen Q/P Ratio	BG Gen PF	Gen Mvar	Loss Mvar	Load Mvar	PU Volt (min)	PU Volt (max)	BG Load PF
1	1	0.007679	0.006500	0.0016093	4.58102	0.21327	0.03518	0.00037	0.03410	0.97089	1.03348	0.18724

	Number	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Load MW	Load Mvar
1	1	1	1	0.40	1.00000	0.400	0.01100	0.005600
2	2	2	1	0.40	0.99830	0.399	0.00500	0.001800
3	3	3	1	0.40	1.00027	0.400	0.00500	0.005600
4	4	4	1	0.40	1.00246	0.401		
5	5	5	1	0.40	1.01374	0.405	-0.00850	0.003800
6	6	6	1	0.40	0.99796	0.399		
7	7	7	1	0.40	1.00607	0.402	-0.00850	0.001100
8	8	8	1	0.40	0.99252	0.397		
9	9	9	1	0.40	1.00969	0.404	-0.00850	0.003800
10	10	10	1	0.40	0.97089	0.388	0.02000	0.007300
11	11	11	1	0.40	0.99821	0.399	-0.00400	0.001800
12	12	12	1	0.40	0.99437	0.398	0.01000	0.001100
13	13	13	1	0.40	1.03348	0.413	-0.01500	0.002200

Figure (5.47): Results at 100% Penetration

1- All the main feeders, lines back feeding and reverse power occur to the transformer point.

2- Power on Transformer Decrease to = 0 KW

3- Losses on the Grid increase to = 2.6 KW

4- Power Factor start to increase again to = 0.3

5- Voltage Levels on the Buses Varying between 0.97 – 1.04 PU.

6- The Transformer Point is a Reactive Power Source only.

5.6 Comparison Analysis of PV Penetration Levels on Al-Jeeb Network, Using Power World Simulator.

See table (5.18).

Table (5.18): Comparison Analysis of Al-Jeeb Grid at Different PV Penetration Levels

Penetration\ Outputs	Power Factor	Losses	Transformer Power (KW)	Voltages (p.u)
Current Case	0.95	3.5	109	0.94-1
25% PV	0.92	1.7	78.38	0.96-1
50% PV	0.83	1	51	0.97-1
75% PV	0.56	1.2	23	0.97-1.02
85% PV	0.27	1.7	10	0.97-1.03
95% PV	0.01	2.2	3.5	0.97-1.032
100% PV	0.3	2.6	0	0.97-1.04

5.6.1 Voltage level

From the simulation results, improving in the voltage level at the end of network was noticed at 25 % PV grid tied penetration, but after 50 % of PV penetration overvoltage on the grid but still within the acceptable levels according to the grid code and IEC standard, over voltage out of the range after 75% start to occur especially in the rural feeder with law load.

At 100% penetration all the feeders were feeding back causing reverse power flow in the network towards the source, raising the voltage above the nominal.

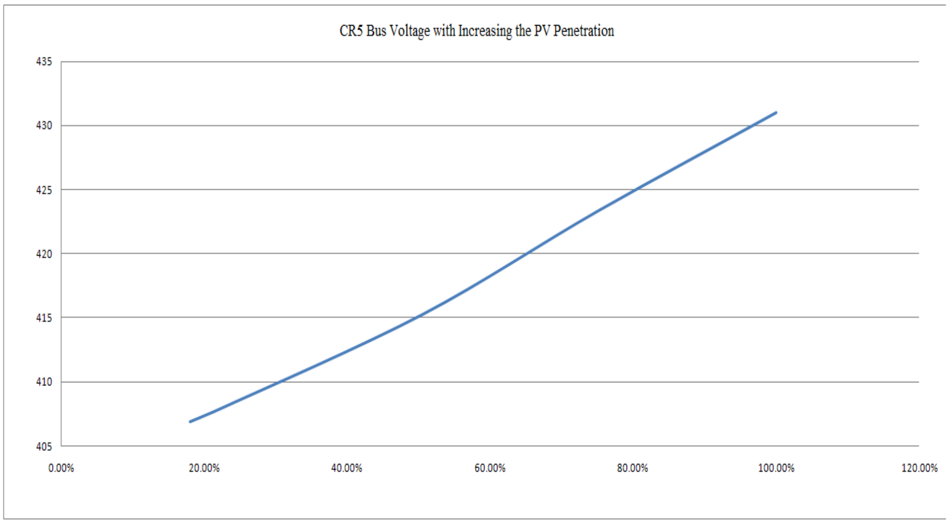

Figure (5. 48): CR5 Voltage Bus with Increasing the PV Penetration

5.6.2 Power Factor:

From the simulation results it was noted that as the penetration level increases in the feeder the power factor level at the grid's transformer point (Bus) decreases significantly, until it reaches around zero level. If the penetration level of PV exceeds 90 % and reverses power flow occurs, the power factor level starts to increase again.

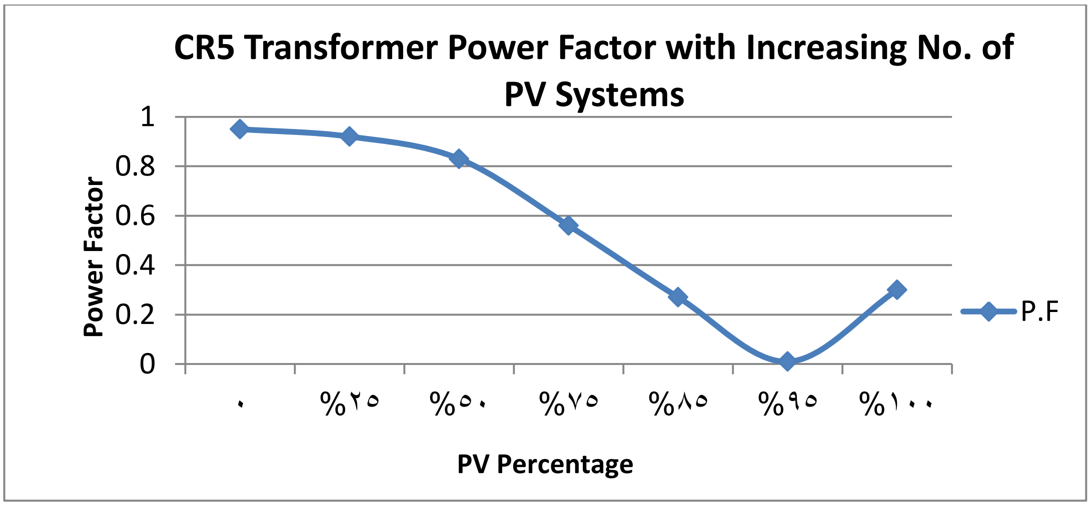

Figure (5.49): CR5Transformer Power Factor

5.6.3 Current Swings

It was simulated by switching off all the PV generation suddenly and calculating the difference in current. After 80% penetration the value of the swing current exceed 100 A which can be harmful on the network.

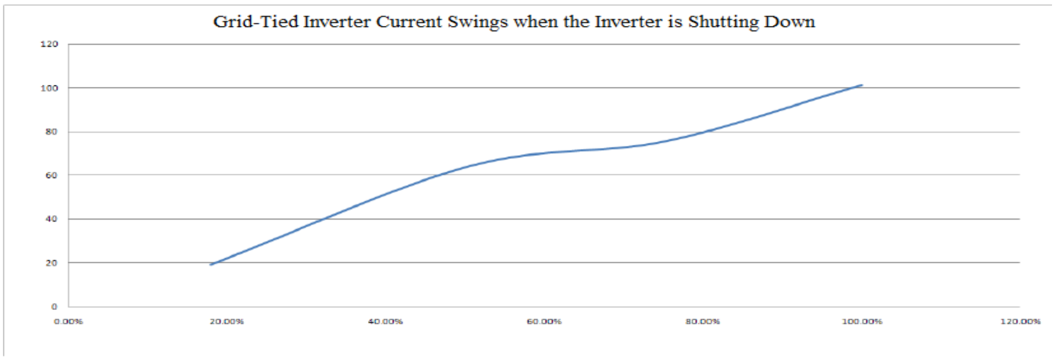

Figure (5.50): Grid Tied Inverter Current Swings

5.6.4 Line Losses:

From the diagrams and results tables of simulation it was obvious that the improvement in the line losses as the penetration level of PV increases which was expected. But after 50% PV penetration on the grid the line losses start to increase again.

As showed from the analysis, after 90% penetration level there will be significant voltage increase especially on the rural feeders and it's expected to affect the power quality of the source, and after 50% the line losses increase again and the current swing at any sudden shutting off of the inverters can be harmful on the network.

One of the most concerns from the grid and network provider perspective technical impact that the grid will be after 75 % PV penetration acting as a reactive power source only, which will cause heating on the network's equipments and so less life time of it. Additionally less efficient of this equipment especially the distribution transformer with poor power factors after 50% penetration levels.

5.7 Environmental Impact Assessment for PV Penetration on the Grid (PSI)

Life cycle emission of carbon dioxide by Gas-Combined Cycle Power Plant ($Kg - CO_2/KWh$) is equal to (0.692-0.742) according to different approved references. [66]

The above paragraph is applied in the environmental impact assessment calculations in chapter five and chapter six.

The installation of PV technology in producing energy is reducing the amount of carbon dioxide emissions that caused the Global Warming. It's important to study the quantity of carbon dioxide that avoided by the PV systems as a positive impact. The equation below describes how to find the peak power out from the PV system.

$$W_p = \frac{E}{5.4\ KWh/m^2 - day * \eta_{inverter} * Saftey\ Factor}$$

For 5 KWp PV System:

The yearly expected output energy generated is:

$$E = 7{,}982\ KWh$$

The yearly avoided quantity of carbon dioxide resulting from implementation 5 KWp PV system on the grid is:

$$CO_2\ quantity = 7{,}982\ KWh * 0.7\ \ Kg\ CO_2/KWh \quad = 5{,}587\ Kg\ CO_2$$

5.7.1 Environmental Impact Assessment for 25% PV Penetration on Al-Jeeb Network

The total power of Al-Jeeb network is 109 KW, so the 25% PV power will be 31 KWp.

The yearly expected output generated energy is:

$$E = 49{,}491\,\frac{KWh}{year}$$

The yearly quantity of CO_2 that avoided by the 25% PV Penetration is: $49{,}491\ KWh * 0.7\ \ Kg\ CO_2/KWh = 34{,}644\ Kg\ CO_2$

The same calculations done for the other levels of penetration in Al-Jeeb Network and the results are shown in table (5.19).

Table (5.19): Avoided Carbon Dioxide and the Generated Energy for Different PV Penetration Levels

PV Penetration Level	Energy Generated in One Year (KWh)	Quantity of Carbon Dioxide (Kg)
25%	49,491	34,644
50%	87,808	61,465
75%	135,703	94,992
85%	151,668	106,167
100%	174,019	121,813

5.7.2 Environmental Impact Assessment for the whole PSI Project in Palestine for 15 Years

The final goal of PEA in 3-4 years is to implement 5 MWp of solar PV rooftop panels in West Bank according to PSI.

The output energy from the project in one year is:

$$E = 7{,}982\,\frac{MWh}{year}$$

The avoided amount of CO_2 in one year is:

$$CO_2\ Emissions = 5{,}587\ ton\ \ CO_2/year$$

The avoided $CO_2\ Emissions\ in\ 15\ years = 83{,}805\ tons\ of\ CO_2$

Chapter Six

The Impact of Penetration Level of Grid Tied PV Systems on Medium Voltage Network of Jericho Case Study: Jericho PV Station

Chapter Six

The Impact of Penetration Level of Grid Tied PV Systems on Medium Voltage Network of Jericho- case study: Jericho PV Station

Introduction

The solar electricity generation station in Jericho is the first of its kind in Palestine; it's an introduction of clean energy by solar electricity generation system. It was implemented by Japan International Cooperation Agency. This station has a PV capacity of 300 KW_p, and it connected to the 33KV medium voltage distribution network in Jericho under JDECO electrical network. The initial capacity of the PV station was supposed to be 550 KW_p, but it was reduced to 300 KW_p due to budget limitation.

In this study, the first simulation will be on the current state which is the 300 KW_p of PV penetrations on the medium voltage network, and then the simulations will be performed on different levels of penetration capacity of the station up to 7 MWp, to investigate the future extreme effects on the grid.

6.1 Description of Jericho Network

Jericho grid information and statistical data were mentioned briefly in chapter one, the distribution network in Jericho controlled by JDECO electricity company. However, in this chapter the medium voltage network will be investigated and analyzed in details.

Jericho area has 10.97 MW, maximum power, where the total consumption in Jericho area is 113,964,857 kWh (from chapter one). The medium distribution network in Jericho works on 33 KV which the PV station is connected to. Jericho network is fed from Jordan through Swaimah substation which is in the eastern bank of Jordan River and from IEC through Khan Al Ahmar substation. Swaimah substation connects with Jericho network through two overhead transmission lines of 33 KV. Both lines at the western bank of the river change their state to be underground until they reach the Sea Level substation, then they separate to feed the Jericho distribution network. The 33 KV's feeder which comes from Khan Al Ahmar substation is also connected with Sea Level substation. Figure (6.1) represent the Distribution network of Jericho District.

The next diagrams and tables summarize Jericho electrical grid situation and information.

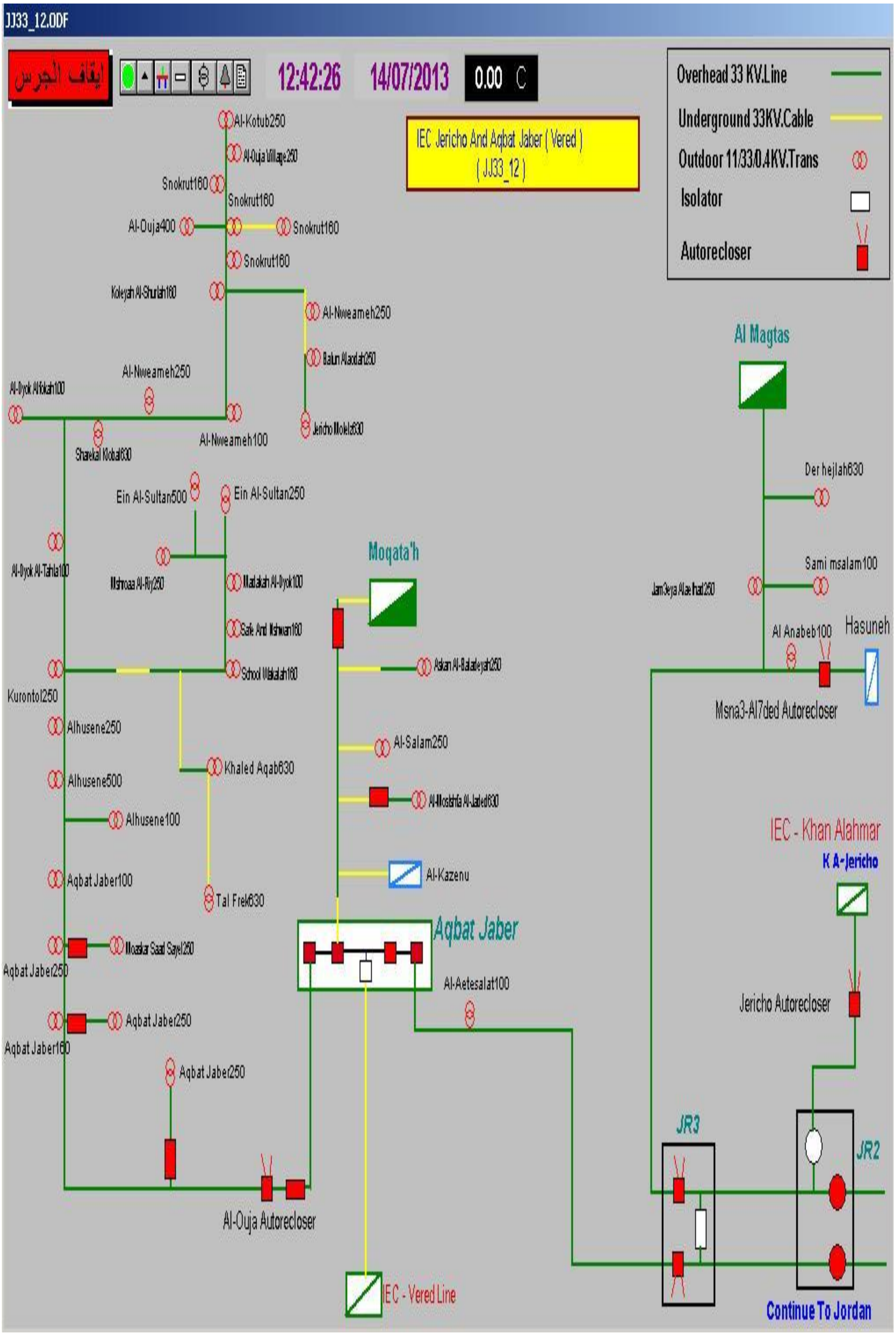

Figure (6.1): Jericho Distribution Network Single Line Diagram [61]

Table (6.1): Number of Electrical Services in Jericho [61]

Year	2009	2010	2011	2012
Number of Electrical Services	7,982	8,378	8.997	9,513

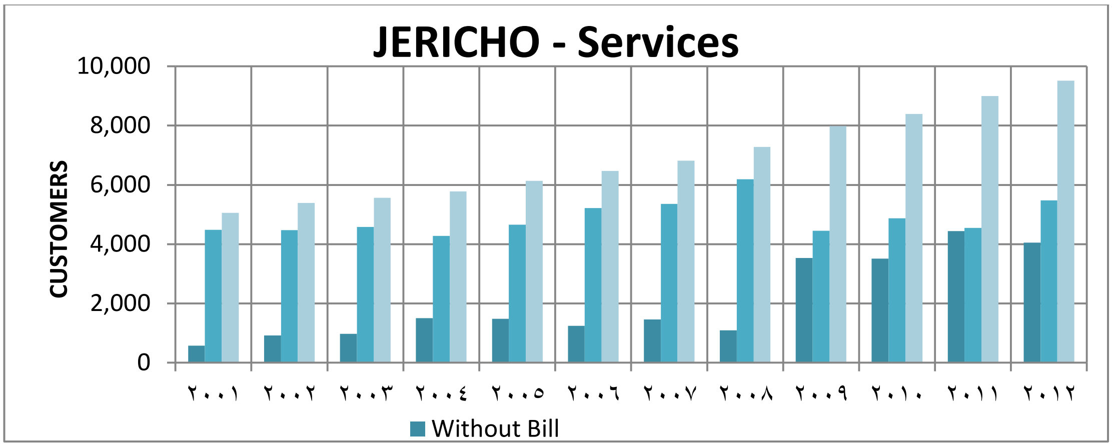

Figure (6.2): Number of Electrical Services in Jericho [61]

Table (6.2): Jericho Peak Load [61]

Year	2009	2010	2011	2012
P.L (MW)	19.36	21.04	23.00	24.32

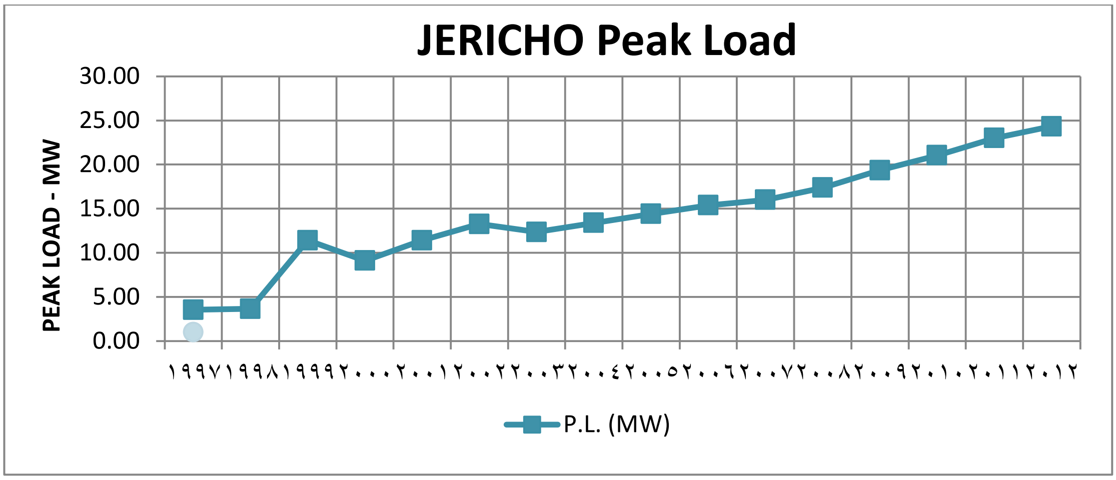

Figure (6.3): Jericho Peak Load[61]

Table (6.3): Jericho Yearly Consumption Units [61]

Year	2009	2010	2011	2012
Units Paid (GWH)	90.4	100.7	95.6	113.6

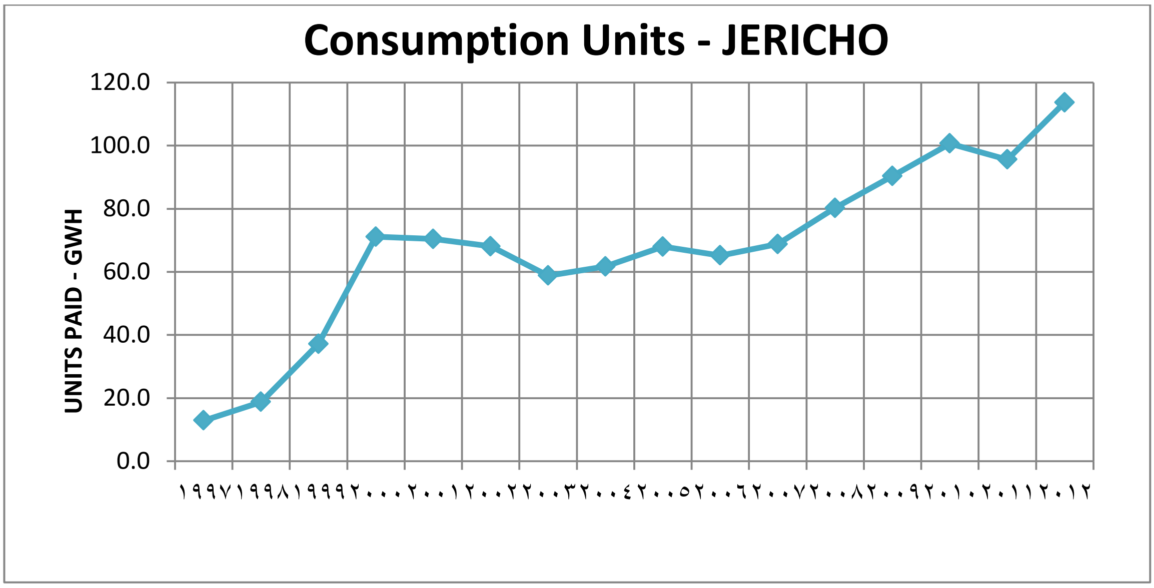

Figure (6.4): Jericho Yearly Consumption [61]

One of the main substations of Jericho distribution network is Sea Level and Al-Magtas substations which are shown in the previous graph.

The single line diagram of the Al-Magtas and Sea Level Substations is shown in figure (6.5), figure (6.6).

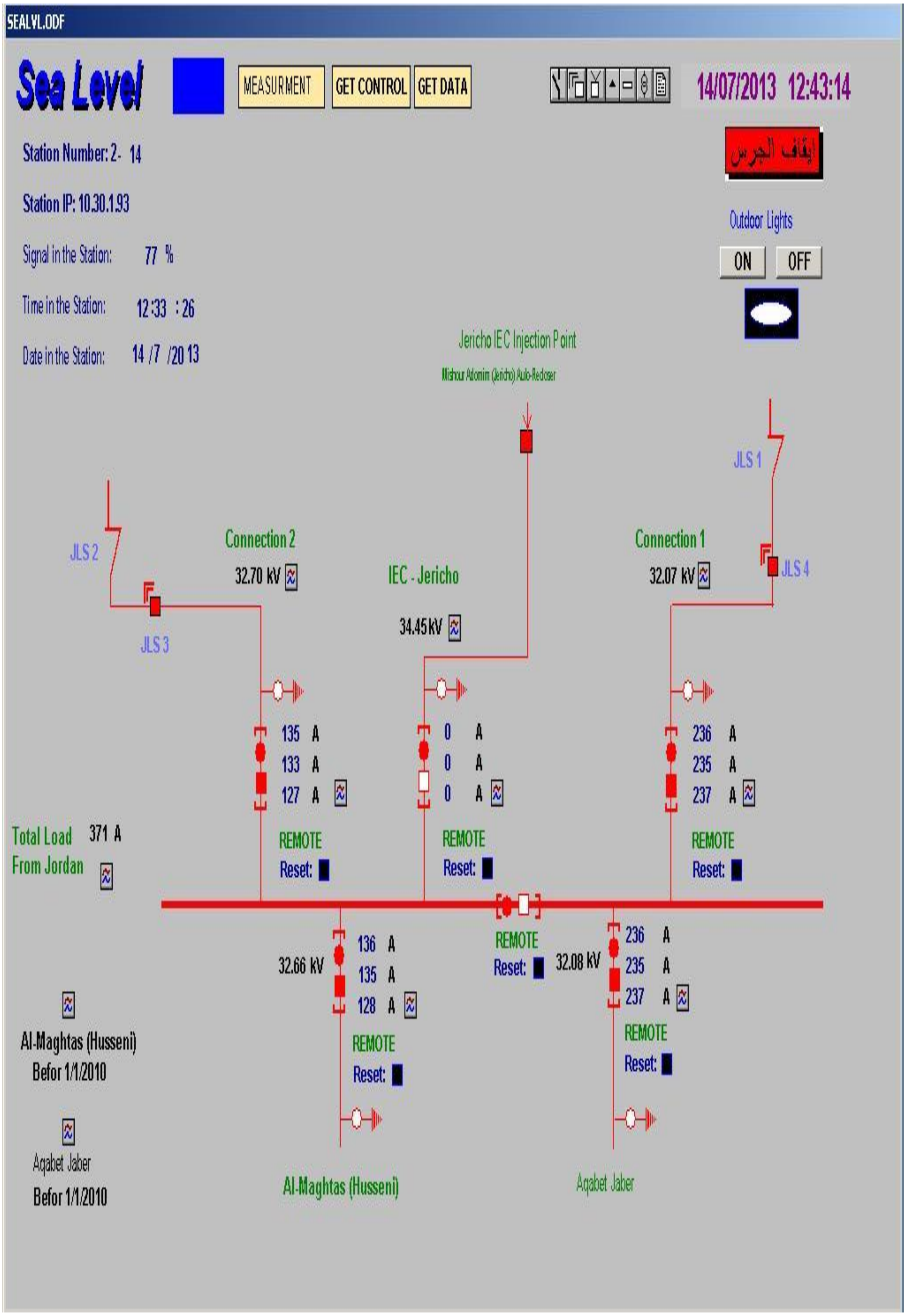

Figure (6.5): The Single Line Diagram of Sea Level Substations [61]

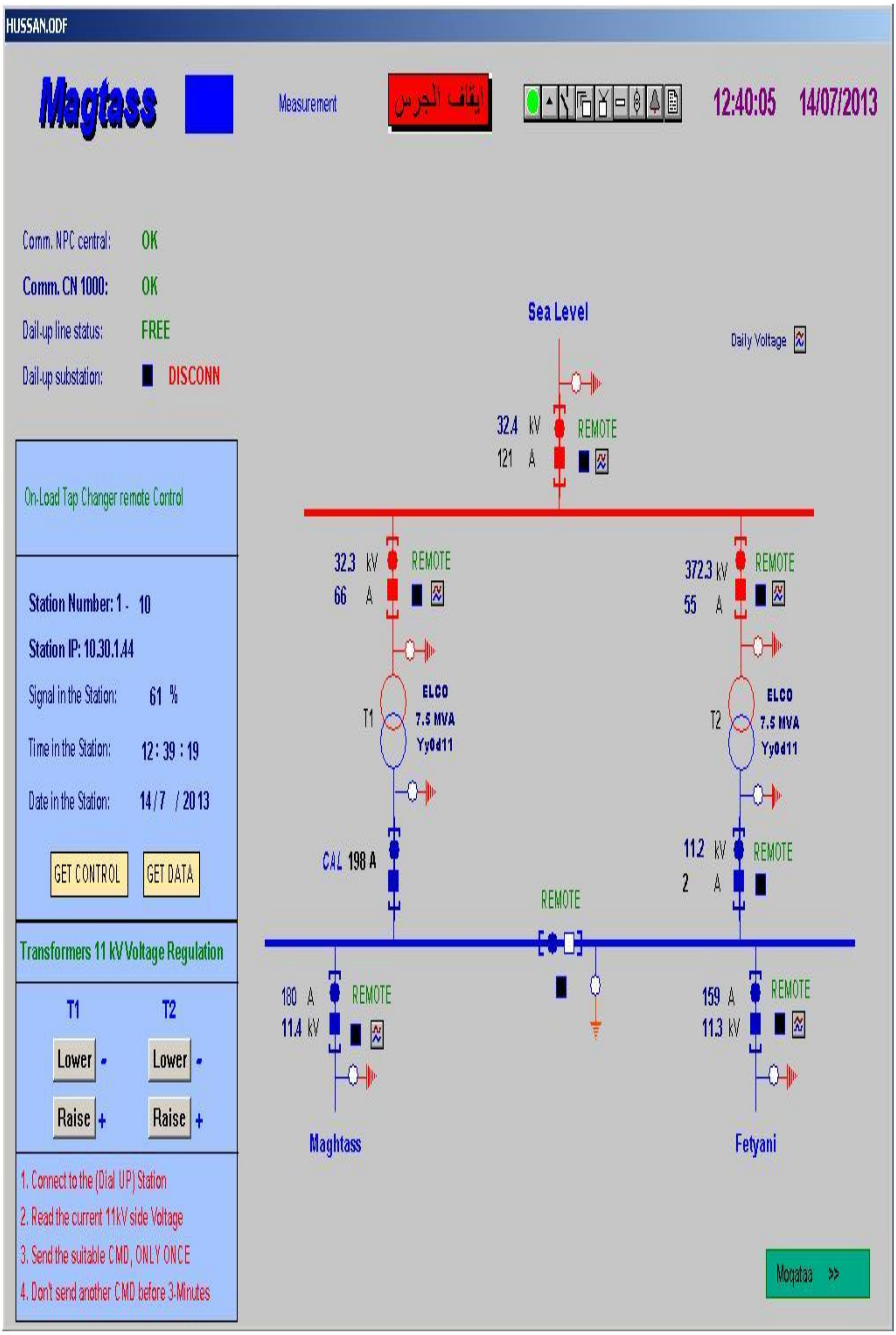

Figure (6.6): The Single Line Diagram of Al-Magtas Substation [61]

The Solar Station is located on the main 33KV line between Al-Magtas station and Sea Level station, and so the simulation and calculation will be performed on this point at maximum load time between 11:00 AM – 2:00 PM

6.2 Jericho Solar Energy Station.

Jericho station is an example of integrating the PV systems into the medium voltage distribution network. Unlike the low voltage grid connected PV systems, Jericho station will be fed, in the grid, through a step up LV/MV transformer to supply the distribution network.

The rated power of this station is 300 KWp. This study aims to provide an understanding of PV integration to the medium distribution network from technical point of view.

- Rated Capacity = 300 KWp at 1'st stage, 550 KWp at 2'nd stage
- Number of Modules = 2700, 115W
- Expected Yearly KWh=422,000 KWh, Actual for the 1'st year= 552,657.8
- Area of Installation = 13,000 m^2
- Expected Amount of Reduction of Carbon Dioxide = 290.6 tons

Real information and data and grid parameter will be used to build the one line diagram for the simulation model using power world simulator.

Some mathematical calculations will be done to fond the number of PV modules and the parallel, series connections between the PV modules.

The real data were collected and gathered from different sections and departments at JDECO and PEA beside physical data that were gathered from the sight location of Jericho Solar Station.

- SCADA department at JDECO
- GIS department
- Jericho Branch of JDECO
- PEA
- From the main monitoring system at Jericho Solar Station
- Using Energy Analyzer (Jupiter) at the output point for 3 days at 7/2013

6.2.1 Geographical Position of Solar Station.

The station is located in Jericho district; near Jericho city and figure (6.7) describes the area of the station, through a picture from Google Earth program. The electricity generated by the PV system to be procured and installed by the station will be fed into the existing JDECO power distribution grid. The reverse power flow through a new substation with 630kVA (33kV to 380V) transformer which is built at east-south corner of

JAIP by the station and Ring Main Unit RMU being installed in JDECO owns switchgear station located at neighboring Iron factory.

Figure (6.8) shows the location Jericho PV station on the single line diagram of Jericho distribution network.

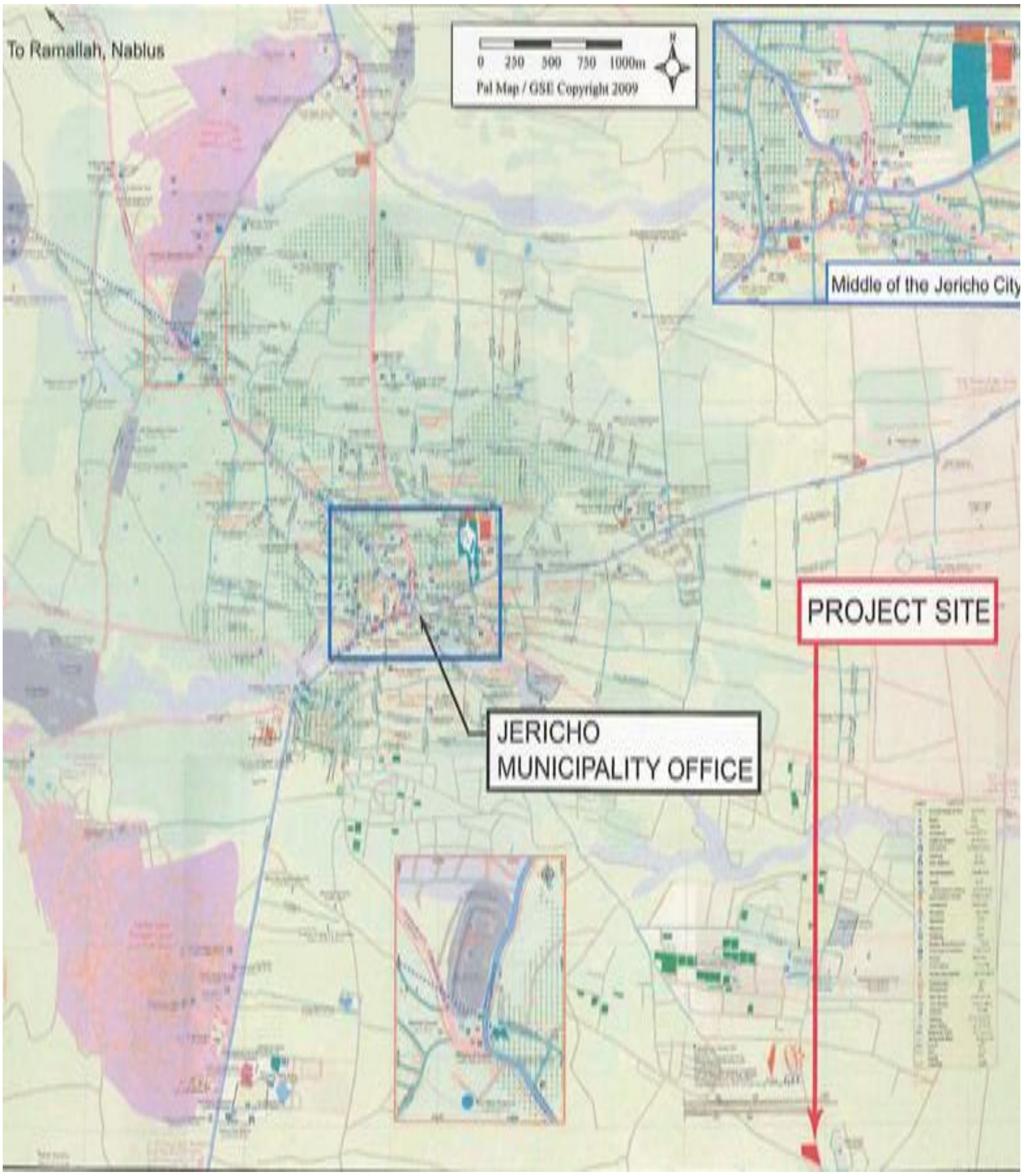

Figure (6.7): Map of Jericho Including the PV Station Location [62]

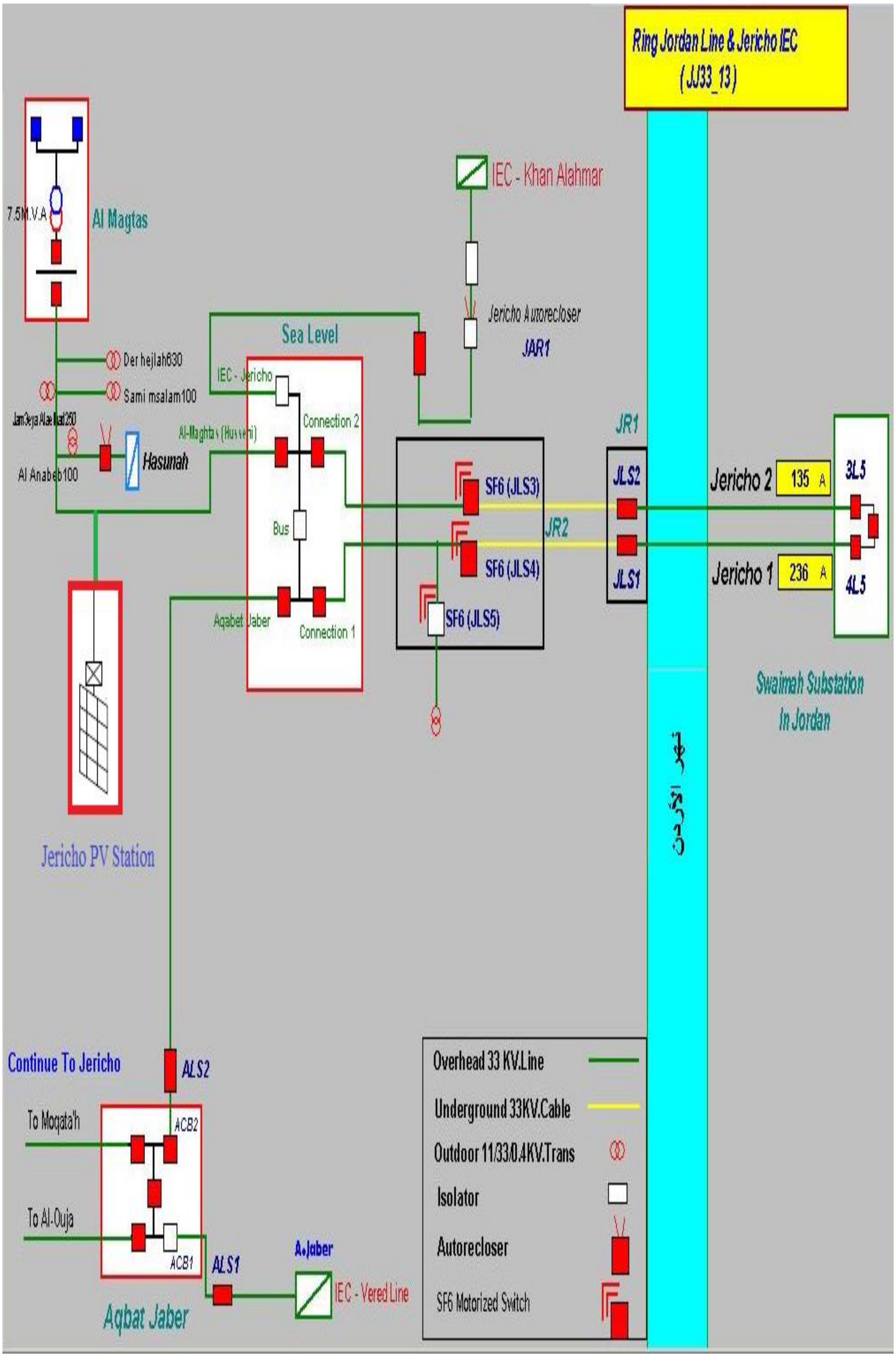

Figure (6.8): Single Line Diagram of Jericho Distribution Network with the PV station [61]

6.2.2 System's Model Components

The system rated power is 300 KWp. It consists of 2700 PV panels (115W), grouped into three groups. Each group had 10 blocks and each blocks consist of six parallel panels.

The whole system is distributed into multiple stages, DC power from the panels, into AC law voltage after the inverter stage, and finally to M.V stage through a step up transformer, see figure (6.9).

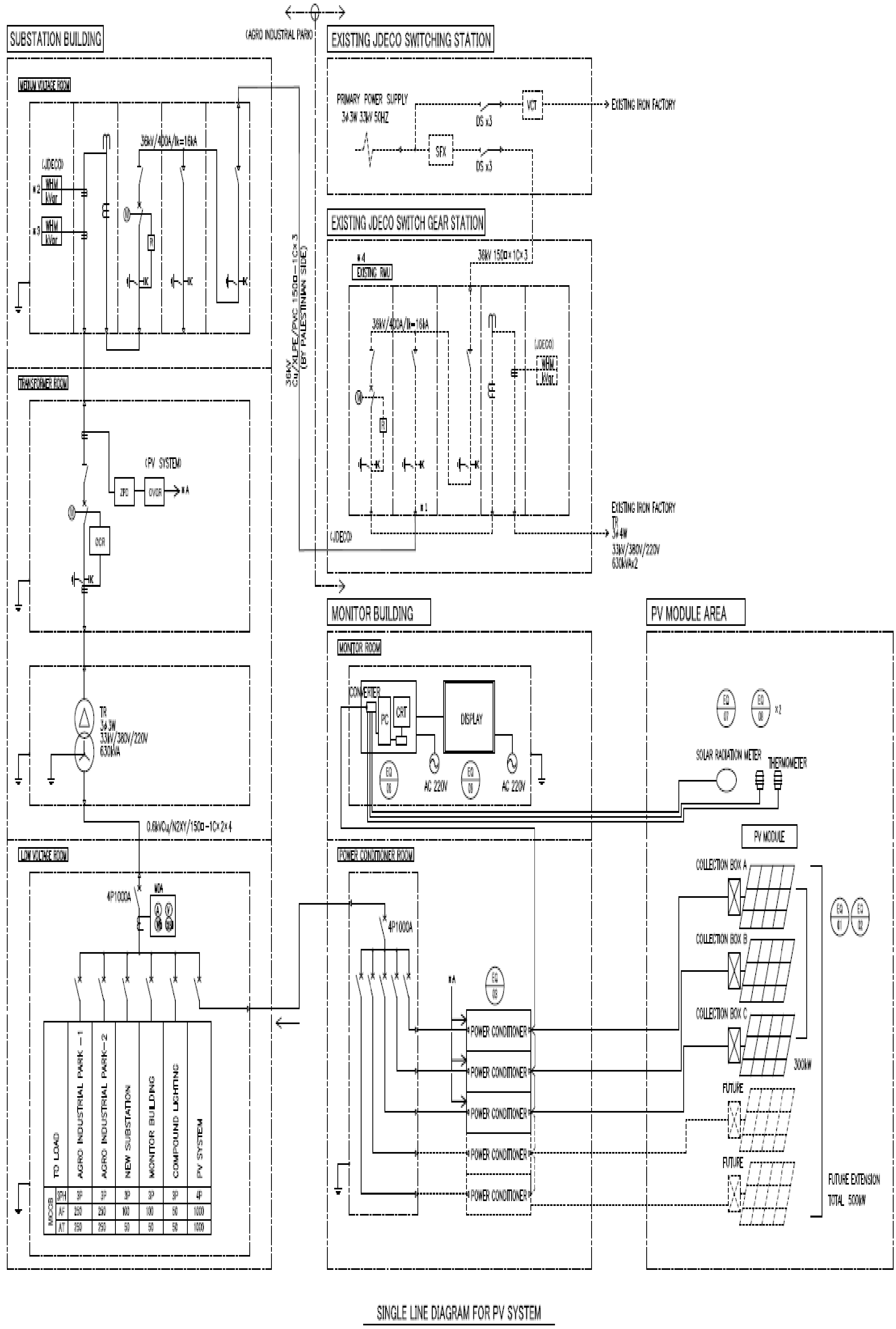

Figure (6.9): Jericho PV Station Single Line Diagram [62]

6.2.2.1 PV System

The PV system in Jericho station has a peak power of 300 KW. This system is built from the Thin-Film (Amorphous) Silicon solar panels from Kaneka Corporation. The datasheet of the solar panel which is used in designing this PV system is shown in table (6.4).

Table (6.4): Kaneka PV Module's Datasheet [62]

Product: Thin-Film Silicon PV Module from Kaneka Corporation		
Model: U-EA115		
Specification Lists	Unit	Value
Performance at STC (Stabilized)		
Nominal Power (P_{max})	W	115 (+10%/-5%)
Open Circuit Voltage (V_{oc})	V	71.0 (±10%)
Short Circuit Current (I_{sc})	A	2.50 (±10%)
Voltage at (P_{max})	V	55.0
Current at (P_{max})	A	2.09
Max. System Voltage	V	600
Dimension	mm	1210.0±2.5x1008.0±2.5
Depth	mm	40.0±1.0
Weight	Kg	18
Performance at STC (Initial)		
Power (P_{max})	W	132
Open Circuit Voltage (V_{oc})	V	71
Short Circuit Current (I_{sc})	A	2.5
Voltage at (P_{max})	V	56
Current at (P_{max})	A	2.4

The base element in this system is 115 W module, every six modules in series represent a string of modules. The system separated into 30 blocks, each block consists of 10 KW of combination of PV strings. The block alone has 15 parallel strings and the block is connected to its own distribution board. A group of 10 blocks that have a power of 100 KW are connected to one DC/AC inverter of 100 KW.

Briefly, the PV system is a group of 30 blocks where 10 blocks are connected to one inverter; each block consists of 15 parallel strings which are connected to a distribution board. The PV string consists of 6 PV panels which are connected in series. The total PV system connection of 300 KW and additional capacity that is predicted by the Japanese is shown in figure (6.10).

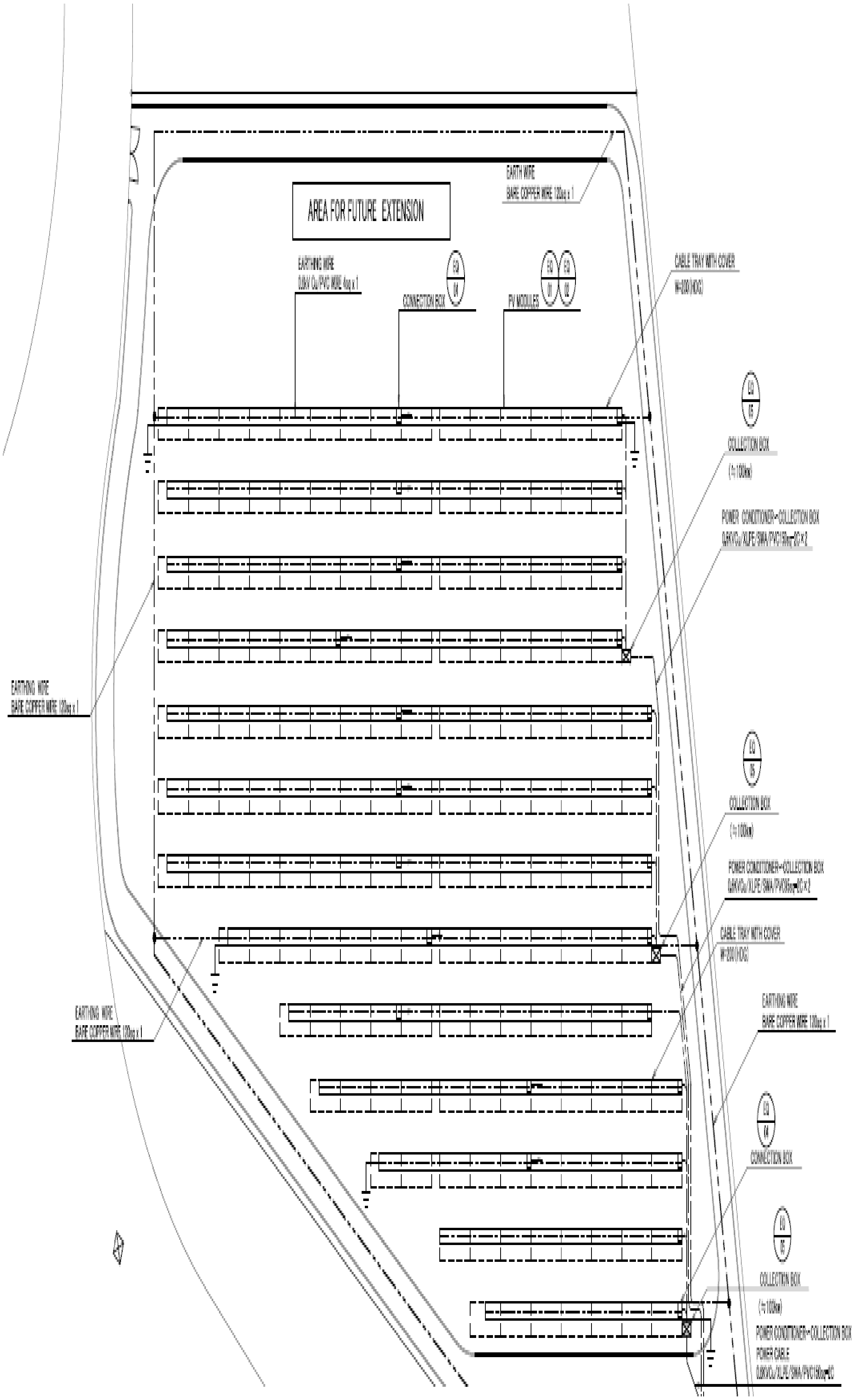

Figure (6.10); PV System of Jericho Station [62]

Figure (6.11) is a picture taken from Jericho PV station which shows the PV panels.

Figure (6.11): PV Panels

6.2.2.2 DC/AC Inverter

As mentioned above, the station has three DC/AC inverters. The inverter which is used in this station has a rated power of 100 KW, table (6.5) shows the datasheet of the (P83B104R) inverter in grid connected operation mode and figure (6.12) shows the inverter's connection with 100 KW PV strings.

Table (6.5): Grid Connected Inverter Datasheet [61]

Item	Specifications
Rated output	100 KW
Rated input voltage	900 V DC
Max. allowable input voltage	500 V DC
Input operating voltage range	240-450 V DC
Max. power point tracking range	240-420 V DC
Output electrical system	3-Phase, 3-Wire System
Rated output voltage	202 V AC
Rated frequency	50 Hz. or 60 Hz.
Grid connected operating range	Voltage: ±20 V, Frequency: ±1%
Rated output current	286 A AC
Ac output current distortion factor	Current: 5%, Harmonics: 3% or Less
Output power factor	0.95 or More
Efficiency	93%

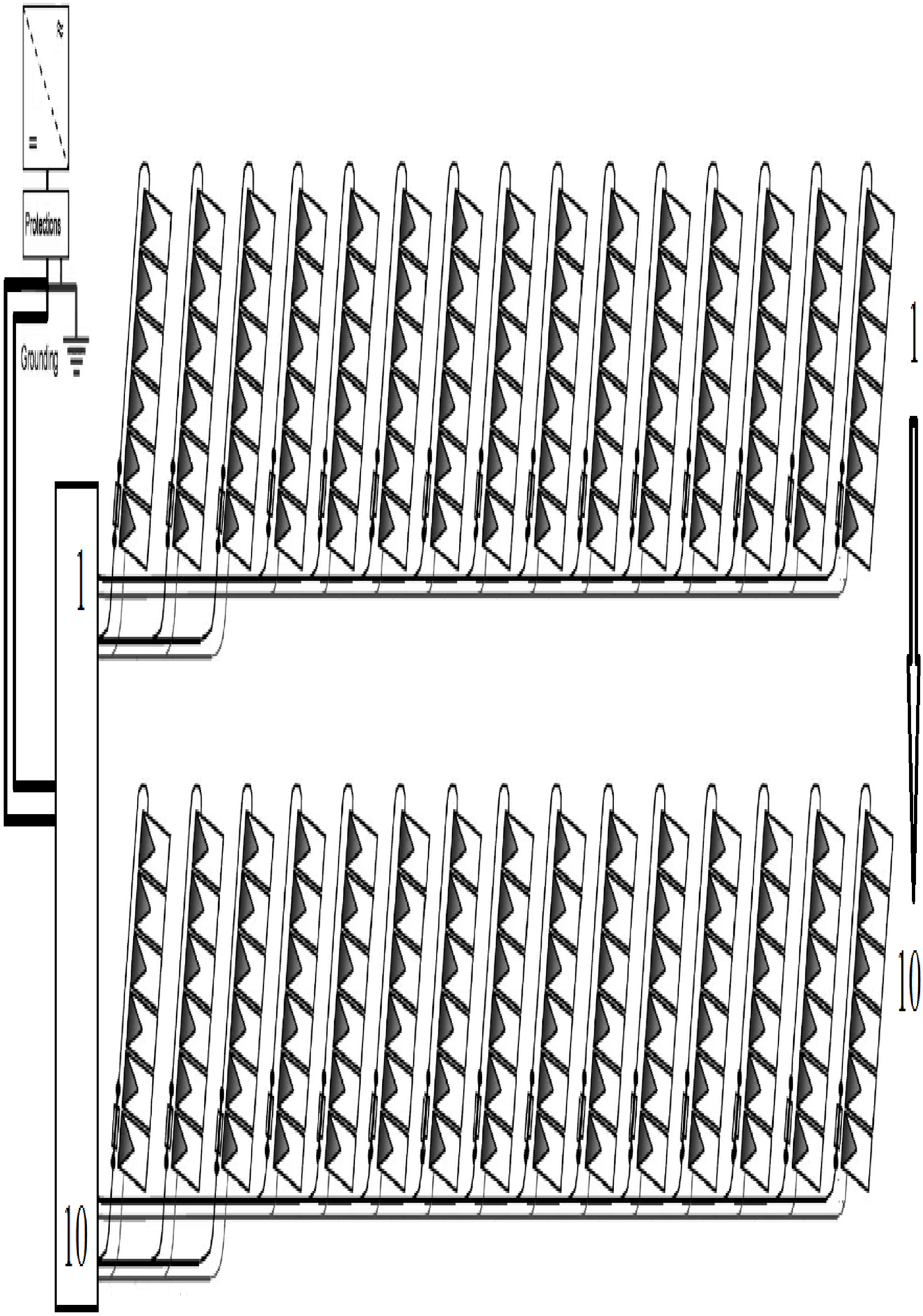

Figure (6.12): DC/AC Inverter with 100 KW's PV Strings

The three inverters are supplied by the DC power from the PV system which is divided into three parts in order to provide the DC power to the three inverters. Each part of this PV system as mentioned earlier above contains 10 groups, each group consists of 15 parallel strings, so each inverter is connected to 150 parallel strings at 6 panels in series per string as shown in figure (6.8). The output power from the inverters is 300 KW (AC) three phase at output voltage about 200 V as shown in table (6.5).

6.2.2.3 Step-up Voltage Transformer

Jericho station has two stages of transforming using two types of transformers; voltage transformer and distribution transformer.

The usage of the voltage transformer is to raise the output voltage from the inverter from 200 V to 380 V. As we use three inverters, here we need a voltage transformer to each inverter. Figure (6.13) shows a picture taken to one 200/280 V AC and 100 KVA voltage transformer.

Figure (6.13): Voltage Transformer of 100 KVA

6.2.2.4 LV/MV Transformer

After raising the voltage to 380 V and in order to integrate the PV system to the medium voltage distribution grid, LV/MV transformer is needed. The main specifications of this transformer are; the voltage levels are from 380 V to 33 KV, the transformation is from Star connection to Delta connection and the rated output power is 630 KVA. Figure (6.14) shows the 0.38/33 KV distribution transformer.

Figure (6.14): 33KV Ring Main Unit

6.2.2.5 Switchgear

The switchgear limits the switching of the electric components in the system at the low voltage level, provides protection to the devices in the system throw circuit breakers and fuses and isolates the electrical sections of the system. The electrical protection at low voltage level is apart from fuses normally incorporated in circuit breakers, in the form of thermal, magnetic devices and/or residual current operated. The over voltage protection and under voltage protection are provided by specific devices like contactors and isolators.

The low voltage systems of Jericho PV station need the switchgears to control the switching between the different devices, different supplying systems (PV and the grid) and to protect them from faults and damages. Figure (6.15) shows the JDECO's switchgear station circuit diagram. In addition, figure (6.16) shows a picture of the low voltage switch gear in Jericho PV station.

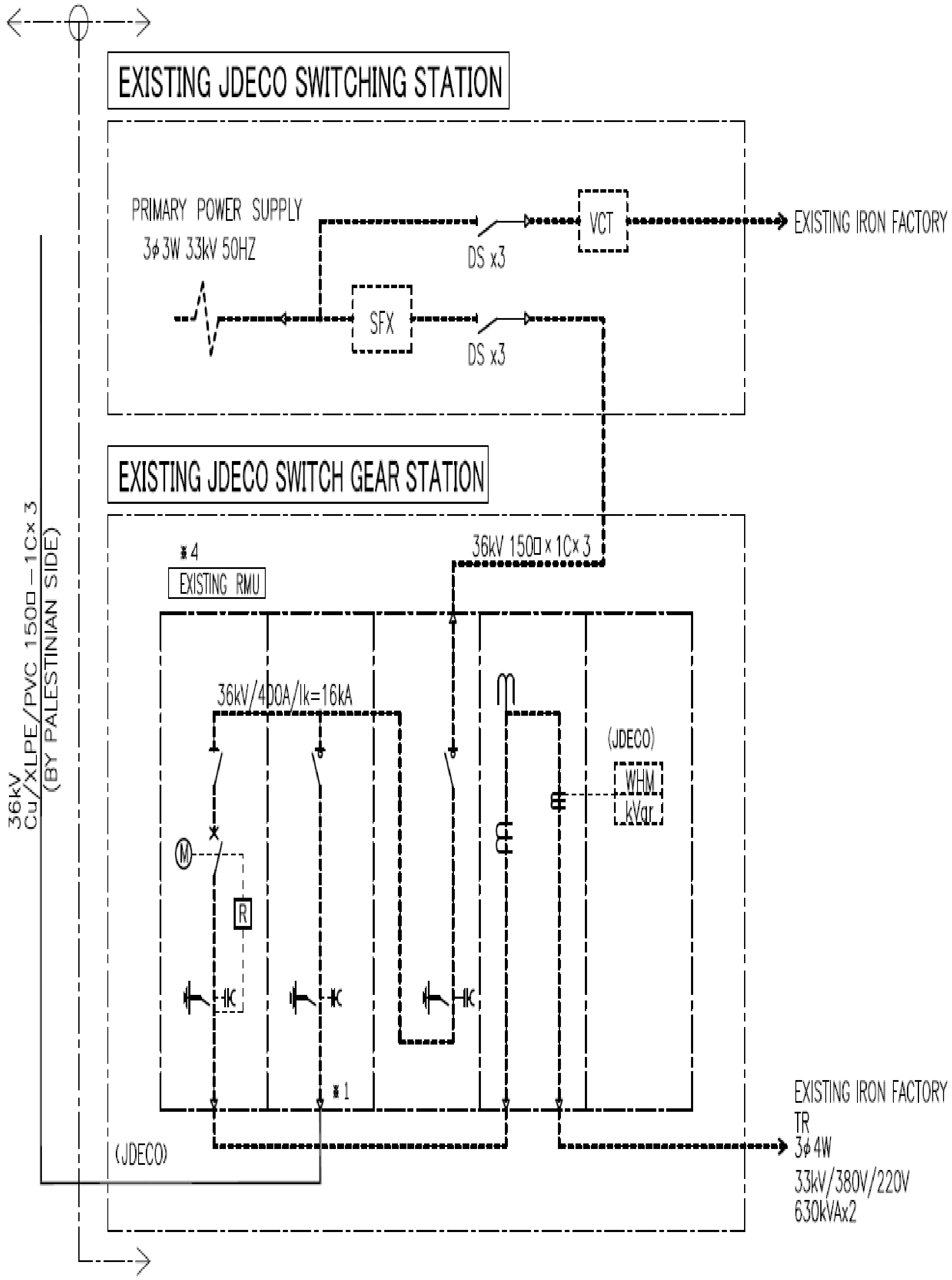

Figure (6.15): JDECO's Low Voltage Switchgear and Medium Voltage Switching Station [61]

Figure (6.16): Low Voltage Switchgear

6.2.2.6 Main Monitoring System.

In the main monitoring room at Jericho Solar Station, many screens that it connected to the computer are observing all parts of the system through a special software acting like SCADA system which can managing control and observing the system and its parts. From this software system we can extract different type of reports (hourly, daily, yearly), about the system performance, generating units, voltages and currents, metrological data.

The next figures (6.17), (6.18), show some of these screens, on 29/8/2013, 10:23 AM

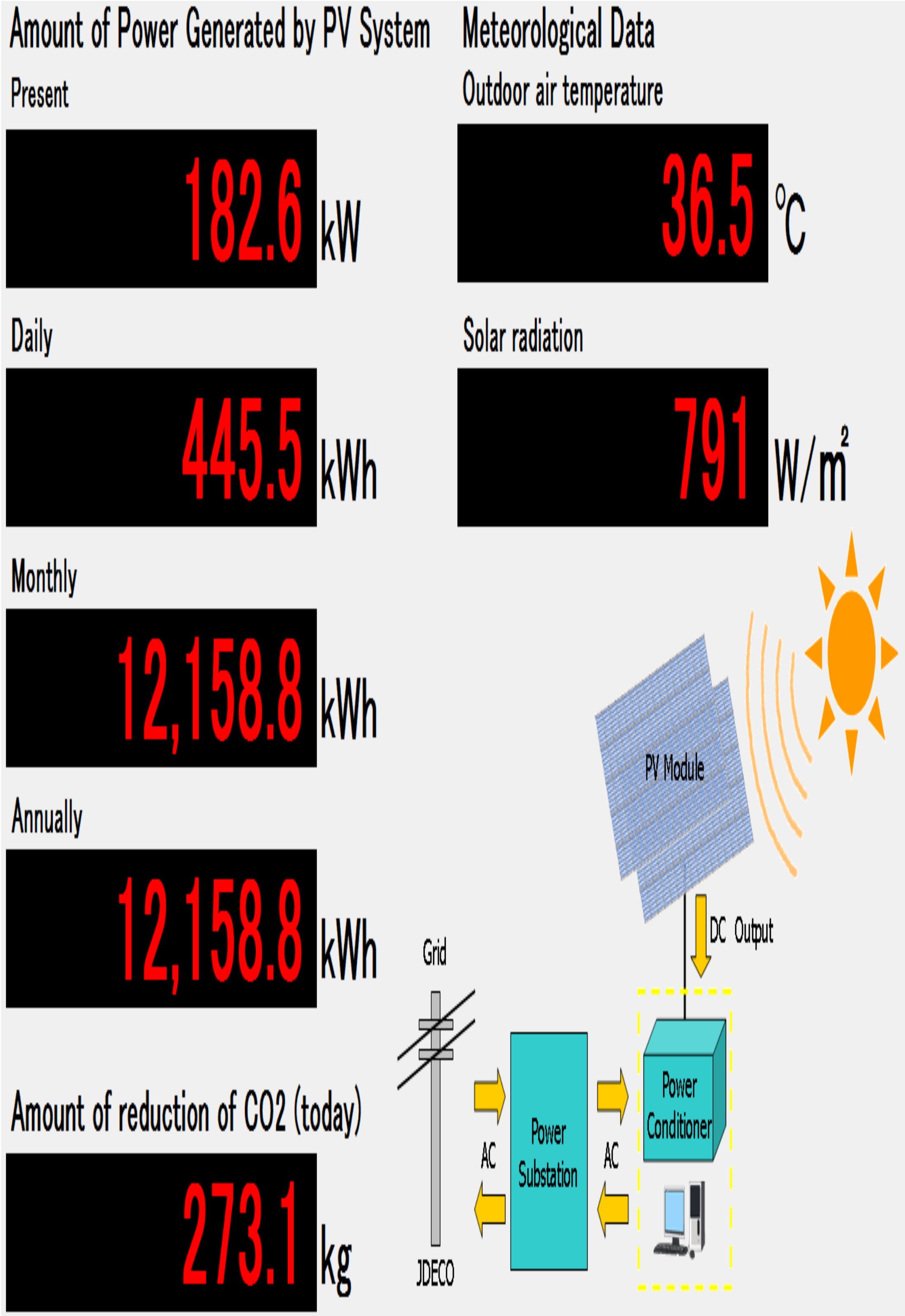

Figure (6.17): The Main Monitoring system Screen [64]

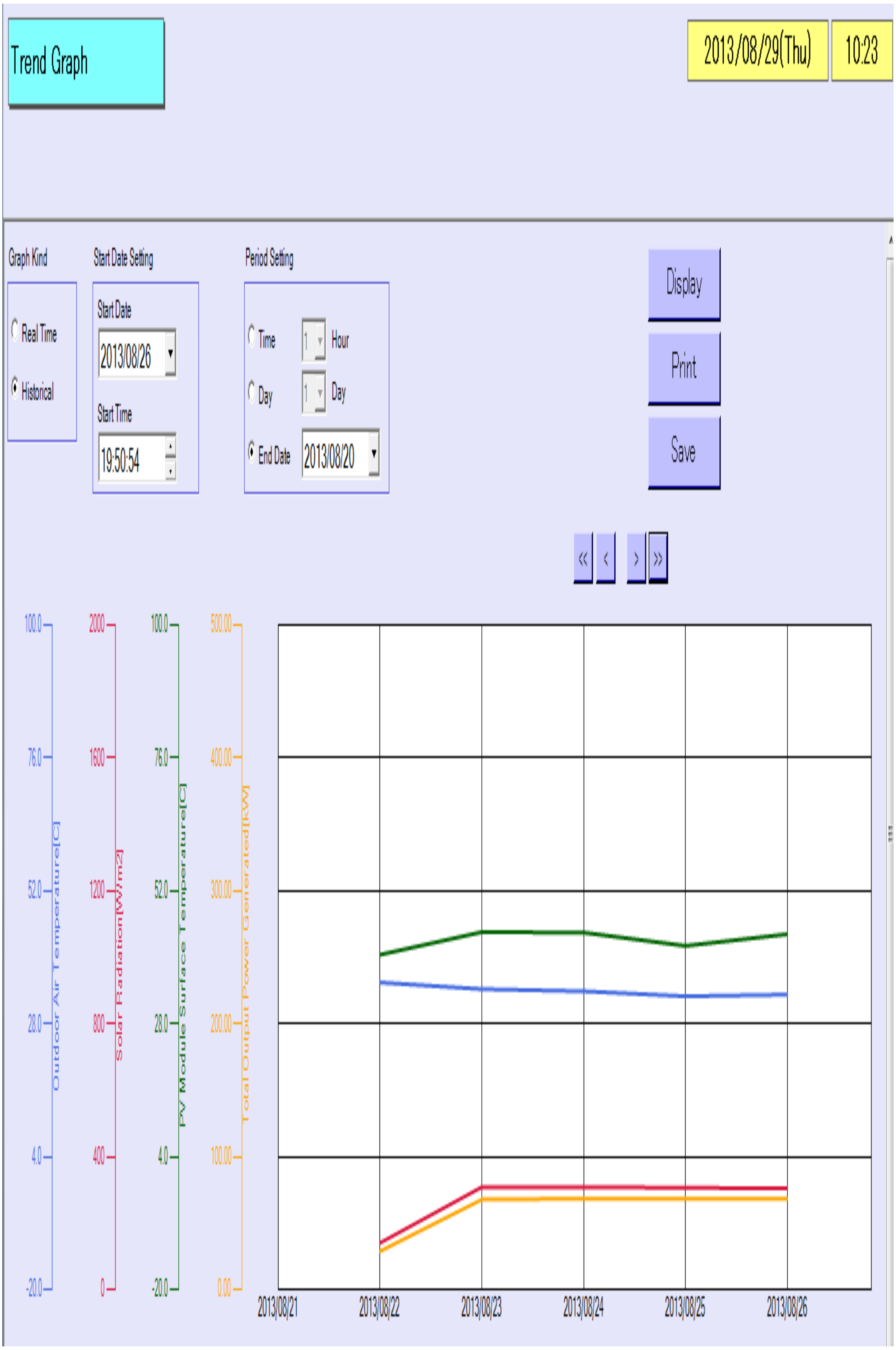

Figure (6.18): Live Data from the System on 29/8/2013 [64]

6.3 Analysis and Simulation of the Current Case.

6.3.1 Data Collection and Processing

6.3.1.1 Solar Radiation, Metrological Data Collection.

The daily solar radiation of Jericho and the mean air temperature are measured; by NASA, table (6.6) and table (6.7) show the collected data.

Table (6.6): Daily Solar Radiation and Mean Air Temperature from Jan. to Jun [63]

Item	Jan	Feb	Mar	Apr	May	Jun
Daily Solar Radiation (KWh/d/m^2)	2.8	3.5	4.6	6	7.1	7.9
Mean Air Temperature (℃)	10.6	11.4	14.2	18.9	22.2	24.3

Table (6.7): Daily Solar Radiation and Mean Air Temperature from Jul. to Dec.[63]

Item	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Daily Solar Radiation (KWh/d/m^2)	7.8	7.2	6	4.7	3.4	2.6	5.31
Mean Air Temperature (℃)	26	26.4	25	21.7	17	12.3	19.2

Other historical data about the solar radiation in Jericho were collected in 1994-1995 shown, showing in fig (6.19). They were extracted from one metrological station by the Applied Research Institute at Jerusalem, in 1994 for environmental profile.

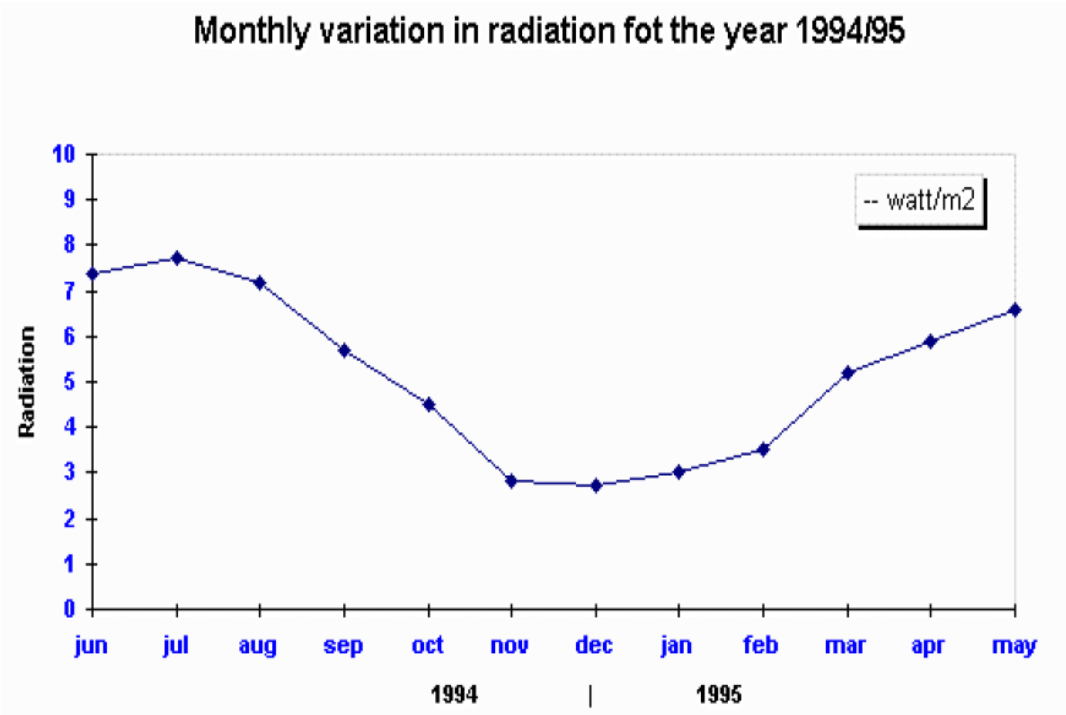

Figure (6.19): Solar Radiation in Jericho, 1995 [65]

Also, real and accurate metrological data in the sight location of Jericho Station were collected from 8/2012 until 1/2013, will be shown in the next sections.

6.3.1.2 Solar PV Station, Data Collection

From the main monitoring system at Jericho station different reports and data were collected per month and per day, and it’s attached in the appendixes, summary of some important information for this study in the next table (6.8).

Table (6.8): Solar Station Data From 8/2012 – 1/2013 [64]

Item \ Month	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13
Generated Energy KWh	50,536	43,490	35,021	28,669	29,240	29,506
Sold Energy KWh	45,570	39,270	31,540	21,140	26,700	27,029
Energy Counted by JDECO KWh	44,802	38,637	33,237	26,028	26,172	26,710
Monthly Avg. Solar Radiation KWh/m²-day	7.34	6.89	5.25	3.38	3.92	4.10
Avg. PV Surface Temp. °C	45.50	42.40	37.40	25.10	24.00	22.00
Avg. Outdoor Air Temp. °C	35.30	32.60	29.40	19.40	17.50	15.50
Max. Solar Radiation KW/m²	1.043	1.070	1.090	2.000	2.000	1.270
CO_2 Kg	30.978	26.659	21.468	17.573	17.924	18.087
Max. Air Temp. °C	48.90	44.20	41.10	70.00	70.00	26.40
Max. PV Temp. °C	83.00	78.70	74.80	100.00	100.00	62.40

Unfortunately that the monitor system were not working from 2/2013 – 8/2013 due to technical problem.

It was noted that there were differences between generated KWh units that were counted by the monitoring system at the station and the number of units that seen by the grid through the number of units that were counted by JDECO Meter, and this due to transmission and step up transformer losses. There are three transmission stages to deliver the generated energy units to JDECO M.V grid, and at each stage there are losses.

Technical losses from the PV panels to the end point of the conditioner = (8.7% - 9.8%), and the total technical losses to JDECO grid= (9.5%- 11.4%)

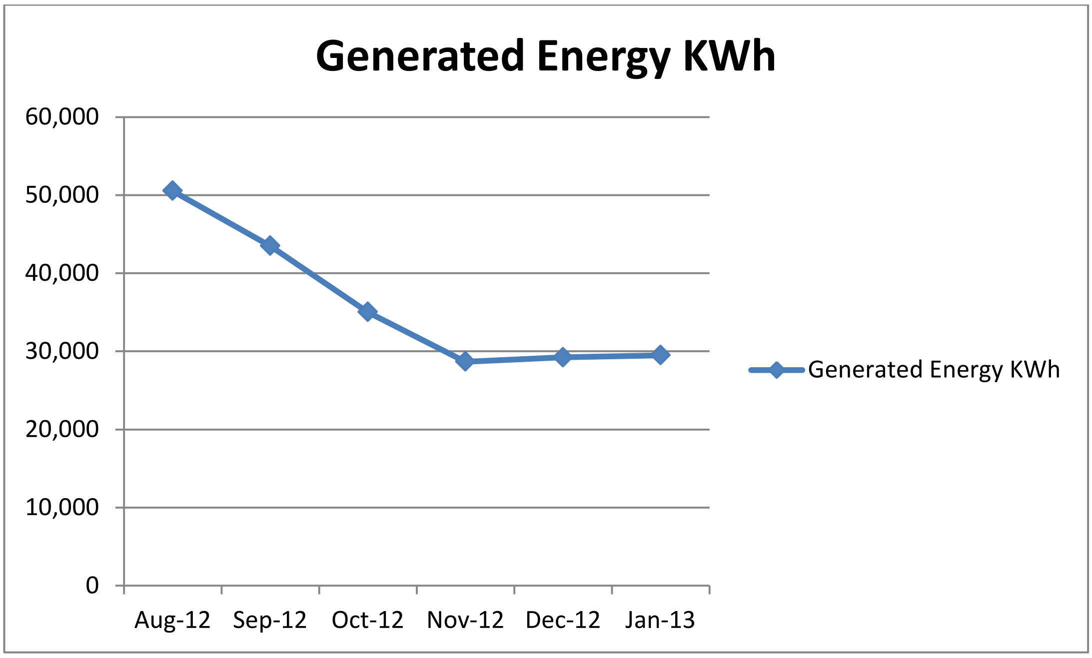

Figure (6.20): Generated KWh Units from Jericho Solar Station [64]

The next figure and table, include the number of KWh units generated by the solar station that were delivered and counted by JDECO grid, for a total one year from 8/2012 – 8/2013, the total quantity of KWh units that were generated by PV solar station and delivered to grid = 480,572 KWh

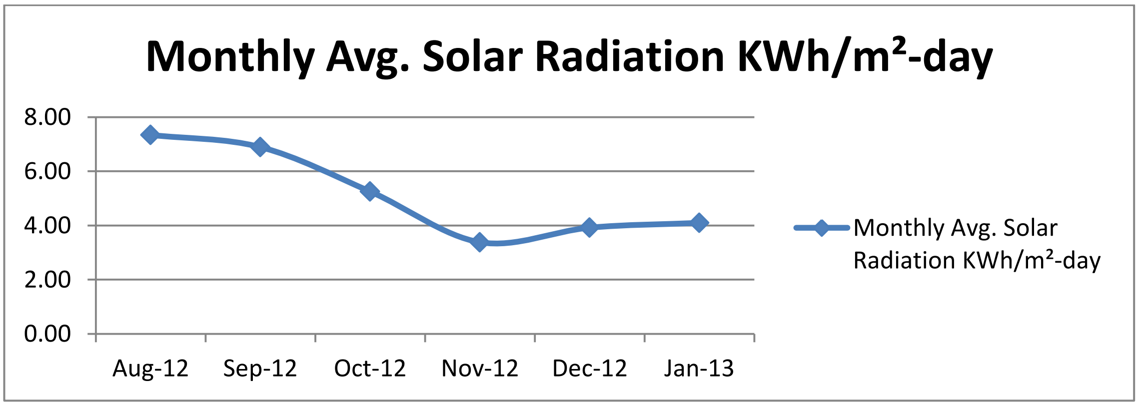

Figure (6.21): Monthly Average Solar Radiation in Jericho Station [64]

Table (6.9): Generated KWh Units from Solar Station that Seen by Grid [64]

Month	KWh Gen	Month	KWh Gen
Aug-12	44,802	Mar-13	38,061
Sep-12	38,637	Apr-13	40,158
Oct-12	33,237	May-13	43,479
Nov-12	26,028	Jun-13	43,227
Dec-12	26,172	Jul-13	46,755
Jan-13	26,271	Aug-13	45,035
Feb-13	28,710	**Sum**	**480,572**

Average losses percent = 10.5 %, and so the Total Generated Units from the Solar Station for the First year = 480,572 + (480,572 * 0.1) = 552657.8 KWh.

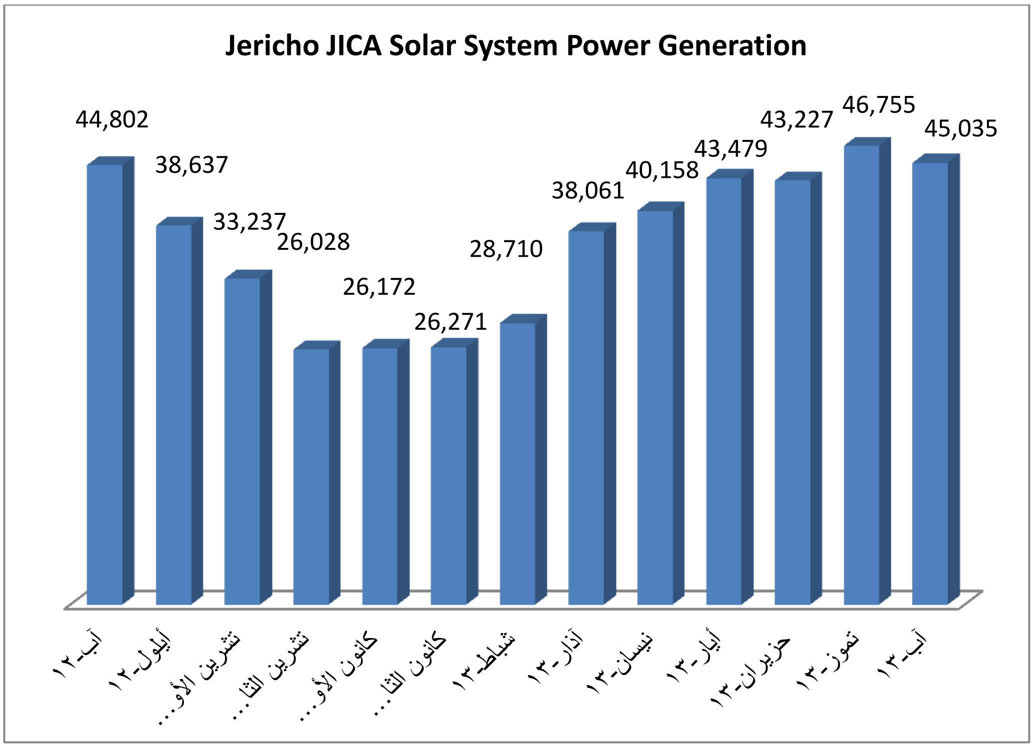

Figure (6.22): Generated Kwh Units from Solar Station that seen by Grid [64]

6.3.1.3 Grid Data Collection.

From the previous sections it was obvious that the solar station located at the main 33 KV, M.V network of Jericho is exactly in the line between Sea Level Station and Al-Magtas Station, and so the needed data and parameters and information for the analysis and simulation are for the grid and the two substations.

Many physical works were performed to collect data from the sights and by SCADA data and GIS systems.

The desired period for simulation was at the Peak times, where the maximum values for loads and the critical values of voltages appeared, and so at these times period the extreme effect of an additionally PV generator on the grid can be investigated.

- Maximum and Minimum Voltages at the Substations. In addition to the Feeder Consumption.

The maximum loads at the Sea Level Feeder with the readings of maximum and minimum voltages are shown in table (6.10). In addition, the consumption at this feeder is shown in table (6.11).

Table (6.10): Maximum Load with Maximum and Minimum Voltages of Sea Level Feeder [61]

Maximum load the 33 kV Feeder of Sea Level Substation			MAX	MIN	
Jul-12	141	A	33.8	32.4	KV
Aug-12	137	A	34.3	32.7	KV
Sep-12	138	A	33.3	32.7	KV
Oct-12	135	A	34.5	32.8	KV
Nov-12	119	A	34.5	32.9	KV
Dec-12	88	A	34.4	32.6	KV
Jan-13	87	A	34.5	32.5	KV
Feb-13	52	A	34.8	32.6	KV
Mar-13	62	A	34.8	33.7	KV
Apr-13	120	A	34.8	32.4	KV
May-13	152	A	34.6	32.6	KV
Jun-13	148	A	34.6	32.3	KV

The maximum loads at the Al-Magtas Feeder (which is the second main substation in Jericho distribution network) with the readings of maximum and minimum voltages are shown in table (6.12). In addition, the consumption at this feeder is shown in table (6.13).

Table (6.11): Sea Level Feeder Consumption [61]

Consumption of Sea Level Feeder		
Jul-12	42688	MWh
Aug-12	41369	MWh
Sep-12	38826	MWh
Oct-12	56425	MWh
Nov-12	42276	MWh
Dec-12	24679	MWh
Jan-13	18919	MWh
Feb-13	14244	MWh
Mar-13	16865	MWh
Apr-13	22475	MWh

Table (6.12): Maximum Load with Maximum and Minimum Voltages of Al-Magtas Feeder [61]

Maximum load the 33 kV Feeder. Al-Magtas Substation			MAX	MIN	
Jul-12	131	A	33.7	30.99	KV
Aug-12	129	A	33.5	32.00	KV
Sep-12	128	A	33.3	31.60	KV
Oct-12	119	A	33.9	30.40	KV
Nov-12	114	A	34.3	32.00	KV
Dec-12	79	A	34.1	32.10	KV
Jan-13	75	A	34.2	32.20	KV
Feb-13	48	A	34.7	32.40	KV
Mar-13	50	A	34.7	33.50	KV
Apr-13	110	A	34.6	32.10	KV
May-13	133	A	33.7	31.70	KV
Jun-13	137	A	33.3	31.06	KV
Jul-13	138	A	33.4	31.20	KV

Tables (14), (15) show the loads, power and the voltages at Al-Magtas and Sea Level substations at peak time (Real time Data), the time range is between 11:00 AM and 2:00 PM. Table (6.14) shows the voltages and loads power at both substations in three days in June, 2013. Table (6.15) shows the voltages and loads power at both substations in three days in July, 2013. Whole data recorded in June and July is shown in Appendix (C).

Table (6.13): Al-Magtas Feeder Consumption [61]

Consumption of Al-Magtas Feeder		
Jul-12	37830	MWh
Aug-12	37520	MWh
Sep-12	33990	MWh
Oct-12	33090	MWh
Nov-12	23600	MWh
Dec-12	21160	MWh
Jan-13	15590	MWh
Feb-13	11340	MWh
Mar-13	13390	MWh
Apr-13	18070	MWh
May-13	35250	MWh
Jun-13	38590	MWh
Jul-13	42120	MWh

- Sample days and Hours of Voltage and Load Power in June and July 2013.

- GIS information, data and parameters where collected and gathered to feed up the simulator with the real and actual case.

The next table and diagrams show some of these data which describe each segment parameters at the testing feeder. The full range of data is in the Appendix (C).

Table (6.14): Voltage and Load Power in June [61]

MAGTAS			Sea Level	
	Load (MW)	**Voltage (KV)**	**Load (MW)**	**Voltage (KV)**
1/6/2013				
10:06:05	93	32.45	109	32.6
11:32:40	102	32.16	114	32.6
12:59:15	107	31.75	122	32.02
14:25:50	114	31.75	131	32.02
15-6-2013				
10:20:00	87	32.36	104	32.83
11:46:35	91	32.36	104	32.83
13:13:10	96	32.36	116	32.83
14:39:45	100	32.36	116	32.83
30-6-2013				
11:05:50	115	31.79	133	31.89
12:32:25	115	31.79	127	31.89
13:59:00	115	31.79	138	31.89

Table (6.15): Voltage and Load Power in July [61]

MAGTAS			Sea Level	
	Load (MW)	**Voltage (KV)**	**Load (MW)**	**Voltage (KV)**
1/7/2013				
10:26:16	112	31.78	127	34.01
11:55:44	106	31.78	122	34.01
13:25:12	116	31.78	133	34.51
14:54:40	118	31.78	129	34.51
15-7-2013				
11:25:44	115	32.2	135	32.24
12:55:12	119	31.97	134	32.24
14:24:40	126	31.97	137	32.24
30-7-2013				
10:47:12	121	32.2	136	32.84
12:16:40	122	32.2	138	32.84
13:46:08	121	32.2	136	32.84
15:15:36	127	32.2	143	32.84

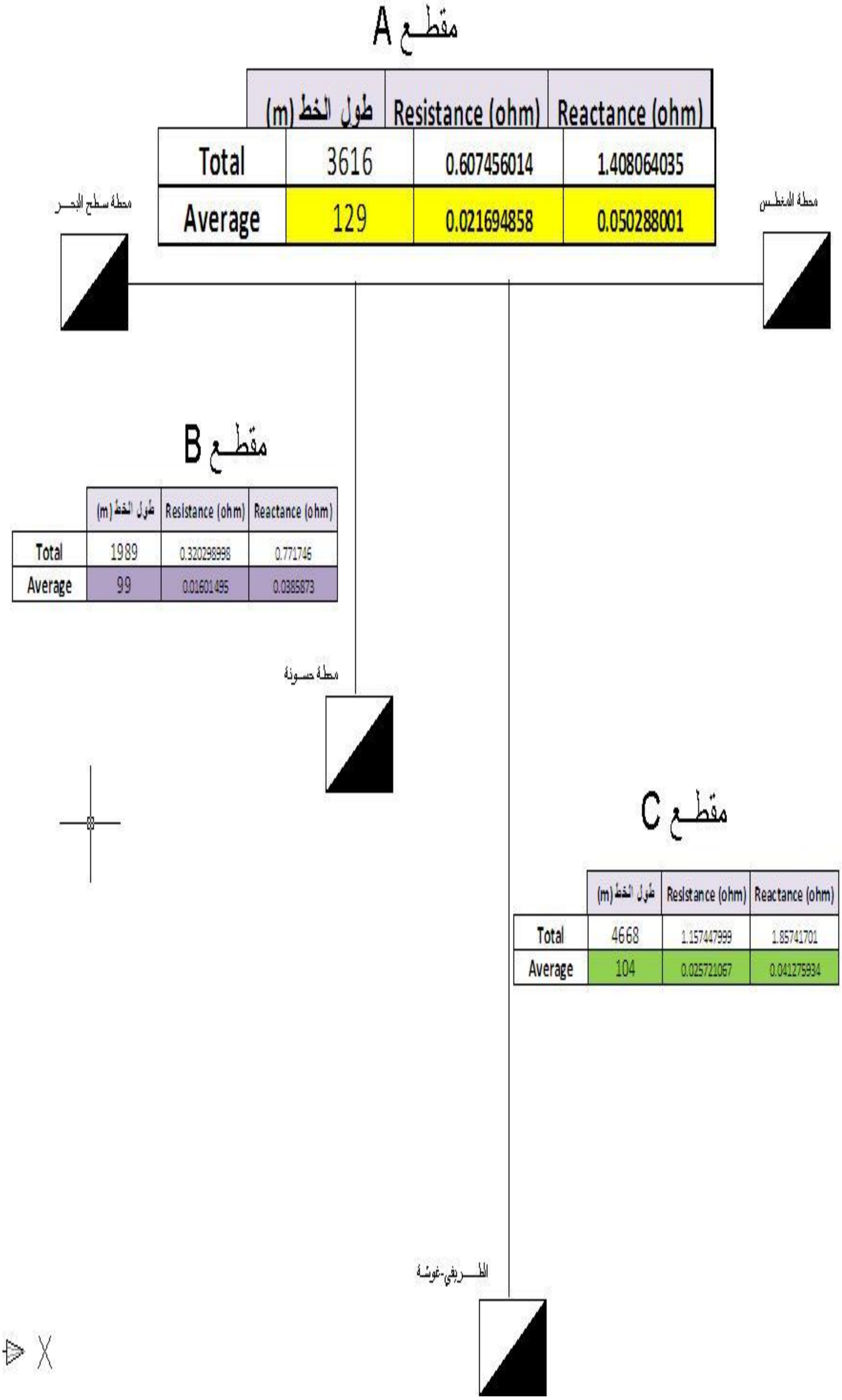

Figure (6.23): One Line Parameters of the Tested Line Using GIS Data [61]

Table (6.16): 33 K.V Line Parameters Using GIS Data [61]

33 K.V Line Parameters From Dead Sea Sub to Al-Magtas Sub-Section D					
From Pole	**To Pole**	**Line Type**	**Line Length (m)**	**Resistance (ohm)**	**Reactance (ohm)**
MG22	MG23	FEAL 1X95	25	0.004775	0.00985
MG23	MG24	FEAL 1X95	141	0.026931001	0.055554003
MG24	MG25	FEAL 1X95	136	0.025976002	0.053584002
MG25	MG26	FEAL 1X95	103	0.019672999	0.040582001
MG26	MG27	FEAL 1X95	104	0.019864	0.040975999
MG28	MG29	FEAL 1X120	116	0.017516	0.044776
MG29	MG30	FEAL 1X120	79	0.01208	0.030879999
		Total	**704**	**0.126815003**	**0.276202003**
		Average		**0.018116429**	**0.039457429**

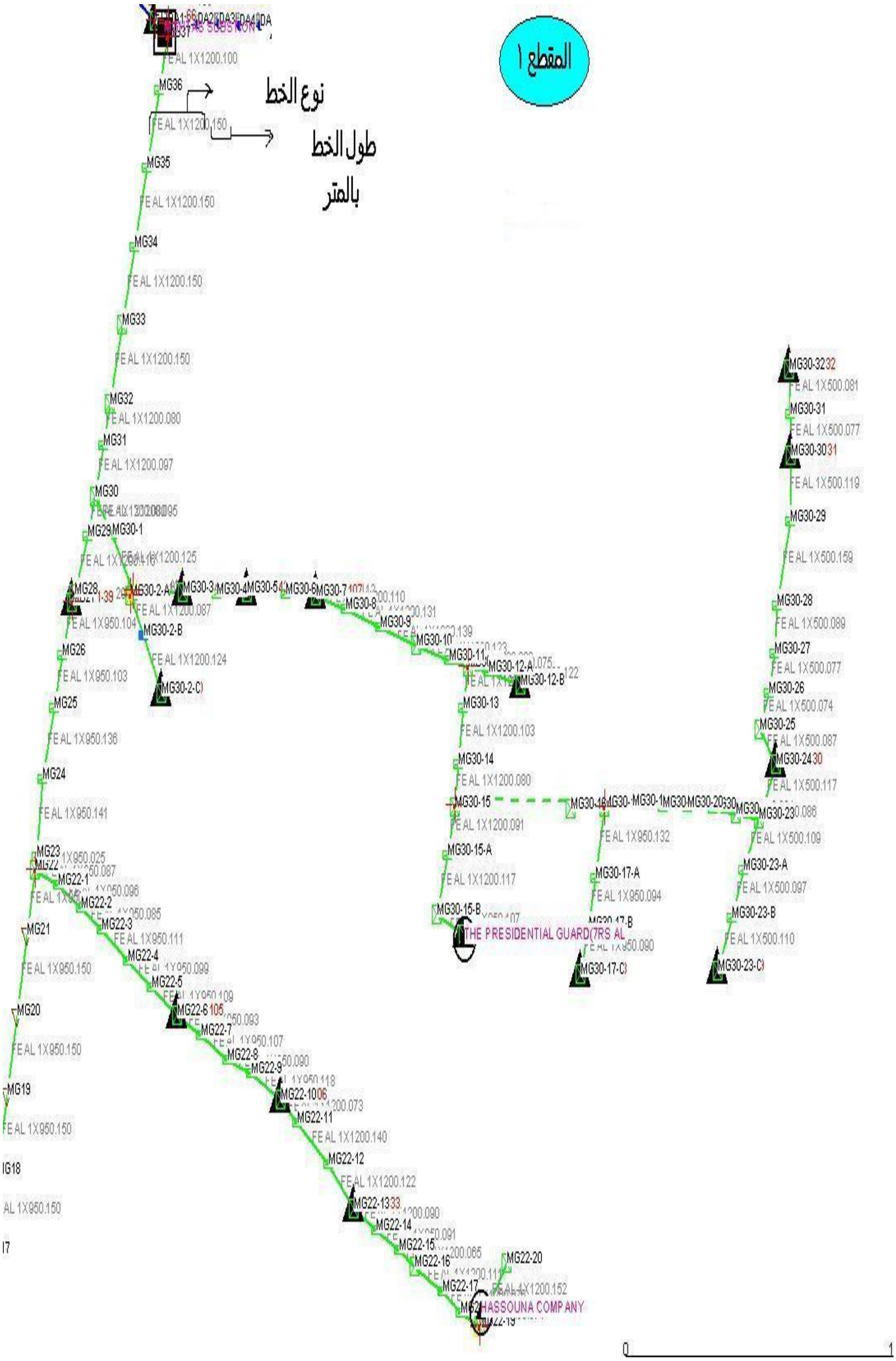

Figure (6.24): Pole to Pole Parameters for the Tested Line Using GIS Data [61]

6.3.2 Jericho One Line Diagram Simulation for the Current Case, using Power World Simulator

- From the above single line diagram it's figured that the solar PV station located between Al-Magtas and Dead Sea stations
- Dead Sea Station is the main source station, load flow from it towards Al-Magtas Station
- Al-Magtas Station is a Load Station which feeding residential loads
- In the middle of this line located industrial area beside the branch of the PV station

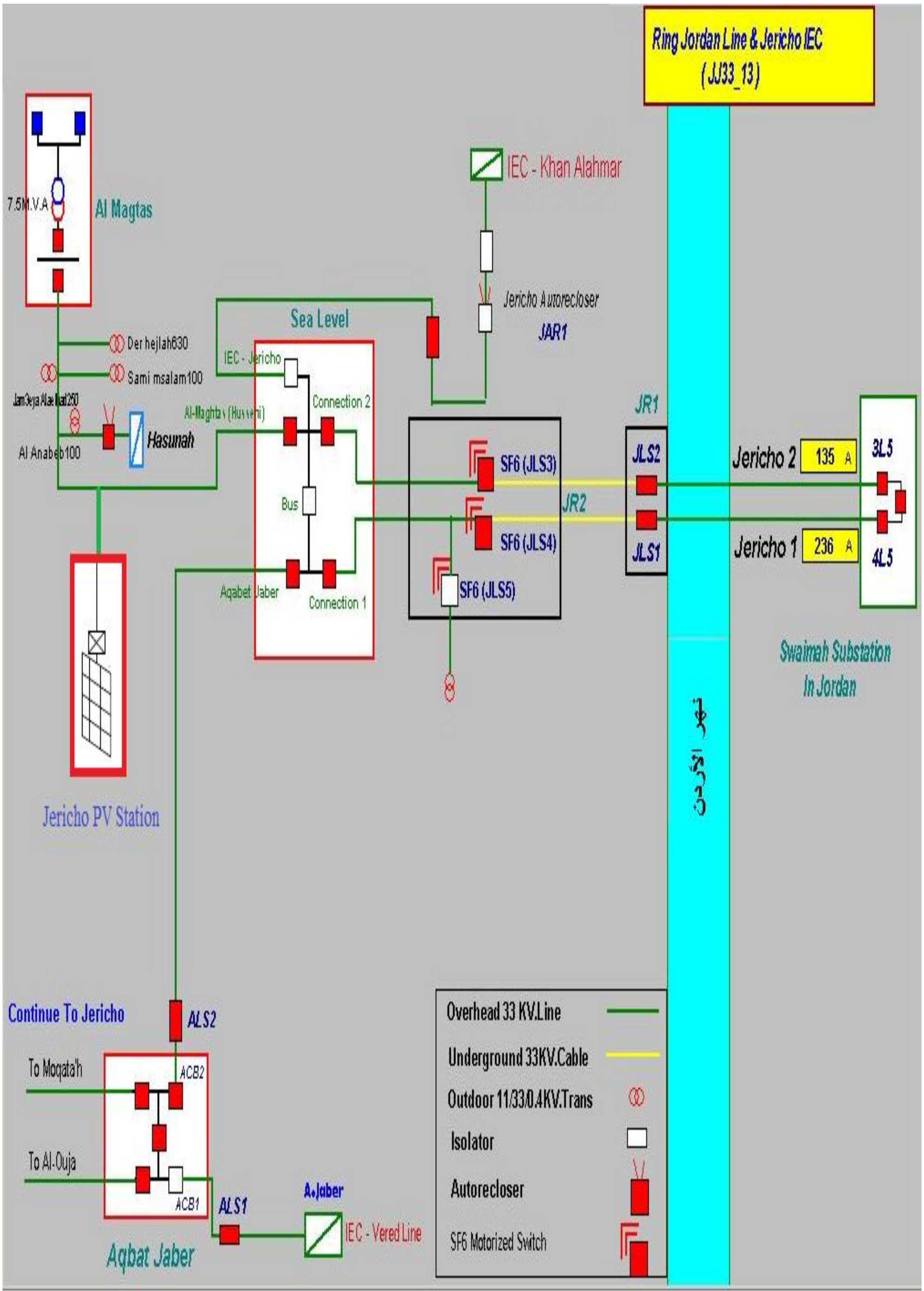

Figure (6.25): Single Line Diagram of Jericho Distribution Network with the PV Station [61]

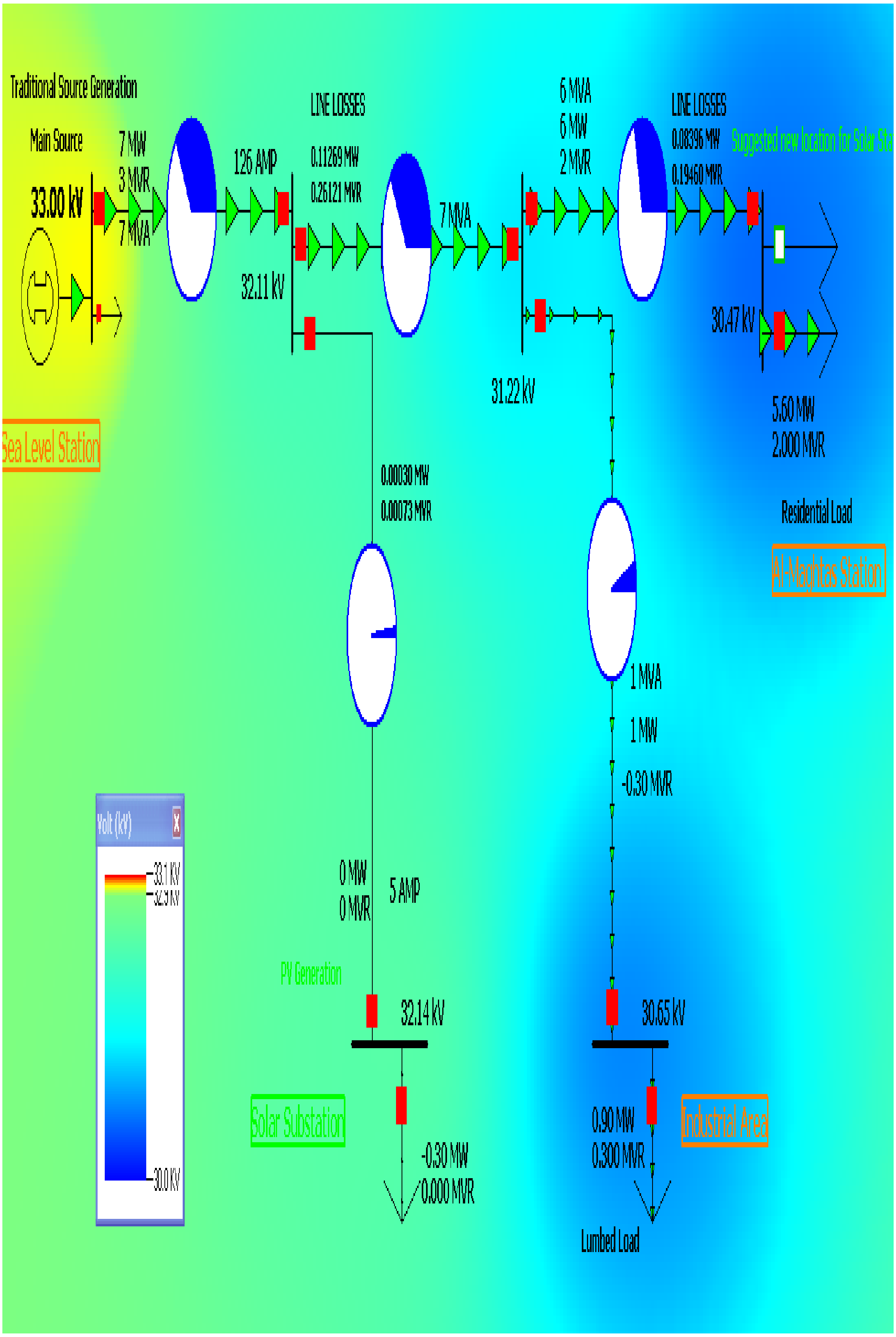

Figure (6.26): One Line Diagram Simulation for Jericho line Current Case Using Power World Simulator

6.3.2.1 Simulation Analysis of the Jericho Current Case

Simulation results:

- It was noted that the solar PV station is located at far distance from the residential loads, and on the same 33 K.V branch there is no loads except the Iron Factory which is not working since a very long time ago. So there are no loads, and the next closest load is in the next branch and it’s a fully industrial load

- It was noted that there is a voltage drop in Al-Magtas Bus, since there is no active AVR on this simulation for simulation purposes to investigate the real effect of PV generator on the voltage level.

- V= 30.47 K.V, at Al-Magtas Station, which is still accepted by grid code and IEC voltage standard + 10 %.

- Line Losses= 197 KW, to Al-Magtas ,

- PV Generator was modeled as a negative load rather than an embedded generator, since the PV generator is acting like a current source.

- No evidence of any little effects on the voltage levels or line losses due to the current PV integration on Jericho medium voltage network.

- Power Factor on the Transformer Bus = 0.92

6.4 Impacts of Increasing PV Penetration Levels on the M.V Network, Simulation Analysis using Power World Simulator

6.4.1 25 % PV Penetration.

The PV penetration Level was increased to 2 MW using the simulator on the same Jericho model with its real parameters and data.

It was noted that there is a little evidence of improving the voltage level or line losses. But there is a significant decreasing on the source bus's power factor value.

- Voltage Level at the residential Load Bus = 30.6 KV
- Power Factor at the Transformer Bus = 0.86
- Line Losses = 195 KW.
- Current Swings=36 A.

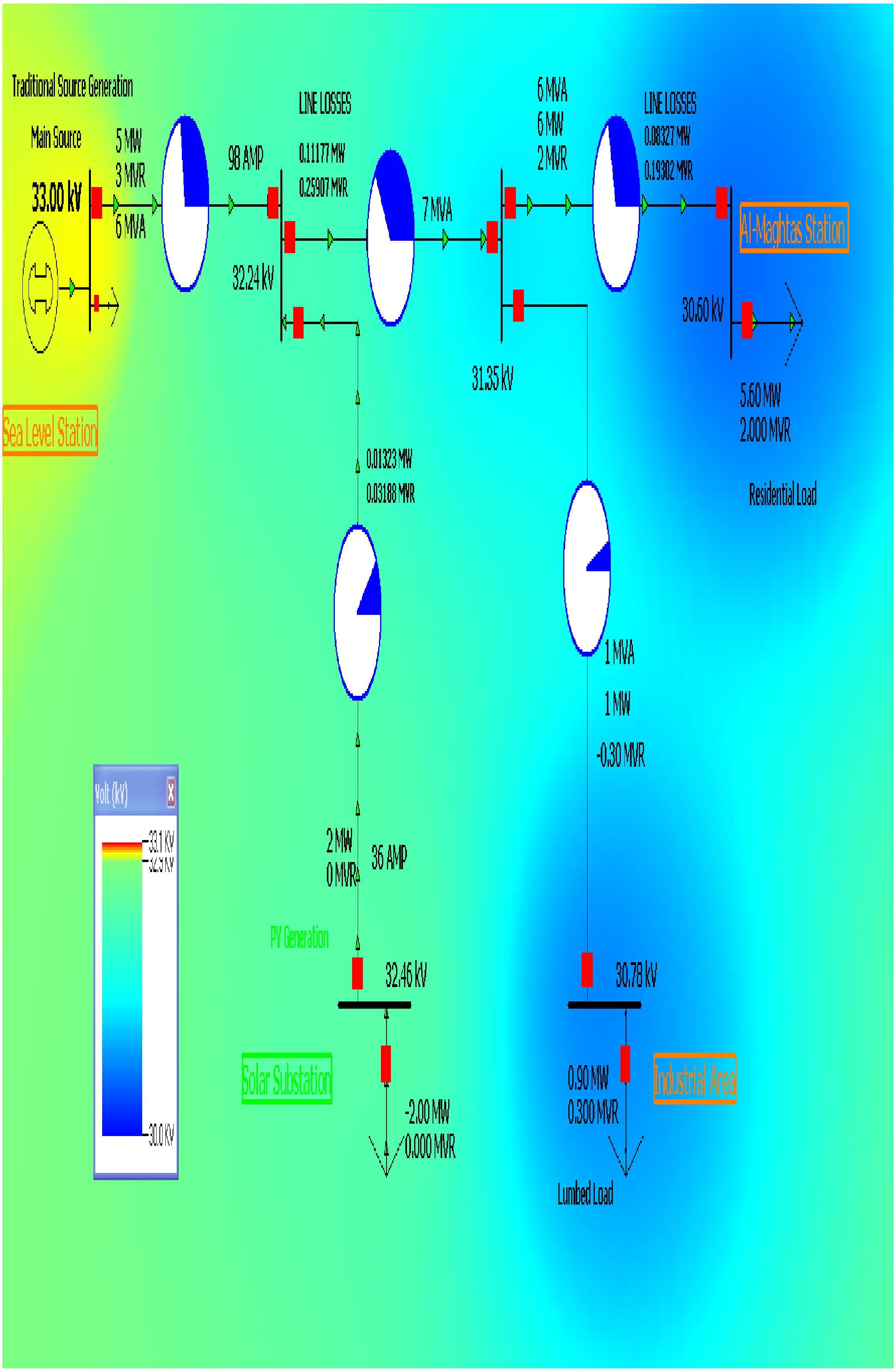

Figure (6.27): 25% PV Penetration on MV of Jericho Network

6.4.2 50 % PV Penetration

It was also noted that there is a little evidence of improving the voltage level or line losses. But there is a significant decreasing on the source bus's power factor value. And no evidence of significant voltage rise on the closest buses.

- Voltage Level at the residential Load Bus = 30.7 KV
- Power Factor at the Transformer Bus = 0.71
- Line Losses = 193 KW.

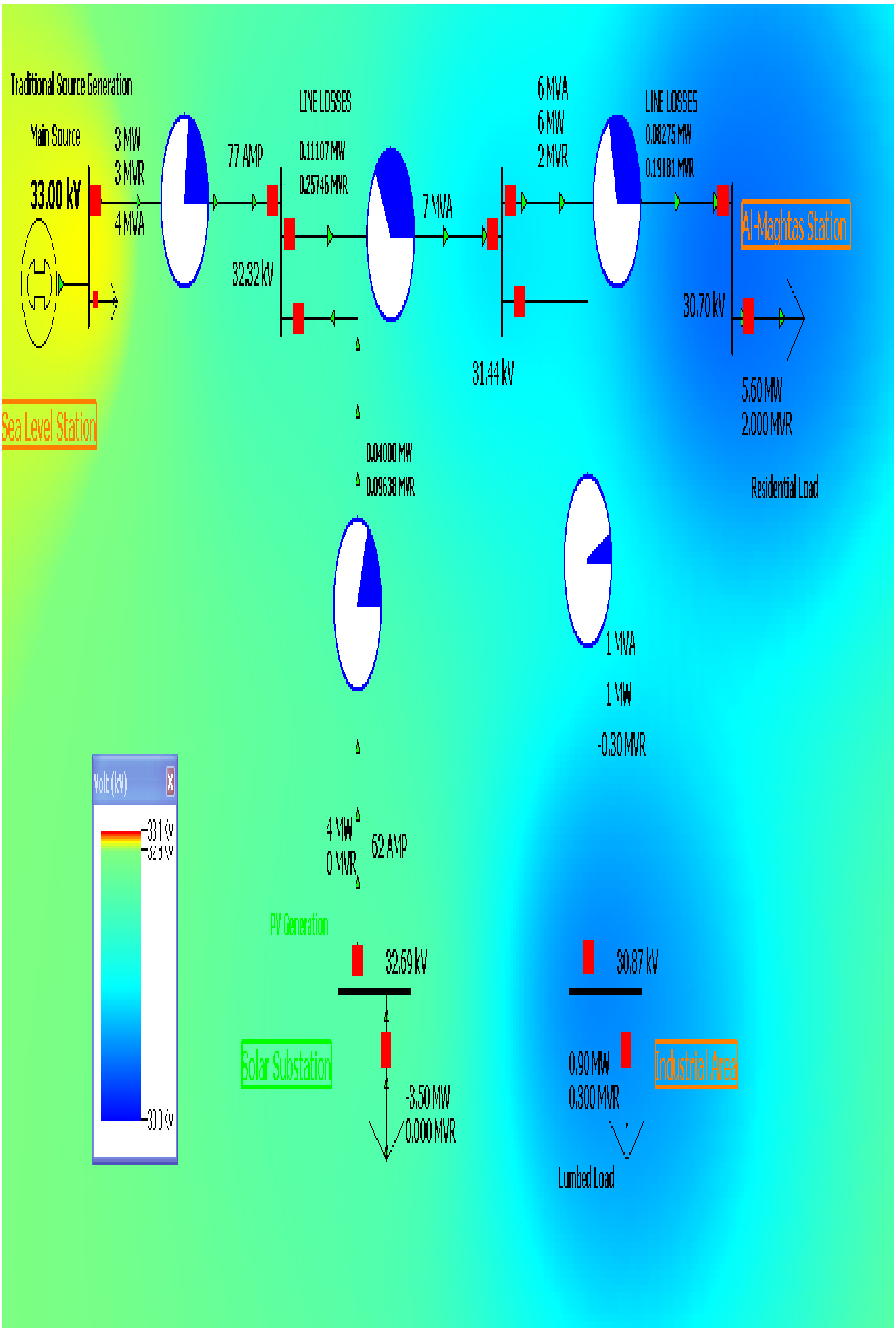

Figure (6.28): 50% PV Penetration on MV of Jericho Network

6.4.3 70 % PV Penetration

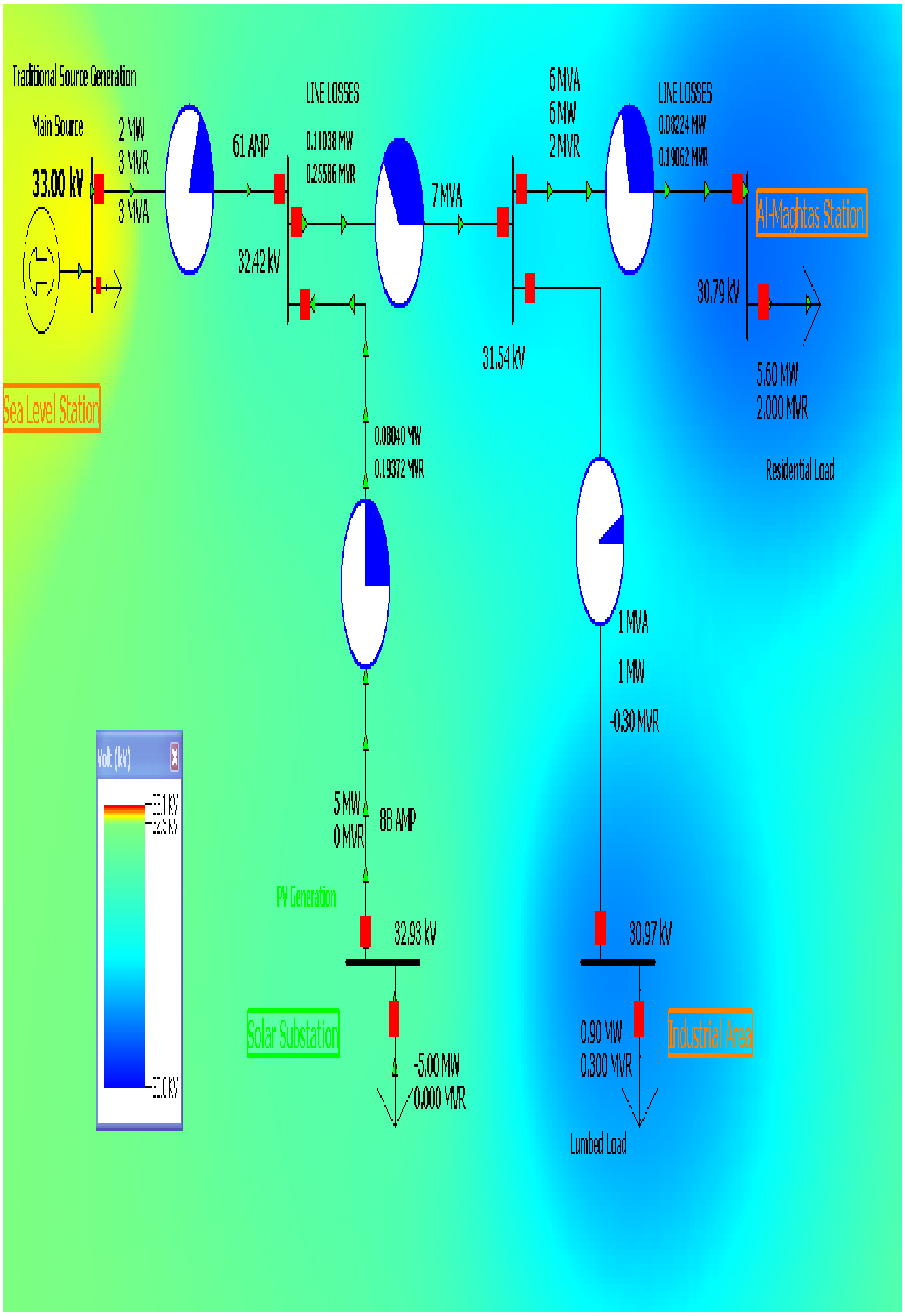

Figure (6.29): 70% PV Penetration on M.V of Jericho Network

Again there is no significant different on the values, it was also noted that there is a little evidence of improving the voltage level or line losses. But there is a significant decreasing on the source bus's power factor value, and no evidence of significant voltage rise on the closest buses.

A significant current swing value appears in the moment of sudden shutting down of the PV generator for any reason.

- Voltage Level at the residential Load Bus = 30.8 KV
- Power Factor at the Transformer Bus = 0.56
- Line Losses = 192 KW.
- Current swing = 69 A.

6.4.4 100 % PV Penetration

Reverse Power flow noted significantly to the source raising the voltages on the buses, the source bus appear as reactive power source only, heating on the grid elements and less efficiency occurring on the grid,

- Voltage Level at the residential Load Bus = 30.9 KV
- Power Factor at the Transformer Bus = zero
- Line Losses = 190 KW.
- Current swing = 69 A.

Research was performed on the current geographical location of the solar station. If it was on another location near or close to the residential load, it will have more positive impacts on the network performance.

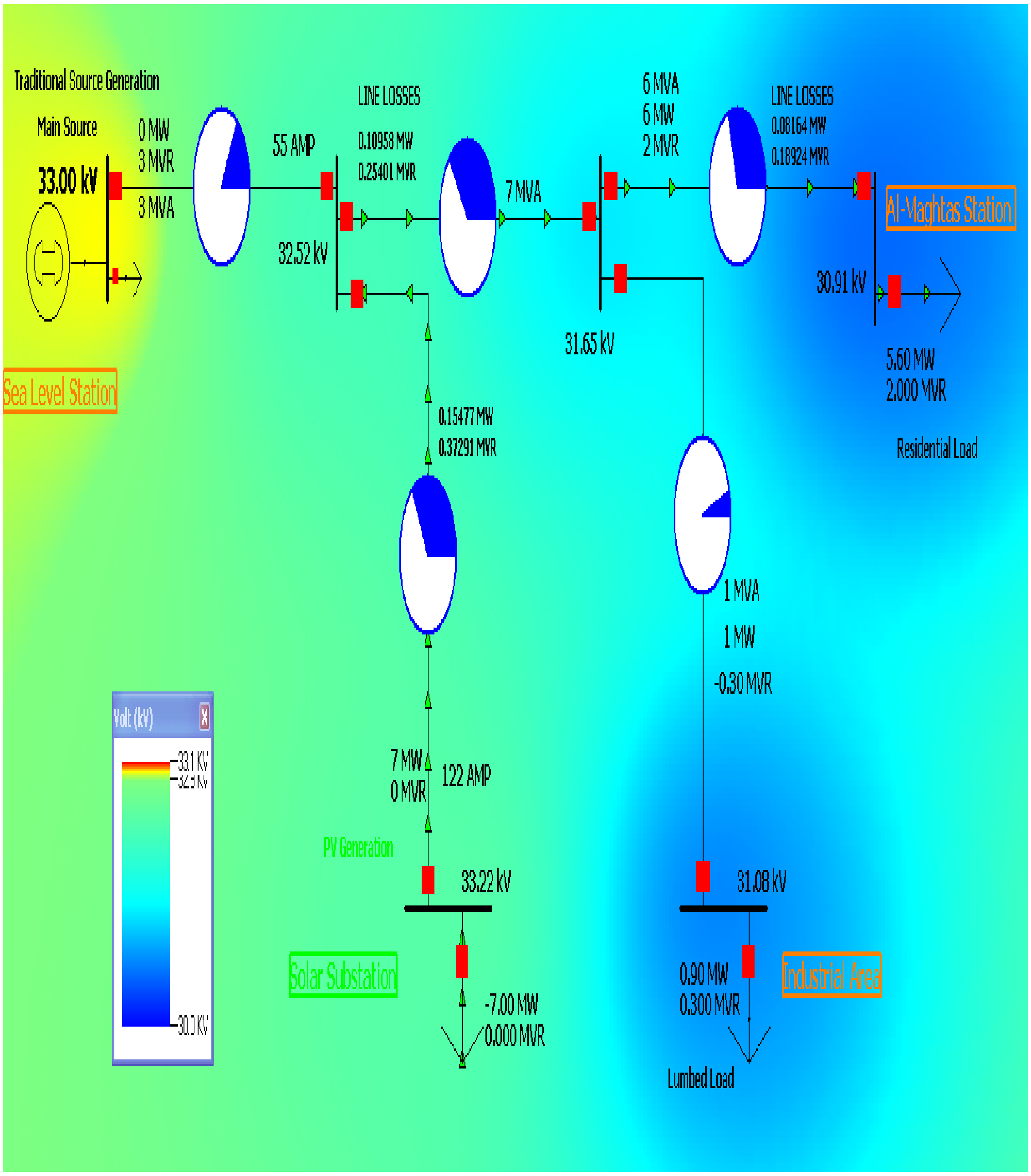

Figure (6.30): 100% PV Penetration on M.V of Jericho Network

6.4.5 Simulation of Suggested New Location for the Solar PV Station

Research was performed on the current geographical location of the solar station and whether if it was on other location near or close to the residential load will have more positive impacts on the network performance.

The next diagrams show some simulation analysis on different PV penetration on Jericho Network with new location of the Solar Station on the residential Load Bus.

6.4.5.1 25% PV Penetration

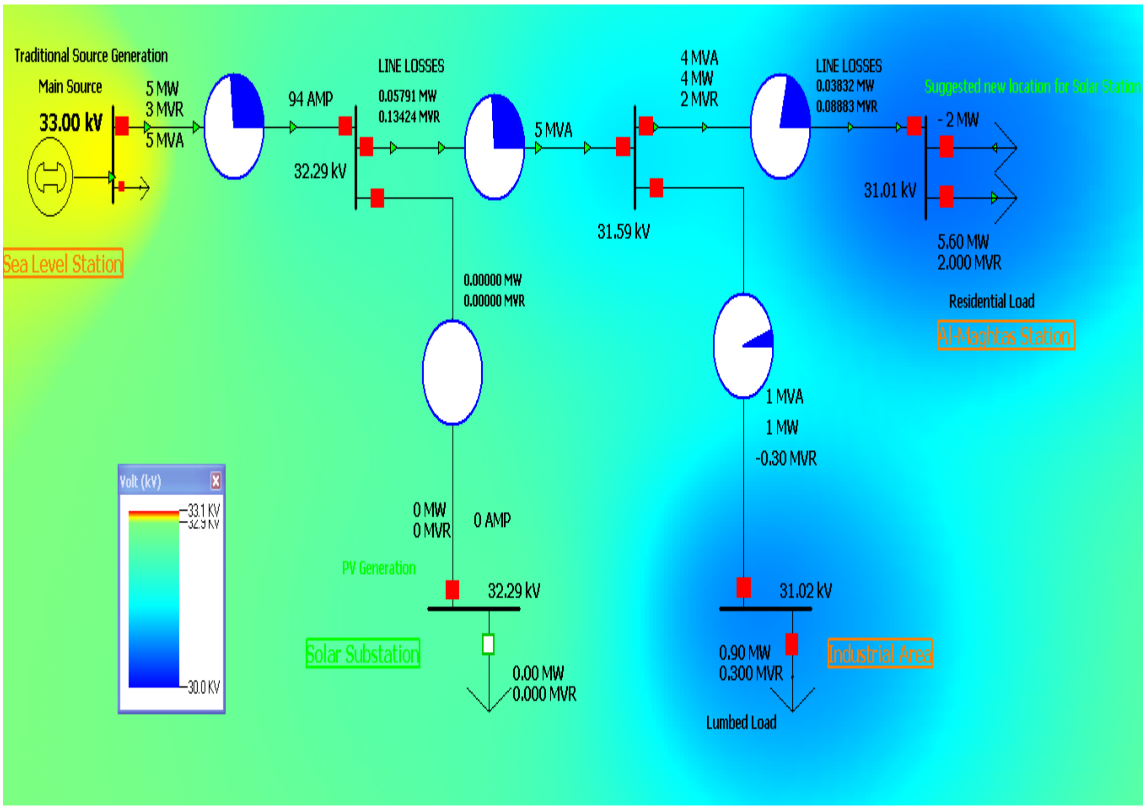

Figure (6.31): New Suggested Location of the Solar Station with 25 % PV Penetration

- Voltage Level at the residential Load Bus = 31.01KV
- Power Factor at the Transformer Bus = 0.86
- Line Losses = 96.23 KW.

6.4.5.2 50% PV Penetration

- Voltage Level at the residential Load Bus = 31.71KV
- Power Factor at the Transformer Bus = 0.7
- Line Losses = 25.22 KW.

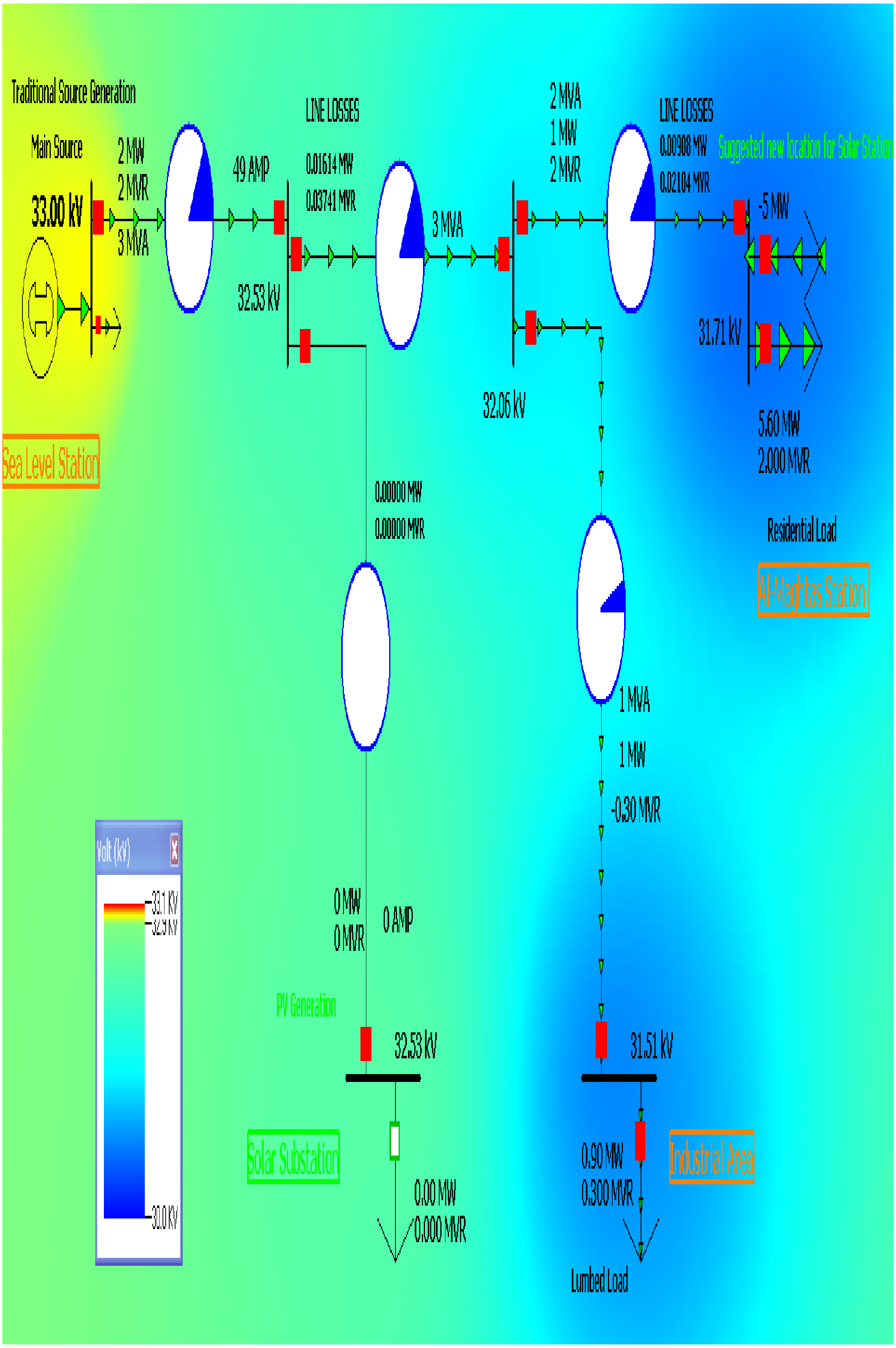

Figure (6.32): New Suggested Location of the Solar Station with 50 % PV Penetration

6.4.5.2 100% PV Penetration

- Voltage Level at the residential Load Bus = 32.12KV
- Power Factor at the Transformer Bus = 0
- Line Losses = 23.78 KW.

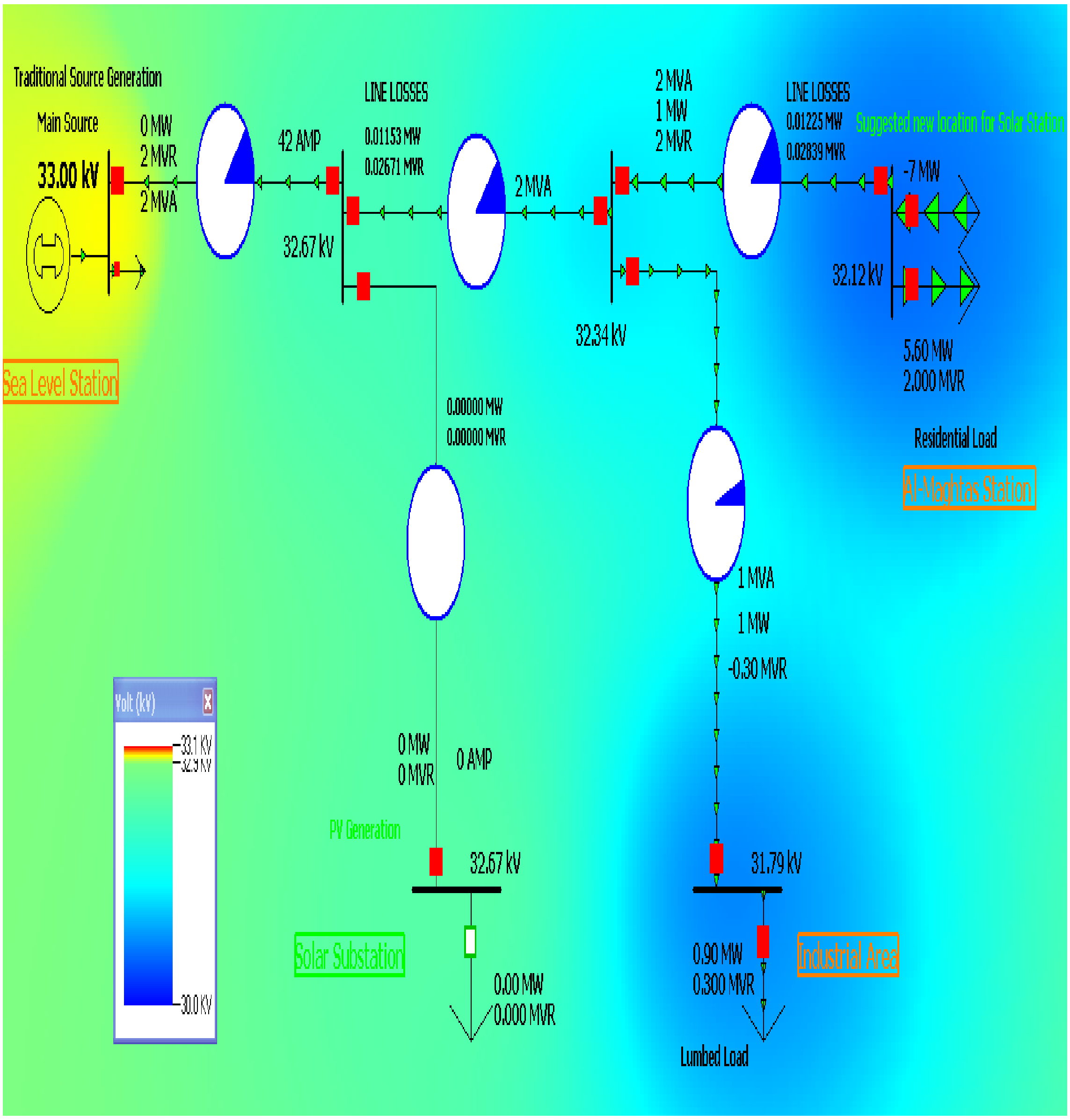

Figure (6.33): New Suggested Location of the Solar Station with 100 % PV Penetration

6.5 Comparison Analysis between the Current and the Suggested Situation of the Solar Station

Table (6.17): Comparison for three Penetration Levels for the new and the suggested situation for the Solar Station

	25% PV		50% PV		100% PV	
	Current	**Suggested**	**Current**	**Suggested**	**Current**	**Suggested**
Power Factor	0.86	0.86	0.71	0.7	0	0
Voltage (KV)	30.6	31.01	30.7	31.7	30.9	32.12
Line Losses (KW)	195	96.23	193	25.22	190	23.78

6.6 Environmental Impact Assessment for PV Penetration of Jericho Solar Station

The calculations of environmental impact assessment in this section are depending on three types of data:

- Expected amount of energy generated by Jericho Solar Station according to the station designer and developer (JAIP) is equal to (422,000 KWh). [61]
- The amount of generated energy from Jericho Solar Station by theoretical calculations is:

$$E = Wp * Average\ Solar\ Irradiance * pf * S.f * 365$$

$$E = 300 * 5.4 * 0.9 * 0.9 * 365 = 478{,}953\ KWh$$

The actual amount of generated energy units from Jericho Solar Station according to the real data that were gathered from the main monitoring system at Jericho Solar Station and from JDWCO KWh meter from 8/2012 to 8/2013 is equal to 480,572KWh. The previous data from JDECO are after discount of the losses which are approximately 10%, so this data are equal to 552,657 KWh.

The previous amounts are shown in Table.

Type	**Amount of Energy (KWh)**
Energy According to Station's Designer	422,000
Energy Calculated (My Calculation)	478,953
Energy According to Readings at Jericho Station (Actual)	480,572
Energy According to Readings at JDECO (Actual)	552,657

The expected amounts of carbon dioxide emissions reduction according to the data here and in section 5.7 are: 480,572*0.7=336,400 Kg of carbon dioxide per year.

Conclusion and Recommendations

Using Power World Simulator, Low Voltage case study of Al-Jeep electrical distribution network was simulated and analyzed and PSI was projected on the network using 5 KW_p grid tied PV systems .Then, the capacity of PV systems were increased and doubled, and each PV penetration level of 25%, 50%, 75%, 100% on the grid were simulated and investigated by modeling the one line diagram. Moreover, the PV systems using the simulator and the technical impacts regarding the power supply quality were examined.

It was noted that as the penetration level of grid tied PV on the grid increased above 50% of the transformer load, the distribution transformer would suffer from very poor power factor values and reverse power flow was detected on the grid towards the source causing the grid to appear as a reactive power source only, which beside the law power factor value would lead to less efficient grid elements and equipment and to heating generation due to the reactive power flow which will decrease their life time. Although the lines losses decreased as the PV penetration level increased and voltage levels improved at 25% PV penetration level. However after 50% penetration level, over voltage on the grid appeared beyond the acceptable range according to IEC and grid code, especially on the rural feeder with high impedance and low loads, A significant current swing occurred and exceeded 100 A at 80% penetration level.

On the M.V case study of Jericho network and Jericho Solar PV station, negligible technical impacts were noted on the current level of penetration which, the current capacity of the station, equals 300 KW_p

Different levels of PV penetration level on the M.V network where examined by raising the capacity of the solar station gradually. This was modeled using Power World Simulator and physical and real time data of Jericho network and Jericho solar station.

No evidence of over voltage values where investigated at any PV penetration levels, but also no significant improving on the voltage level were noted on poor values buses voltages. Power factor of source bus decreased significantly as the penetration of the grid tied PV station capacity increased. Negligible effect of the line losses improvement appeared at all the tested penetration levels. An important current swing occurred beyond 50% penetration level.

Regarding the M.V case, it’s recommended from the researcher point of view, as a result of this study, that it was more justified and preferable if the sight location of the solar station was shifted to a new position closet to the residential load (AL-Magtas station).this new geographical position was investigated using the simulator and better values resulted for voltage levels and losses.

On the low voltage case study, the recommendation is to minimize the negative technical impact of the distributed PV generators on the conventional grid:

- Using smart grid systems to monitor the grid performance hourly and control the energy exchange times to mitigate the negative impacts, and maximize the benefits.

- Limiting the PV penetration level on the grid to 40% by the regulator for more safety. Or limiting the PV penetration level to the value of the minimum value of the nutrient load.

- Study the storage system on the grid to act as a buffering zone.

- Limiting the penetration level of the grid tied PV system on the network (Feeder) to equal the minimum load of the feeder due to the potential rising of the voltage assuming no tap changing in L.V/M.V transformer.

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Appendix

Appendix (A) Al-Jeeb Network

- Al-Jeeb Feeders Specifications

TR1034-3 160KVA (Al-Jeeb Transformer)		
OVER HEAD LINE		
Conductor Type	**Length (m)**	**Feeder**
AL 1X50	330 m	CR5
AL 1X25	355 m	
AL 1X50	271 m	CR6
AL 1X25	572 m	

ABC		
Conductor Type	**Length (m)**	**Feeder**
ABC 25	429 m	CR5
ABC 50	291 m	
ABC 25	291 m	CR6
ABC 50	633 m	

CABLE		
Conductor Type	**Length (m)**	**Feeder**
3X10 CU	187 m	CR5
4X16 CU	137m	
3X185+95 AL	15 m	
3X10 CU	615 m	CR6
4X16 CU	183 m	
3X185+95 AL	15 m	

-

CR6 Feeder (4) segment E – G

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (1/Ohm)
134-3-27	134-3-32	35	0.012565	0.011305
134-3-32	134-3-33	44	0.015796	0.014212
134-3-33	134-3-34	39	0.014001	0.012597
134-3-34	134-3-35	48	0.017232	0.015504
134-3-35	134-3-36	46	0.029486	0.003542
134-3-36	134-3-37	96	0.061536	0.007392
134-3-37	134-3-38	53	0.033973	0.004081
134-3-38	134-3-39	53	0.038001	0.018285
134-3-39	134-3-40	42	0.030114	0.01449
134-3-40	134-3-41	24	0.015384	0.001848
TOTAL		480	0.268088	0.103256

CR5 Feeder (1) Segment A–I

From Tower	To Tower	Length (m)	Resistance (Ohm)	Reactance (1/Ohm)
134-3-1	134-3-11	27	0.017307	0.002079
134-3-11	BN73	30	0.01923	0.00231
BN73	134-3-12	33	0.021153	0.002541
134-3-12	BN72	29	0.018589	0.002233
BN72	134-3-14	54	0.019386	0.017442
134-3-14	BN71	42	0.015078	0.013566
BN71	134-3-15	24	0.008616	0.007752
134-3-15	BN70	61	0.021899	0.019703
TOTAL		300	0.14126	0.067626

- CR-5 Feeder Network

Al-Jeeb Al-Khalayleh Transformer TR1034-3

FEDER 1= CR5 18 Open Customer + 2 Closed

Columne No.	Service No.	Connection	Collection Box No.
134-3-4	CLOSED		
134-3-5	103400848	L1-L2-L3-PEN	
134-3-6	103400213	L2-PEN	
	103400211	L3-PEN	
134-3-7	103400204	L1-L2-L3-PEN	
134-3-8	103400900		
134-3-10	103400269	L1-PEN	134-3-CX3
	103400271	L1-PEN	
	103400849	L1-L2-L3-PEN	
134-3-12	103400197	L1-L2-L3-PEN	
134-3-13	103400370	L3-PEN	
134-3-19	103400249	L1-PEN	
134-3-21	103400168	L1-PEN	
	103400799	L1-PEN	
BN71	CLOSED		
BN72	103400198	L1-L2-L3-PEN	
BN73	103400230	L3-PEN	134-3-CX2
	103400191	L3-PEN	
	103400819	L1-L2-L3-PEN	
	103400196	L1-L2-L3-PEN	

- CR-6 Feeder Network

Al-Jeeb Al-Khalayleh Transformer TR1034-3			
FEDER 2 = CR6 37 Open customer + 11 Closed			
Columne No.	Service No.	Connection	Collection Box No.
134-3-24	103400878	L3-PEN	
	103400877	L2-PEN	
	103400193	L1-PEN	
	103400917	L1-L2-L3-PEN	
134-3-25	103400234	L2-PEN	
134-3-26	NO METER		
	103400310	L1-PEN	
134-3-27	103400808	L1-L2-L3-PEN	
134-3-29	103400203	L2-PEN	
134-3-30	103400257	L2-PEN	
134-3-31	103400880	L2-PEN	
	103400881	L2-PEN	
134-3-32	103400218	L2-PEN	
	103400202	L3-PEN	
	103400836	L3-PEN	
134-3-33	CLOSED		
134-3-35		L1-PEN	
134-3-38	103400301	L1-PEN	134-3-CX1
	103400857	L1-PEN	
	103400858	L2-PEN	
	103400859	L2-PEN	
	103400860	L2-PEN	
	CLOSED		
	CLOSED		
134-3-40	CLOSED		
134-3-41	103400879	L2-PEN	
	103400619	L2-PEN	
134-3-46	103400833	L3-PEN	
	103400321	L3-PEN	
134-3-47	103400335	L1-PEN	
	103400411	L3-PEN	
134-3-48	103400845	L1-L2-L3-PEN	
134-3-51	CLOSED		
	CLOSED		
134-3-52	CLOSED		
	103400314	L2-PEN	
	103400336	L2-PEN	
134-3-53	CLOSED		
	103400891	L3-PEN	134-3-CX5
	103400890	L3-PEN	
	103400341	L3-PEN	
	103400882	L3-PEN	
BN76	103400206	L1-PEN	134-3-CX4
	103400207	L1-PEN	
	103400382	L2-PEN	
	103400672	L2-PEN	
BN77	CLOSED		
	CLOSED		

- 6 from 31 Days of Readings of service in Al-Jeeb village for a single phase service

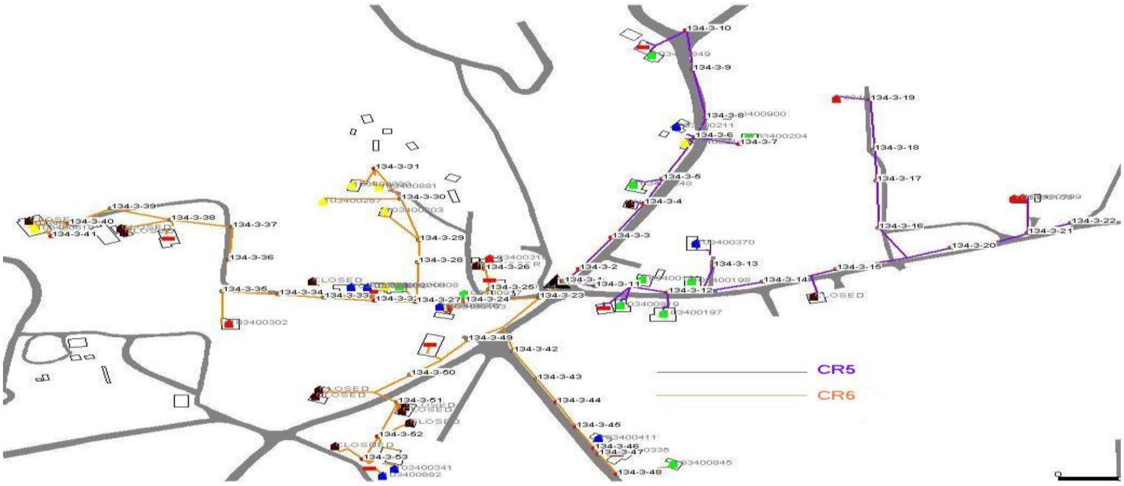
Name	Date	Total	Consumption	Name	Date	Total	Consumption
SP103400799	1/5/2013 12:00 AM	3858.88	0.17	SP103400799	4/5/2013 12:00 AM	3876.51	0.2
SP103400799	1/5/2013 1:00 AM	3859.05	0.16	SP103400799	4/5/2013 1:00 AM	3876.71	0.68
SP103400799	1/5/2013 2:00 AM	3859.21	0.13	SP103400799	4/5/2013 5:00 AM	3877.39	0.16
SP103400799	1/5/2013 3:00 AM	3859.34	0.13	SP103400799	4/5/2013 6:00 AM	3877.55	0.16
SP103400799	1/5/2013 4:00 AM	3859.47	0.13	SP103400799	4/5/2013 7:00 AM	3877.71	0.16
SP103400799	1/5/2013 5:00 AM	3859.6	0.13	SP103400799	4/5/2013 8:00 AM	3877.87	0.17
SP103400799	1/5/2013 6:00 AM	3859.73	0.13	SP103400799	4/5/2013 9:00 AM	3878.04	0.19
SP103400799	1/5/2013 7:00 AM	3859.86	0.2	SP103400799	4/5/2013 10:00 AM	3878.23	0.18
SP103400799	1/5/2013 8:00 AM	3860.06	0.22	SP103400799	4/5/2013 11:00 AM	3878.41	0.19
SP103400799	1/5/2013 9:00 AM	3860.28	0.25	SP103400799	4/5/2013 12:00 PM	3878.6	0.18
SP103400799	1/5/2013 10:00 AM	3860.53	0.25	SP103400799	4/5/2013 1:00 PM	3878.78	0.18
SP103400799	1/5/2013 11:00 AM	3860.78	0.27	SP103400799	4/5/2013 2:00 PM	3878.96	0.09
SP103400799	1/5/2013 12:00 PM	3861.05	0.27	SP103400799	4/5/2013 3:00 PM	3879.05	0.28
SP103400799	1/5/2013 1:00 PM	3861.32	0.24	SP103400799	4/5/2013 5:00 PM	3879.33	0.27
SP103400799	1/5/2013 2:00 PM	3861.56	0.27	SP103400799	4/5/2013 6:00 PM	3879.6	0.35
SP103400799	1/5/2013 3:00 PM	3861.83	0.26	SP103400799	4/5/2013 7:00 PM	3879.95	0.38
SP103400799	1/5/2013 4:00 PM	3862.09	0.3	SP103400799	4/5/2013 8:00 PM	3880.33	0.43
SP103400799	1/5/2013 5:00 PM	3862.39	0.32	SP103400799	4/5/2013 9:00 PM	3880.76	0.47
SP103400799	1/5/2013 6:00 PM	3862.71	0.32	SP103400799	4/5/2013 10:00 PM	3881.23	0.52
SP103400799	1/5/2013 7:00 PM	3863.03	0.38	SP103400799	4/5/2013 11:00 PM	3881.75	0.76
SP103400799	1/5/2013 8:00 PM	3863.41	0.37	SP103400799	5/5/2013 1:00 AM	3882.51	0.33
SP103400799	1/5/2013 9:00 PM	3863.78	0.38	SP103400799	5/5/2013 2:00 AM	3882.84	0.25
SP103400799	1/5/2013 10:00 PM	3864.16	0.24	SP103400799	5/5/2013 3:00 AM	3883.09	0.25
SP103400799	1/5/2013 11:00 PM	3864.4	0.24	SP103400799	5/5/2013 4:00 AM	3883.34	0.48
SP103400799	2/5/2013 12:00 AM	3864.64	0.22	SP103400799	5/5/2013 6:00 AM	3883.82	0.28
SP103400799	2/5/2013 1:00 AM	3864.86	0.21	SP103400799	5/5/2013 7:00 AM	3884.1	0.25
SP103400799	2/5/2013 2:00 AM	3865.07	0.2	SP103400799	5/5/2013 8:00 AM	3884.35	0.29
SP103400799	2/5/2013 3:00 AM	3865.27	0.21	SP103400799	5/5/2013 9:00 AM	3884.64	0.15
SP103400799	2/5/2013 4:00 AM	3865.48	0.21	SP103400799	5/5/2013 10:00 AM	3884.79	0.1
SP103400799	2/5/2013 5:00 AM	3865.69	0.3	SP103400799	5/5/2013 11:00 AM	3884.89	0.12
SP103400799	2/5/2013 6:00 AM	3865.99	0.31	SP103400799	5/5/2013 12:00 PM	3885.01	0.08
SP103400799	2/5/2013 7:00 AM	3866.3	0.27	SP103400799	5/5/2013 1:00 PM	3885.09	0.09
SP103400799	2/5/2013 8:00 AM	3866.57	0.25	SP103400799	5/5/2013 2:00 PM	3885.18	0.11
SP103400799	2/5/2013 9:00 AM	3866.82	0.15	SP103400799	5/5/2013 3:00 PM	3885.29	0.12
SP103400799	2/5/2013 10:00 AM	3866.97	0.19	SP103400799	5/5/2013 4:00 PM	3885.41	0.09
SP103400799	2/5/2013 11:00 AM	3867.16	0.1	SP103400799	5/5/2013 5:00 PM	3885.5	0.14
SP103400799	2/5/2013 12:00 PM	3867.26	0.1	SP103400799	5/5/2013 6:00 PM	3885.64	0.19
SP103400799	2/5/2013 1:00 PM	3867.36	0.25	SP103400799	5/5/2013 7:00 PM	3885.83	0.27
SP103400799	2/5/2013 3:00 PM	3867.61	0.11	SP103400799	5/5/2013 8:00 PM	3886.1	0.36
SP103400799	2/5/2013 4:00 PM	3867.72	0.11	SP103400799	5/5/2013 9:00 PM	3886.46	0.39
SP103400799	2/5/2013 5:00 PM	3867.83	0.1	SP103400799	5/5/2013 10:00 PM	3886.85	0.31
SP103400799	2/5/2013 6:00 PM	3867.93	0.43	SP103400799	5/5/2013 11:00 PM	3887.16	0.19
SP103400799	2/5/2013 8:00 PM	3868.36	0.39	SP103400799	6/5/2013 12:00 AM	3887.35	0.19
SP103400799	2/5/2013 9:00 PM	3868.75	0.37	SP103400799	6/5/2013 1:00 AM	3887.54	0.19
SP103400799	2/5/2013 10:00 PM	3869.12	0.38	SP103400799	6/5/2013 2:00 AM	3887.73	0.19
SP103400799	2/5/2013 11:00 PM	3869.5	0.37	SP103400799	6/5/2013 3:00 AM	3887.92	0.2
SP103400799	3/5/2013 12:00 AM	3869.87	0.22	SP103400799	6/5/2013 4:00 AM	3888.12	0.4
SP103400799	3/5/2013 1:00 AM	3870.09	0.19	SP103400799	6/5/2013 6:00 AM	3888.52	0.27
SP103400799	3/5/2013 2:00 AM	3870.28	0.2	SP103400799	6/5/2013 7:00 AM	3888.79	0.18
SP103400799	3/5/2013 3:00 AM	3870.48	0.2	SP103400799	6/5/2013 9:00 AM	3888.97	0.09
SP103400799	3/5/2013 4:00 AM	3870.68	0.3	SP103400799	6/5/2013 10:00 AM	3889.06	0.36
SP103400799	3/5/2013 5:00 AM	3870.98	0.18	SP103400799	6/5/2013 1:00 PM	3889.42	0.17
SP103400799	3/5/2013 6:00 AM	3871.16	0.1	SP103400799	6/5/2013 2:00 PM	3889.59	0.2
SP103400799	3/5/2013 7:00 AM	3871.26	0.2	SP103400799	6/5/2013 3:00 PM	3889.79	0.27
SP103400799	3/5/2013 9:00 AM	3871.46	0.2	SP103400799	6/5/2013 4:00 PM	3890.06	0.26
SP103400799	3/5/2013 10:00 AM	3871.66	0.4	SP103400799	6/5/2013 5:00 PM	3890.32	0.21
SP103400799	3/5/2013 12:00 PM	3872.06	0.22	SP103400799	6/5/2013 6:00 PM	3890.53	0.09
SP103400799	3/5/2013 1:00 PM	3872.28	0.33	SP103400799	6/5/2013 7:00 PM	3890.62	0.17
SP103400799	3/5/2013 2:00 PM	3872.61	0.4	SP103400799	6/5/2013 9:00 PM	3890.79	0.09
SP103400799	3/5/2013 3:00 PM	3873.01	0.41	SP103400799	6/5/2013 10:00 PM	3890.88	0.17
SP103400799	3/5/2013 4:00 PM	3873.42	0.4	SP103400799	6/5/2013 11:00 PM	3891.05	0.36
SP103400799	3/5/2013 5:00 PM	3873.82	0.37				
SP103400799	3/5/2013 6:00 PM	3874.19	0.37				
SP103400799	3/5/2013 7:00 PM	3874.56	0.44				
SP103400799	3/5/2013 8:00 PM	3875	0.48				
SP103400799	3/5/2013 9:00 PM	3875.48	0.83				
SP103400799	3/5/2013 11:00 PM	3876.31	0.2				

\- Monthly Average Consumption for Single Phase Service from 7, 2012 – 6, 2013

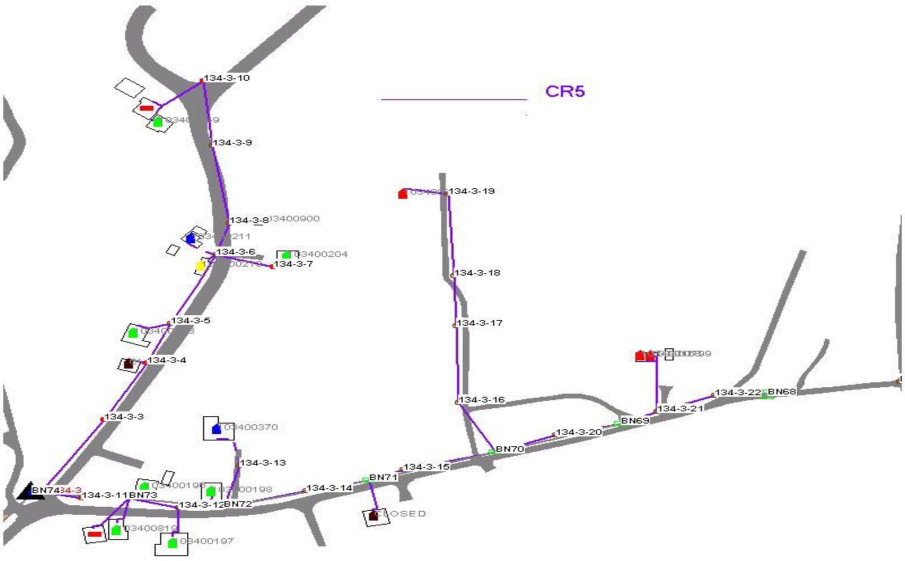
Name	Total/7/2012	Total/8/2012	Total/9/2012	Total/10/2012	Total/11/2012	Total/1/2013	Total/2/2013	Total/3/2013	Total/4/2013	Total/5/2013	Total/6/2013
SP103400186	213.76	207.43	198.04	628.37	3251.69	921.78	625.93	758.07	939.05	817.84	643.32
SP103400191	73.16	80.96	78.13	74.29	175.72	102.77	149.29	66.62	75.43	77.8	80.87
SP103400192	0		5.94								
SP103400193	551.08	495.57	377.33	284.07	1002.05	753.05	721.75	470.55	440.12	389.66	408.48
SP103400195	5.33	0.44	2.21	3.36	0.22	0.4	0.3	23.05	29.53	5.52	4.86
SP103400199	0										
SP103400200	324.52	313.27	248.34	224.8	688.32	308.59	374.97	408.22	311.32	231.48	121.57
SP103400201											
SP103400202	576.92								0	0	0
SP103400203	298.88	293.25	297.78	285.66	750.85	608.45	484.94	477.39	382.27	371.14	331.26
SP103400206	626.73	704	512.32	614.49	883.48	480.07	399	554.78	596.63	647.2	610.71
SP103400207	739.07	716.23	647.41	621.53	245.53	114.93	223.23	81.94	59.45	123.88	158.5
SP103400211					1890.34	836.08	570.92	900.66	527.39	643.59	601.8
SP103400213	1715.34	1724.05	1467.31	1348.49	2699.41	1835.16	1557.21	1499.9	1465.06	1468.44	1502.97
SP103400230	1233.34	2204.91	1772.06	1559.41	2224.69	1132.39	1001.49	987.82	1172.05	1603.24	1723.18
SP103400234	634.17	704.75	591.26	736.21	1691.38	882.36	986.31	1075.86	846.91	248.48	166.66
SP103400237											
SP103400238	638.02	551.01	163.82	279.08	285.95	31.56	50.84	4.4	0	90.21	
SP103400240	348.57	344.06	305.13	397.12	648.15	327.43	295.49	339.71	337.64	349.87	374.66
SP103400249	479.63	389.46	235.4	146.15	367.97	650.66	323.16	78.45	192.77	22.33	102.84
SP103400257	668.63	738.49	639.68	613.99	1322.06	731.78	584.59	614.21	628.38	546.63	514.21
SP103400269	371.89	421.59	356.31	384.75	666.13	362.45	299.72	287.32	301.13	296.44	355.26
SP103400271	26.68	66.17	125.39	41.61	36.74	2.55	8.47	43.08	8.93	1.69	0.77
SP103400301	1097.15	893.08	0								
SP103400302	130.18	153.06	110.07	92.6	150.84	87.82	61.34	69.54	73.79	101.9	109.21
SP103400310	1655.3	1601.81	1573.62	1415.55	2195.32	1294.18	1722.56	2044.73	1305.87	1460.24	1458.51
SP103400311	1738.07										
SP103400314	646.97	656.7	689.99	595.46	1782.56	1205.22	1037.4	815.14	656.05	614.82	727.65
SP103400321	282.67	250.44	233.73	236.77	339.92	468.49	96.35	131.3	125.97	172.65	148.67
SP103400335	516.62	482.63	409.85	415.66	916.54	573.03	502.17	451.53	429.85	477.14	481.77
SP103400336	1095.01	1149.24	937.16	924.06	2085.67	1566.6	1336.24	1058.67	865.25	868.95	845.9
SP103400341	789.6	805.4	662.2	1233.58	5316.24	3725.65	3481.57	2676.01	2156.24	1714.01	1677.74
SP103400367	0				0	0					
SP103400370	359.89	360.72	346.81	328.8	1019.96	770.58	584.4	411.94	375.78	322.2	343.37
SP103400382	410.94	447.92	378.23	434.24	901.26						
SP103400411	338.32	374.41	322.67	365.5	1059.08	1114.02	684.8	915.41	654.76	321.07	298.72
SP103400557	57.97	115.49	113.76	107.12	270.24	161.58	171.63	72.83	26.44	20.91	56.9
SP103400619	165.54	200.25	172.3	164.98	290.86	160.11	141.65	160.29	156.12	146.95	150.07
SP103400672	0	0	0.04	0	0.01	0	0.01	4.17	0.82	0	0
SP103400799	123.51	127.77	130.24	287.44	1016.05	477.87	407.39	347.72	226.49	178.84	217.95
SP103400822	474.47	337.37	399.18	722.03	1535.16	900.43	845.56	602.59	465.16	516.41	535.61
SP103400833	439.49	440.83	414	417.43	697.14	436.14	265.04	314.2	306.69	367.65	359
SP103400836	1475.07	1427.27	1357.04	1455.38	2806.99	1463.4	1223.13	1428.02	1563.64	1738.11	1753.78
SP103400846	544.08	488.55	353.71	292.08	826.95	691.28	422.83	324.09	286.33	246.69	311.12
SP103400857	646.61	720.58	649.91	694.76	1934.7	1349.48	1262.48	928.96	713.87	481.44	531.77
SP103400858	328.08	369.81	346.01	505.35	2173.98	1448.57	886.72	863.74	672.14	553.02	606.2
SP103400859	209.99	364.44	1124.64	924.83	2500.15	2029.37	1377.44	978.9	1005.35	756.27	660.24
SP103400860	346.75	366.09	366.05	412.5	785.32	393.52	331.87	369.09	294.54	271.15	301.12
SP103400877	160.93	141.26	136.84	152.29	364.37	295.35	311.63	243.78	168.52	105.71	112.48
SP103400878	435.18	437.03	313.29	289.75	927.57	680.27	531.07	512.88	372.78	255.07	313.75
SP103400879	273.32	253.08	216.74	290.4	751.67	510.39	354.46	379.08	318.95	213.57	239.56
SP103400880	433.87	428.61	304.73	337.22	909.84	571.09	537.46	487.89	396.36	341.84	386.07
SP103400881	291.28	379.5	415.31	397.27	808.49	380.65	347.88	384.49	351.5	402.62	399.62
SP103400890	164.51	157.65	217.11	153.15	578.47	381.44	275.77	277.02	266.15	181.45	184.3
SP103400891	183.63	152.79	141.96	125.22	473.13	264.47	9.55	11.68	8.17	4.49	9.84
SP103400892	204.93	191.84	171.56	266.55	1183.77	148.43	95.48	964.03	761.32	718.73	358.63
SP103400900	9.2	12.18	5.56	11.8	3.17	0	0	3.57	1.59	5.33	104.39
SP103400932	253.04	266.35	446.74	383.72	1222.5	1060.98	1013.94	753.87	585.53	269.29	266.75
SP103400933	212.87	208.35	186.66	310.05	584.44	550.79	817.64	499.32	437.11	219	207.55
SP103400934					1301.38	565.55	532.43	503.37	654	777.28	755.94
SP103400938											384.72
SP103400943											
TP103400196	2617.13	2302.1	2581.12	2435.3	3102.63	1821.32	1638.52	1436.66	1608.16	1263.34	1326.3
TP103400197	1007.08	1050.86	1384.32	886.3	2397.51	2037.35	1808.19	1518.87	1314.75	1071.91	1291.29
TP103400198	4228.46	3820.69	3961.4	4101.74	12353.03	7791.54	5740.27	4623.33	3522.22	3643.79	3640.26
TP103400204	1378.71	1155.86	1414.1	1258.91	3828.02	2115.32	1755.66	2512.19	1869.71	1962.94	2062.26
TP103400808	1747.27	1706.66	2832.31	2054.76	4404.6	2524.21	1591.22	1368.78	1110.64	874.82	631.45
TP103400819	248.74	201.23	181.44	175.83	402.11	394.07	308.07	246.11	210.88	143.18	178.79
TP103400845	195.25	387.77	199.54	275.93	363.2	211.19	114.4	296.82	130.06	285.29	253.99
TP103400848	168.54	170.73	128.61	131.22	322.45	233.08	156.41	148.87	129.57	155.49	163.68
TP103400849	550.69	367.62	432.38	334.12	724.27	350.5	366.99	350	381.43	472.42	509.2
TP103400882										1283.17	500.73
TP103400917	780.93	853.36	715.68	680.4	902.31	504.12	528.37	494.94	482.01	468.58	388.06
TP103400935											
TP103400936											
TP103400937											1598.55
TP103400939										442.85	451.81
TP103400940										596.4	731.35
VL-1034/3-CR5		22760	20858	19148	46977	30231	29003	27503	23251	21624	22143
VL-1034/3-CR6		37396	33796	33625	86541	55395	47896	41437	35054	29706	29664

- GIS Maps

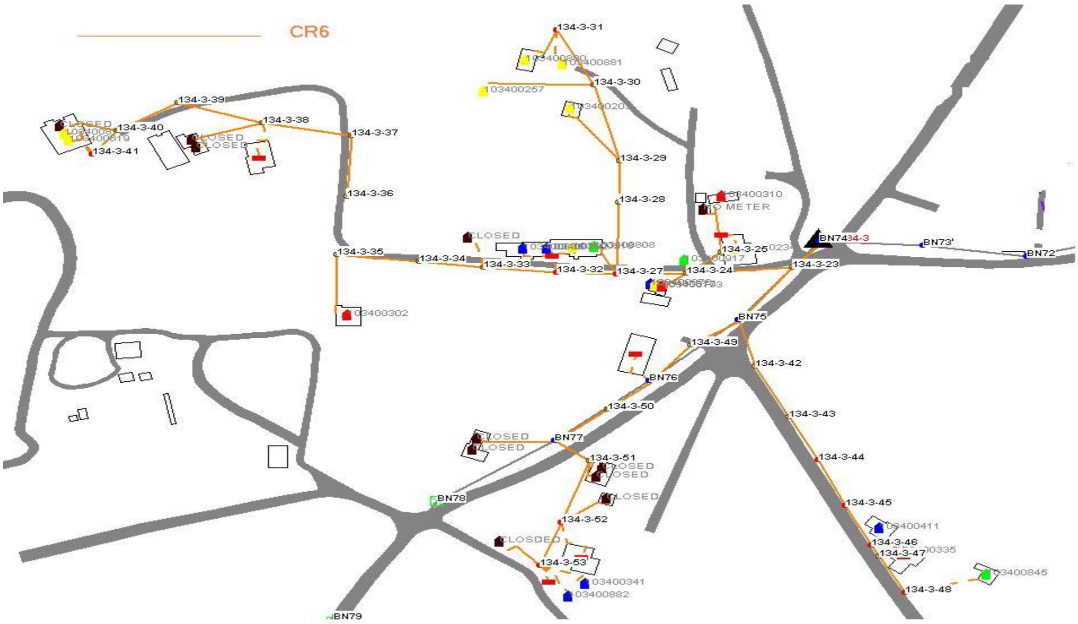
1. Both Feeders:



2. CR-5 Feeder:



3. CR-6 Feeder



4. CR-6 Feeder

Appendix (B) Acceptable International Levels of PV Penetration

Studies Authors

Symbol	The Research Reference
Study 1	Chalmers S, Hitt M, Underhill J, Anderson P, Vogt P, Ingersoll R.The effect ofphotovoltaic power generation on utility operation. IEEE Transactions onPower Apparatus and Systems 1985; PAS-104(March (3)):524–30.
Study 2	Patapoff N, Mattijetz D. Utility interconnection experience with an operatingcentral station MW-Sized photovoltaic plant. IEEE Transactions on Power Systems and Apparatus 1985;PAS-104(August (8)):2020–4.
Study 3	Jewell W, Ramakumar R, Hill S. A study of dispersed PV generation on the PSO system. IEEE Transactions on Energy Conversion 1988; 3(September (3)):473–8.
Study 4	Cyganski D, Orr J, Chakravorti A, Emanuel A, Gulachenski E, Root C, et al. Current and voltage harmonic measurements at the Gardner photovoltaic project. IEEE Transactions on Power Delivery 1989;4(January (1)):800–9.
Study 5	EPRI report EL-6754. Photovoltaic generation effects on distribution feeders, Volume 1: Description of the Gardner, Massachusetts, Twenty-First Century PV Community and Research Program, March; 1990.
Study 6	Jewell W, Unruh T. Limits on cloud-induced fluctuation in photovoltaic generation. IEEE Transactions on Energy Conversion 1990;5(March (1)):8–14.

Results from the above Studies

Reference No.	**Max. PV Penetration Level**	**Description**
Study 1	5%	Ramp rates of main-line generators. PV in central-station mode.
Study 3	15%	Reverse power swings during cloud transients. PV in distributed mode
Study 4	No Limit Found	Harmonics
Study 5	>37%	No problems due to clouds, harmonics, or unacceptable responses to fast transients were found at 37% penetration. Experimental + theoretical study
Study 6	Varied from 1.3 to 36%	Unacceptable unscheduled tie-line flows. The variation is caused by the geographical extent of the PV (1.3% for central-station PV). Results particular to the studied utility because of the specific mix of thermal generation technologies in use

Appendix (C) Jericho Network

- Al-Magtas and Sea Level Substation Readings:

	MAGTAS		Sea Leval			MAGTAS		Sea Leval	
	Load	Voltage	Load	Voltage		Load	Voltage	Load	Voltage
0:00:00	110	32	118	32.61	17:05:25	108	32.11	115	32.65
1:26:35	106	32.57	111	32.61	18:32:00	107	32.11	115	32.65
2:53:10	101	32.57	104	32.61	19:58:35	103	32	115	32.65
4:19:45	95	32.57	99	33.13	21:25:10	104	31.98	113	32.65
5:46:20	87	32.57	88	33.13	22:51:45	103	32.46	110	32.65
7:12:55	86	33.12	90	33.13	0:18:20	103	32.46	110	32.65
8:39:30	86	32.45	98	32.6	1:44:55	103	32.46	109	32.65
10:06:05	93	32.45	109	32.6	3:11:30	95	32.46	100	32.65
11:32:40	102	32.16	114	32.6	4:38:05	94	32.46	96	32.65
12:59:15	107	31.75	122	32.02	6:04:40	80	33.08	83	33.23
14:25:50	114	31.75	131	32.02	7:31:15	77	33.08	82	33.23
15:52:25	122	31.75	138	32.02	8:57:50	82	33.08	82	33.23
17:19:00	123	32.12	131	32.02	10:24:25	84	33.08	88	32.71
18:45:35	116	32.15	120	32.56	11:51:00	90	32.47	87	32.71
20:12:10	110	32.15	119	32.04	13:17:35	94	32.47	96	32.71
21:38:45	113	32.15	118	32.04	14:44:10	96	32.47	104	32.71
23:05:20	115	31.98	120	32.64	16:10:45	107	32.47	108	32.71
0:31:55	111	32.33	116	32.64	17:37:20	106	32.47	108	32.71
1:58:30	108	32.33	110	32.64	19:03:55	93	32.47	96	32.71
3:25:05	95	32.33	102	32.64	20:30:30	93	32.47	103	32.71
4:51:40	94	32.33	95	32.64	21:57:05	98	32.47	106	32.71
6:18:15	81	32.96	86	33.14	23:23:40	98	32.47	105	32.71
7:44:50	80	32.96	89	33.14	0:50:15	102	32.47	106	32.71
9:11:25	96	31.94	115	32.49	2:16:50	99	32.47	103	32.71
10:38:00	103	31.84	113	32.49	3:43:25	93	32.47	96	33.22
12:04:35	101	32	121	32.49	5:10:00	89	33.05	93	33.22
13:31:10	116	31.34	131	31.74	6:36:35	82	33.05	82	33.22
14:57:45	119	31.34	134	31.74	8:03:10	80	33.05	86	33.22
16:24:20	127	31.34	136	31.74	9:29:45	82	33.05	97	33.22
17:50:55	132	31.34	139	31.74	10:56:20	91	32.33	105	32.6
19:17:30	115	32.23	123	32.49	12:22:55	96	32.33	106	32.6
20:44:05	121	31.54	131	31.83	13:49:30	95	32.33	111	32.6
22:10:40	125	31.54	131	32.38	15:16:05	105	31.9	122	32.6
23:37:15	128	31.97	132	32.38	16:42:40	105	32	115	32.6
1:03:50	123	31.97	130	32.38	18:09:15	103	32	110	32.6
2:30:25	115	32.3	122	32.38	19:35:50	97	32.54	110	32.6
3:57:00	110	32.3	115	32.38	21:02:25	101	32.02	109	32.05
5:23:35	101	32.3	102	32.99	22:29:00	105	31.84	108	32.05
6:50:10	94	32.88	100	32.99	23:55:35	104	32.29	108	32.57
8:16:45	96	32.17	107	32.41	1:22:10	104	32.29	111	32.57
9:43:20	111	31.9	132	31.77	2:48:45	103	32.29	104	32.57
11:09:55	114	31.9	129	31.77	4:15:20	97	32.29	104	32.57
12:36:30	0	0	0	0	5:41:55	96	32.29	93	33.12
14:03:05	125	32.44	154	32.7	7:08:30	87	33.04	96	33.12
15:29:40	129	32.47	146	32.7	8:35:05	89	33.04	104	32.62
16:56:15	132	33.02	142	33.29	10:01:40	105	32.02	119	32.09
18:22:50	125	33.02	130	33.29	11:28:15	104	32.05	122	32.09
19:49:25	114	33.02	122	33.29	12:54:50	114	31.7	128	32.09
21:16:00	114	33.02	124	33.29	14:21:25	118	31.7	132	32.09
22:42:35	116	33.02	121	33.29	15:48:00	119	31.7	136	32.09
0:09:10	114	33.02	122	33.29	17:14:35	115	32.4	126	32.09
1:35:45	113	33.02	116	33.29	18:41:10	113	32.4	118	32.75
3:02:20	103	33.02	109	33.29	20:07:45	106	32.4	117	32.17
4:28:55	101	33.52	106	33.81	21:34:20	111	32.02	116	32.17
5:55:30	89	33.52	92	33.81	23:00:55	106	32.02	111	32.69
7:22:05	87	33.52	91	33.81	0:27:30	106	32.02	114	32.69
8:48:40	88	33.52	107	33.03	1:54:05	102	32.8	110	32.69
10:15:15	101	32.15	116	32.52	3:20:40	97	32.8	104	32.69
11:41:50	106	32.15	119	32.52	4:47:15	97	32.8	94	33.21
13:08:25	106	32.15	126	32.52	6:13:50	80	32.8	85	33.21
14:35:00	112	31.92	132	32.52	7:40:25	82	32.8	95	33.21
16:01:35	114	32.02	129	32.52	9:07:00	94	32.26	108	32.47
17:28:10	116	32.02	127	32.52	10:33:35	81	32.26	95	32.47
18:54:45	107	33.18	121	33.43	12:00:10	80	32.26	95	32.47
20:21:20	109	33.18	113	33.43	13:26:45	86	32.26	98	32.47
21:47:55	109	33.18	114	33.43	14:53:20	114	31.74	131	32.47
23:14:30	108	33.18	114	33.43	16:19:55	116	32.02	134	32.47
0:41:05	106	33.18	108	33.43	17:46:30	112	32.02	120	32.47
2:07:40	99	33.18	104	33.43	19:13:05	104	32.02	116	32.47
3:34:15	95	33.18	101	33.94	20:39:40	101	31.95	112	32.47
5:00:50	87	33.18	92	33.94	22:06:15	105	32.2	112	32.47
6:27:25	82	33.77	85	33.94	23:32:50	109	32.2	115	32.47
7:54:00	84	33.77	86	33.94	0:59:25	109	32.2	115	32.47
9:20:35	89	32.33	110	32.71	2:26:00	100	32.82	108	32.47
10:47:10	95	32.33	118	32.16	3:52:35	96	32.82	100	32.47
12:13:45	99	31.92	111	32.16	5:19:10	88	32.82	90	33.15
13:40:20	102	31.92	118	32.16	6:45:45	82	33.33	85	33.15
15:06:55	110	32.08	126	32.16	8:12:20	89	32.63	100	32.53
16:33:30	115	32.08	122	32.67	9:38:55	92	32.63	105	32.53
18:00:05	113	32.08	122	32.67	11:05:30	96	32.07	114	32.53
19:26:40	99	32.69	120	32.67	12:32:05	103	32.08	114	32.53
20:53:15	103	32.18	112	32.67	13:58:40	109	31.67	130	32.03
22:19:50	99	32.18	107	32.67	15:25:15	111	31.67	128	32.03
23:46:25	97	32.18	108	32.67	16:51:50	116	31.95	126	32.03
1:13:00	97	32.18	103	32.67	18:18:25	112	32.32	122	32.03
2:39:35	95	32.18	99	32.67	19:45:00	106	32.32	114	32.62
4:06:10	89	32.75	93	33.17	21:11:35	109	31.99	116	32
5:32:45	79	33.3	83	33.17	22:38:10	107	32.18	116	32.61
6:59:20	77	33.3	82	33.17	0:04:45	111	32.18	117	32.61
8:25:55	80	32.8	88	33.17	1:31:20	111	32.18	115	32.61
9:52:30	89	32.29	106	32.65	2:57:55	101	32.18	106	32.61
11:19:05	88	32.29	107	32.65	4:24:30	97	32.18	102	32.61
12:45:40	92	32.29	110	32.65	5:51:05	85	32.69	90	33.13
14:12:15	97	32.29	107	32.65	7:17:40	82	32.69	92	33.13
15:38:50	107	31.94	119	32.65	8:44:15	91	32.69	102	32.54
					10:10:50	100	32.19	113	32.54
					11:37:25	101	31.96	115	32.54
					13:04:00	109	31.96	122	32
					14:30:35	117	31.96	130	32

	MAGTAS		Sea Leval	
	Load	Voltage	Load	Voltage
13:35:55	105	31.94	110	32.3
15:02:30	106	32	117	32.3
16:29:05	105	32	120	32.3
17:55:40	106	32.62	110	32.87
19:22:15	94	32.62	104	32.87
20:48:50	98	32.62	110	32.27
22:15:25	98	32.54	104	32.93
23:42:00	100	32.54	107	32.93
1:08:35	102	32.54	108	32.93
2:35:10	99	32.54	103	32.93
4:01:45	92	32.54	98	32.93
5:28:20	86	32.54	86	32.93
6:54:55	79	33.23	81	32.93
8:21:30	77	33.23	82	32.93
9:48:05	85	33.23	88	32.93
11:14:40	87	32.7	91	32.93
12:41:15	91	32.7	93	32.93
14:07:50	93	32.7	99	32.93
15:34:25	99	32.7	105	32.93
17:01:00	103	32.7	110	32.93
18:27:35	107	32.7	107	32.93
19:54:10	93	32.7	97	32.93
21:20:45	101	32.16	107	32.4
22:47:20	100	32.16	106	32.4
0:13:55	102	32.16	106	32.4
1:40:30	104	32.16	110	32.4
3:07:05	94	32.68	100	32.93
4:33:40	90	32.68	98	32.93
6:00:15	84	33.24	85	33.44
7:26:50	80	33.08	85	33.31
8:53:25	83	32.36	99	32.77
10:20:00	87	32.36	104	32.83
11:46:35	91	32.36	104	32.83
13:13:10	96	32.36	116	32.83
14:39:45	100	32.36	116	32.83
16:06:20	104	32.36	115	32.83
17:32:55	103	32.36	114	32.83
18:59:30	94	32.36	103	32.83
20:26:05	93	32.36	107	32.31
21:52:40	99	32.36	107	32.31
23:19:15	100	32.36	109	32.31
0:45:50	103	32.36	110	32.83
2:12:25	96	32.36	104	32.83
3:39:00	96	32.36	98	32.83
5:05:35	87	32.94	90	32.83
6:32:10	80	32.94	83	33.33
7:58:45	80	32.94	89	32.82
9:25:20	87	32.94	107	32.8
10:51:55	96	32.1	110	32.29
12:18:30	104	32.1	109	32.29
13:45:05	103	32.1	124	32.29
15:11:40	110	31.87	123	32.29
16:38:15	107	31.87	125	32.29
18:04:50	109	32.31	115	32.86
19:31:25	97	32.31	106	32.86
20:58:00	103	32.31	110	32.32
22:24:35	101	32.31	108	32.32
23:51:10	102	32.31	109	32.32
1:17:45	101	32.31	108	32.94
2:44:20	99	32.31	104	32.94
4:10:55	91	33	98	32.94
5:37:30	84	33	85	32.94
7:04:05	83	33	86	32.94

	MAGTAS		Sea Leval	
	Load	Voltage	Load	Voltage
8:30:40	87	32.49	103	32.94
9:57:15	93	32.49	110	32.4
11:23:50	94	32.49	114	32.4
12:50:25	103	32.49	116	32.4
14:17:00	100	32.49	118	32.4
15:43:35	106	31.81	121	32.4
17:10:10	98	32.05	113	32.31
18:36:45	102	32.59	111	32.31
20:03:20	100	32.02	110	32.84
21:29:55	103	32.02	113	32.29
22:56:30	103	32.02	114	32.29
0:23:05	108	32.02	116	32.29
1:49:40	103	32.6	111	32.79
3:16:15	99	32.6	104	32.79
4:42:50	95	32.6	98	32.79
6:09:25	82	32.6	88	33.3
7:36:00	84	32.6	92	32.76
9:02:35	93	31.94	104	32.76
10:29:10	93	32.05	113	32.36
11:55:45	98	32.05	113	32.36
13:22:20	105	31.61	122	32.36
14:48:55	107	31.87	124	32.36
16:15:30	113	31.96	131	32.36
17:42:05	111	32.18	120	32.36
19:08:40	105	32.18	110	32.36
20:35:15	101	32.18	118	32.36
22:01:50	105	32.2	116	32.36
23:28:25	111	32.2	117	32.36
0:55:00	108	32.2	115	32.36
2:21:35	104	32.76	109	32.91
3:48:10	98	32.76	105	32.91
5:14:45	90	32.76	97	32.91
6:41:20	86	32.76	95	32.91
8:07:55	87	32.76	97	32.91
9:34:30	99	32.05	116	32.36
11:01:05	102	31.89	118	32.36
12:27:40	104	31.89	119	32.36
13:54:15	115	31.89	132	31.85
15:20:50	117	31.89	128	31.85
16:47:25	125	31.89	132	32.39
18:14:00	113	32.06	122	32.39
19:40:35	108	32.06	115	32.39
21:07:10	110	31.76	115	32.39
22:33:45	111	32.09	120	32.39
0:00:20	115	32.09	125	32.39
1:26:55	115	32.09	122	32.39
2:53:30	109	32.64	118	32.39
4:20:05	105	32.64	111	32.89
5:46:40	98	32.64	99	32.89
7:13:15	90	32.64	99	32.89
8:39:50	97	32.64	110	32.37
10:06:25	99	32.14	116	32.37
11:33:00	104	31.91	122	32.37
12:59:35	110	31.91	126	32.37
14:26:10	112	31.38	133	31.78
15:52:45	119	31.38	133	31.78
17:19:20	119	32.12	132	32.42
18:45:55	120	32.12	120	32.42
20:12:30	103	32.12	119	32.42
21:39:05	112	32.12	117	32.42
23:05:40	114	32.12	124	32.42
0:32:15	116	32.12	123	32.42
1:58:50	112	32.12	117	32.42
3:25:25	109	32.12	112	32.97
4:52:00	97	32.67	105	32.97
6:18:35	90	32.67	93	32.97
7:45:10	91	32.67	94	32.97
9:11:45	93	32.67	98	32.97
10:38:20	95	32.67	101	32.97
12:04:55	99	32.08	101	32.4
13:31:30	98	32.02	107	32.4
14:58:05	114	31.95	120	32.4
16:24:40	120	31.95	128	32.4
17:51:15	122	32.05	129	32.4
19:17:50	109	32.05	113	32.4
20:44:25	103	32.05	118	32.4

	MAGTAS		Sea Leval			MAGTAS		Sea Leval	
	Load	Voltage	Load	Voltage		Load	Voltage	Load	Voltage
22:11:00	116	32.02	123	32.4	6:05:00	97	32.8	100	33.04
23:37:35	115	32.02	121	32.4	7:31:35	95	32.8	102	33.04
1:04:10	114	32.02	118	32.4	8:58:10	105	31.87	124	31.93
2:30:45	110	32.02	115	32.4	10:24:45	105	31.87	119	31.93
3:57:20	104	32.6	110	32.4	11:51:20	109	31.87	122	31.93
5:23:55	97	32.6	100	32.4	13:17:55	110	31.87	127	31.93
6:50:30	93	32.6	97	33	14:44:30	120	31.25	129	31.93
8:17:05	94	32.6	104	32.39	16:11:05	123	31.89	138	31.93
9:43:40	92	32.05	120	32.39	17:37:40	123	31.89	136	31.93
11:10:15	101	32.25	117	32.43	19:04:15	114	32.09	122	32.47
12:36:50	107	31.94	118	32.43	20:30:50	112	31.91	125	31.95
14:03:25	112	31.41	130	31.8	21:57:25	114	31.91	120	31.95
15:30:00	115	31.41	132	31.8	23:24:00	117	32.09	123	32.51
16:56:35	122	31.41	132	31.8	0:50:35	118	32.09	127	32.51
18:23:10	116	31.99	125	32.31	2:17:10	117	32.09	125	32.51
19:49:45	105	31.83	111	32.31	3:43:45	112	32.09	117	32.51
21:16:20	110	31.83	117	32.31	5:10:20	101	32.09	108	32.51
22:42:55	112	31.83	121	32.31	6:36:55	95	32.67	99	32.51
0:09:30	112	32.04	118	32.31	8:03:30	97	32.67	105	32.51
1:36:05	114	32.04	121	32.31	9:30:05	97	31.99	125	31.96
3:02:40	111	32.04	117	32.82	10:56:40	110	31.99	128	31.96
4:29:15	107	32.66	115	32.82	12:23:15	118	31.38	130	31.96
5:55:50	96	32.66	101	32.82	13:49:50	120	31.38	139	31.96
7:22:25	96	32.66	104	32.82	15:16:25	125	31.38	148	31.96
8:49:00	96	32.66	113	32.29	16:43:00	133	31.38	140	31.96
10:15:35	110	31.89	117	32.29	18:09:35	131	31.38	141	31.96
11:42:10	108	31.89	122	31.74	19:36:10	124	32.04	127	31.96
13:08:45	117	31.25	134	31.74	21:02:45	124	31.85	131	31.96
14:35:20	120	31.25	144	31.74	22:29:20	120	31.85	124	31.96
16:01:55	128	31.25	145	31.74	23:55:55	120	31.98	126	32.53
17:28:30	124	31.79	140	31.74	1:22:30	120	32.27	127	32.53
18:55:05	115	32.2	123	32.33	2:49:05	117	32.27	122	32.53
20:21:40	110	32.2	126	32.33	4:15:40	114	32.27	119	32.53
21:48:15	116	31.78	122	32.33	5:42:15	107	32.27	103	33.08
23:14:50	120	32.14	124	32.33	7:08:50	97	32.27	102	32.54
0:41:25	122	32.13	128	32.33	8:35:25	98	32.27	90	32.54
2:08:00	119	32.13	123	32.33	10:02:00	95	32.27	98	32.54
3:34:35	111	32.13	115	32.33	11:28:35	96	32.27	101	32.54
5:01:10	104	32.69	108	32.91	12:55:10	101	32.27	103	32.54
6:27:45	96	32.69	101	32.91	14:21:45	110	31.85	109	32.54
7:54:20	97	32.18	104	32.38	15:48:20	118	31.85	125	32.01
9:20:55	100	31.25	119	31.34	17:14:55	129	31.85	134	32.01
10:47:30	103	30.99	120	31.34	18:41:30	115	32.33	122	32.59
12:14:05	109	31.06	121	31.34	20:08:05	108	32.33	119	32.59
13:40:40	110	31.06	126	31.34	21:34:40	115	31.85	122	32.03
15:07:15	122	31.06	131	31.87	23:01:15	116	32.1	125	32.03
16:33:50	126	31.06	139	31.87	0:27:50	122	32.1	125	32.03
18:00:25	119	32.04	130	32.38	1:54:25	123	32.1	125	32.03
19:27:00	112	32.04	116	32.38	3:21:00	122	32.1	125	32.03
20:53:35	114	31.8	122	32.38	4:47:35	116	32.1	125	32.03
22:20:10	114	32.13	119	32.38	6:14:10	103	32.1	125	32.03
23:46:45	116	32.13	118	32.38	7:40:45	103	32.1	108	32.71
1:13:20	117	32.13	124	32.38	9:07:20	106	31.74	121	32.2
2:39:55	117	32.13	120	32.38	10:33:55	115	31.78	126	31.92
4:06:30	108	32.13	112	32.38	12:00:30	118	31.78	135	31.92
5:33:05	100	32.73	101	32.94	13:27:05	118	31.78	132	31.92
6:59:40	95	32.73	101	32.94	14:53:40	128	31.78	139	31.92
8:26:15	93	32.73	114	32.34	16:20:15	129	31.78	143	31.92
9:52:50	104	31.75	121	32.34	17:46:50	137	31.78	139	31.92
11:19:25	110	31.75	128	31.7	19:13:25	117	32.08	122	32.45
12:46:00	107	31.75	120	32.22	20:40:00	115	31.61	127	31.91
14:12:35	119	31.75	132	31.72	22:06:35	118	31.61	127	31.91
15:39:10	119	31.75	135	31.72	23:33:10	120	32.08	129	32.42
17:05:45	125	31.75	134	32.22	0:59:45	121	32.08	128	32.42
18:32:20	123	31.75	126	32.22	2:26:20	119	32.08	123	32.42
19:58:55	109	32.24	118	32.72	3:52:55	112	32.08	118	32.42
21:25:30	115	31.83	121	32.01	5:19:30	103	32.08	105	32.42
22:52:05	114	32.2	122	32.51	6:46:05	95	32.62	100	32.95
0:18:40	120	32.2	125	32.51	8:12:40	101	32.08	114	32.4
1:45:15	120	32.2	127	32.51	9:39:15	111	31.79	125	31.89
3:11:50	117	32.2	119	32.51	11:05:50	115	31.79	133	31.89
4:38:25	111	32.2	113	32.51	12:32:25	115	31.79	127	31.89
					13:59:00	115	31.79	138	31.89
					15:25:35	115	31.79	149	31.89
					16:52:10	132	31.74	147	31.72
					18:18:45	129	31.74	147	31.72
					19:45:20	113	32.23	0	0
					21:11:55	119	31.83	123	32.28
					22:38:30	119	32.1	125	32.28
					0:05:05	121	32.1	128	32.28

- Electrical Equipments

1- DC\AC Inverter 100 KW

Level 3M: 100 kW DC-AC Inverter

Note: Typical Operating Conditions:

V_{DC}=700, V_{AC}=480, F_{SW}=5kHz, Cos(φ)= .9, airflow = 485 m^3/hr, air temp = 25°C, I_{AC}=150 A_{RMS}

Electrical Characteristics

DC Link	Notes	Symbol	min	typ	max	unit
DC link Voltage	Continuous Operation	V_{DC}	280		900	V
Max Surge Voltage	2 min, non-operational				1200	V
Overvoltage Shutdown	Configurable		700	900	1000	V
Capacitance	See separate datasheet for details	Methode Capacitor Bank datasheet				
Capacitor ESL	See separate datasheet for details	Methode Capacitor Bank datasheet				

AC Data	Notes	Symbol	min	typ	max	unit
Voltage		V_{AC}	280		900	V_{rms}
Continuous Current	See Typical Operating Conditions	I_{AC}			400	A_{rms}
Power Loss	See Typical Operating Conditions	P_{loss}		~1800		W
Switching Freq[1]	See Typical Operating Conditions Max frequency is @ 50°C	F_{SW}		5	10	kHz
Power Factor	Leading or Lagging	Cos(φ)	0		1	
Surge Current	Max for 10 µS				900	A_{rms}

General Data	Notes	Symbol	min	typ	max	unit
Insulation Test Voltage				4		kV

Heat Sink Air Cooled/Thermal Data

Data	Notes	Symbol	min	typ	max	unit
Airflow	See Typical Operating Conditions	$\Delta V/\Delta t_{Air}$		485		m^3/hr
Air Pressure Drop		ΔP_{Air}		410		Pa
Cooling Air Inlet Temperature	Typical Operating Conditions are supported over this operating range, including Tmax.	T_{inlet}	-25	25	50	°C

Environmental Conditions

Data	Notes	Symbol	min	typ	max	unit
Storage Temp	Non-operational	T_{Stor}	-40		85	°C
Ambient Temp	Continuous Operation Note: different from Tinlet	T_{Amb}	-25		50	°C
Altitude above sea level	Derated operation possible above Alt Max	Alt			1000	m
Air Pressure	Standard Atmosphere	P_{air}	900		1100	hPa
Humidity	Non-condensing	Rel. F	5		85	%
Total Weight	Without capacitor			13		kg
Weight w/o Heat Sink	Without capacitor			7.6		kg
Dimensions	L x W x H (Without capacitor)		280	215	165	mm
Heat Sink Dimensions	L x W x H		280	215	80	mm
Torque at AC terminals		M_{AC}	16		20	Nm

1- Step up Transformer

Characteristics

				Loss(kW)				Weight (kg)			(mm)			Gauge	
Rated Capacity	Voltage Group(kV)		Connection Method		(75)	No-load current	Impedance Voltage				(L)	(W)	(H)		
(kVA)	HV	LV		No-load	Load	%	%	Machine	Oil	Gross	Outline Dimension			Vertical	Horizontal
50			Dyn11 Yyn0	0.17	1.15	2		200	145	465	920	610	1000	450	380
100			DYn5	0.23	1.92	1.8		330	165	635	920	680	1100	550	450
125				0.27	2.26	1.7		395	185	745	960	780	1120	550	470
160				0.29	2.69	1.6		505	205	885	1160	710	1180	550	520
200				0.34	3.16	1.5		580	225	995	1190	730	1190	550	520
250				0.41	3.76	1.4		685	245	1130	1280	820	1210	650	550
315	23			0.49	4.53	1.4		745	260	1285	1380	910	1240	650	550
400	22	0.4		0.58	5.47	1.3	5.5	865	305	1500	1430	950	1320	650	550
500	20	0.433		0.69	6.58	1.2		985	335	1710	1520	1020	1360	750	600
630	15	0.415		0.83	7.87	1.1		1165	385	2010	1680	1150	1380	850	660
800	11			0.98	9.41	1		1335	415	2315	1810	1280	1430	850	660
1000	10			1.15	11.5	1		1655	515	2985	1840	1290	1540	850	660
1250	6			1.4	13.9	0.9		1890	630	3460	1850	1300	1730	850	660
1600				1.7	16.7	0.8		2220	710	4015	1920	1350	1790	850	700
2000				2.18	20.4	0.8		2530	730	4425	2020	1770	2040	820	820
2500				2.56	21.9	0.8		3165	795	5260	2080	1800	2130	1070	1070

(Note): (Tapping range of high voltage) ±5%; ±2×2.5%, Frequency: 50Hz,60HZ.

2- LV-MV Transformer

Specifications

1.IEC60076 power transformer distribution transformer
2 Type and voltage can be customized
3 Three years of guarantee period

We're MANUFACTURER and specialize in electrical field for several years,also export products with good quality and right price in China. Our transformers sell well all over the world, and are exported to Ethiopia, Malaysia, Thailand, Kenya, Mozambique, Congo, Rwanda, Pakistan, South Africa and so on. We have won a good reputation among customers at home and abroad. We will do our best to provide more high-quality products and services for you in the future! If the following parameter specifications do not meet your requirements, please contact us to quote and produce according to your requirements.

33kv electric power transformer, Power transformer

Power transformer's Feature

1.Core made of high quality cold-rolled sillicon sheet
2.Coil made of high quality oxygen-free copper
3.Multilayered cylindric structure for high-voltage winding, toroidal structure for low-voltage winding, fine performance
4.New insulation structure enhances the ability agaist short circuit
5.Hermetic radiator oil tank, reduced volume and prolonged service life
6.Special securing structure, no drifting during shipping and sustained operation
7.Security: pressure relief valve, signal thermometer, gas relay
8.Corrosion resisting treatment, maintenance free

General

This kind of product is applied to power system of three-phase, 50/60Hz as well as 35kv and below, it is the main transformer equipment of medium and small-sized transformer substation, supplies power distribution, power and illumination for the industry and agriculture.
Company introduces in domestic and overseas advanced technique, adopts the latest material and optimizes design, which enables the product structure more reasonable, and greatly improves the product electric strength, mechanical strength and heat-sinking capability.

Structural Features

Iron core

The iron core is made of high quality cold rolled silicon steel sheet, adopts the kinds of types like full-bias multi-step seam, no punched hole, winding iron core, etc.. besides, both stainless steel stay plate and epoxy glass belt are for clamping it.

Coil

High quality enameled wire that is made of oxygen free copper or paper wrapped flat copper wire is used as conductor, the coils is provided kinds of types such as drum type, spiral type, improved spiral type, continuous type and interleaved type.

Oil tank

The oil tank is of barrel type or shield type, the heat-sinking element is provided with corrugated plate or plated radiator.
Not been equipped with trolley, but there is a base that accords with national standard rail gauge welded at the bottom of box for your convenience.

Safety protection device

According to national standard and users requirements, It will be equipped with following devices: pressure relief valve, signal thermometer, oil purifier, oil conservator, oil sampling valve, etc..

Service Environment

Device types: outdoor type

Normal environment conditions of use: the elevation not more than 1000 m

Environmental highest temperature + 40°C, lowest -25°C

The special environment conditions of use: elevation of more than 1000 m

Environmental highest temperature + 40°C, lowest -45°C. (when you order details)

Mounting ambient: no corrosive gas, no obvious dirt environment

Accord to standard

1. IEC60076
2. GB1094.1 ~ 2-1996 power transformer
3. GB1094.3. 5-2003 power transformer
4. GB/T6451-2008 oil-immersed three-phases transformer power technical parameters and requirements

Technical specs:

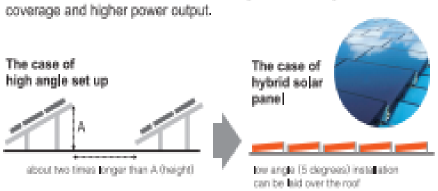
Rated capacity (KVA)	Voltage combination			Connection symbol	Loss(KW)		No-load current(%)	Impedance voltage(%)	Weight(Kg)	
	H.V.(KV)	High voltage tapping range	L.V.(KV)		load	No-load			oil weight	overall weight
50	20 24 33 35 38.5	±5%	0.4 0.415 0.433	Dyn11 Yyno Yd11	1.21	0.21	2.00	6.5	265	860
100					2.02	0.29	1.80		310	1150
125					2.38	0.34	1.70		320	1190
160					2.83	0.36	1.60		360	1230
200					3.33	0.43	1.50		390	1300
250					3.96	0.51	1.40		425	1480
315					4.77	0.61	1.40		460	1590
400					5.76	0.73	1.30		490	1760
500					6.93	0.86	1.20		540	2140
630					8.28	1.04	1.10		620	2380
800					9.9	1.23	1.00		780	2800
1000					12.15	1.44	1.00		910	3850
1250					14.67	1.76	0.90		1060	4600
1600					17.55	2.12	0.80		1210	5200

3- Thin Film PV Panel Datasheet

U-EA type

HYBRID panels are ideal for low angle installations.

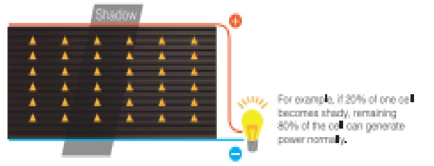
Because of HYBRID's cell structure, low angle (5 degree) roof installations are possible without a significant loss of power generation by shadow. Panels can be installed close together, allowing for more roof coverage and higher power output.



The HYBRID cell structure is shadow tolerant.

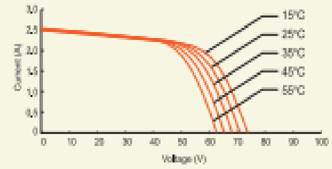
The HYBRID panel measures 1,210x1,008 mm. Unlike traditional crystalline panels, the HYBRID cells allow it to perform even if part of the panel is shaded*.

*The cell configuration allows it to prevent power output deterioration under shadow dropped conditions like picture below.

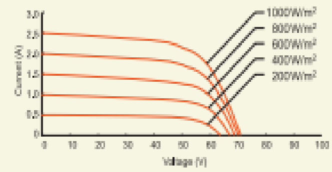


Electrical characteristics U-EA110 type

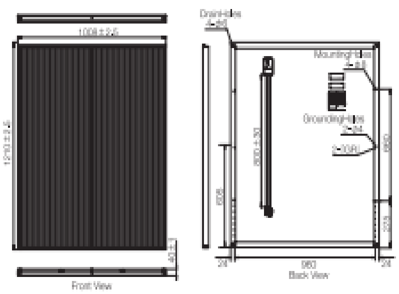
Current-Voltage characteristics at various cell temperature



Current-Voltage characteristics at various irradiance levels



U-EA100/U-EA105/U-EA110/U-EA115/U-EA120



Products		U-EA100	U-EA105	U-EA110	U-EA115	U-EA120
Electrical Data (Standard Test Condition)*1	Maximum Power (Pmax) [W]	100	105	110	115	120
	Tolerance	-5%/+10%	-5%/+10%	-5%/+10%	-5%/+10%	-5%/+10%
	Minimum value of Pmax [W]	95.0	99.75	104.5	109.25	114.0
	Open circuit voltage (Voc) [V]	71	71	71	71	71
	Short circuit current (Isc) [A]	2.25	2.40	2.50	2.50	2.60
	Voltage at Pmax (Vmpp) [V]	53.5	53.5	54.0	55.0	55.0
	Current at Pmax (Impp) [A]	1.87	1.96	2.04	2.09	2.18
	Module Efficiency (η) [%]	8.2	8.6	9.0	9.4	9.8
	Efficiency reduction at 200W/m²	<5%	<5%	<5%	<5%	<5%
Data at normal operating cell temperature (NOCT)*2	Temperature (TNOCT)	45	45	45	45	45
	Maximum Power (Pmax) [W]	74.4	78.1	81.8	85.6	89.3
	Open circuit voltage (Voc) [V]	65.5	65.5	65.5	65.5	65.5
	Short circuit current (Isc) [A]	1.82	1.94	2.02	2.02	2.10
	Voltage at Pmax (Vmpp) [V]	48.8	48.8	49.2	50.2	50.2
	Current at Pmax (Impp) [A]	1.53	1.60	1.66	1.71	1.78
Temperature coefficients	Power [%/K]	-0.35				
	Open circuit voltage [%/K]	-0.39				
	Short circuit current [%/K]	0.056				
Mechanical characteristic Data	Cell Type	Thin film (amorphous Si / thin film micro crystalline Si)				
	No. of cells	106 (53 in series / 2 in parallel)				
	Dimension [mm]	W1,210 × L1,008 × T40				
	Weight [kg]	18.3				
	Junction box (Dimension) [mm]	W64 × L96 × T16.5				
	Output cable	2.5mm² Onamba PV cable with Multi-Contact PV-KBT and KST 3 Ⅱ connectors				
	Front panel	low iron glass with 5.0mm thickness				
	Frame material	anodised aluminum				
Limits and Others	Maximum system voltage [V]	600				
	Limiting reverse current [A]	3.5				
	Operating module temperature [°C]	-20...+80°C (module temperature)				
	Maximum load [Pa]	2,400				
	Application classification (IEC 61730-Ed.1)	A				
	Fire classification (IEC 61730-Ed.1)	Class C				
	Safety classification (IEC 61730-Ed.1)	Ⅱ				

*1 Irradiance 1000 W/m², spectrum Air Mass 1.5 and cell temperature 25°C
*2 Irradiance 800 W/m², wind speed 1m/s and air temperature 20°C

IEC 61646/EN61730 Safety Class Ⅱ CE

Certification : IEC 61646-Ed. 2, IEC 61730-Ed. 1 Manufactured in ISO 9001 certificated factories.

kaneka http://www.pv.kaneka.co.jp

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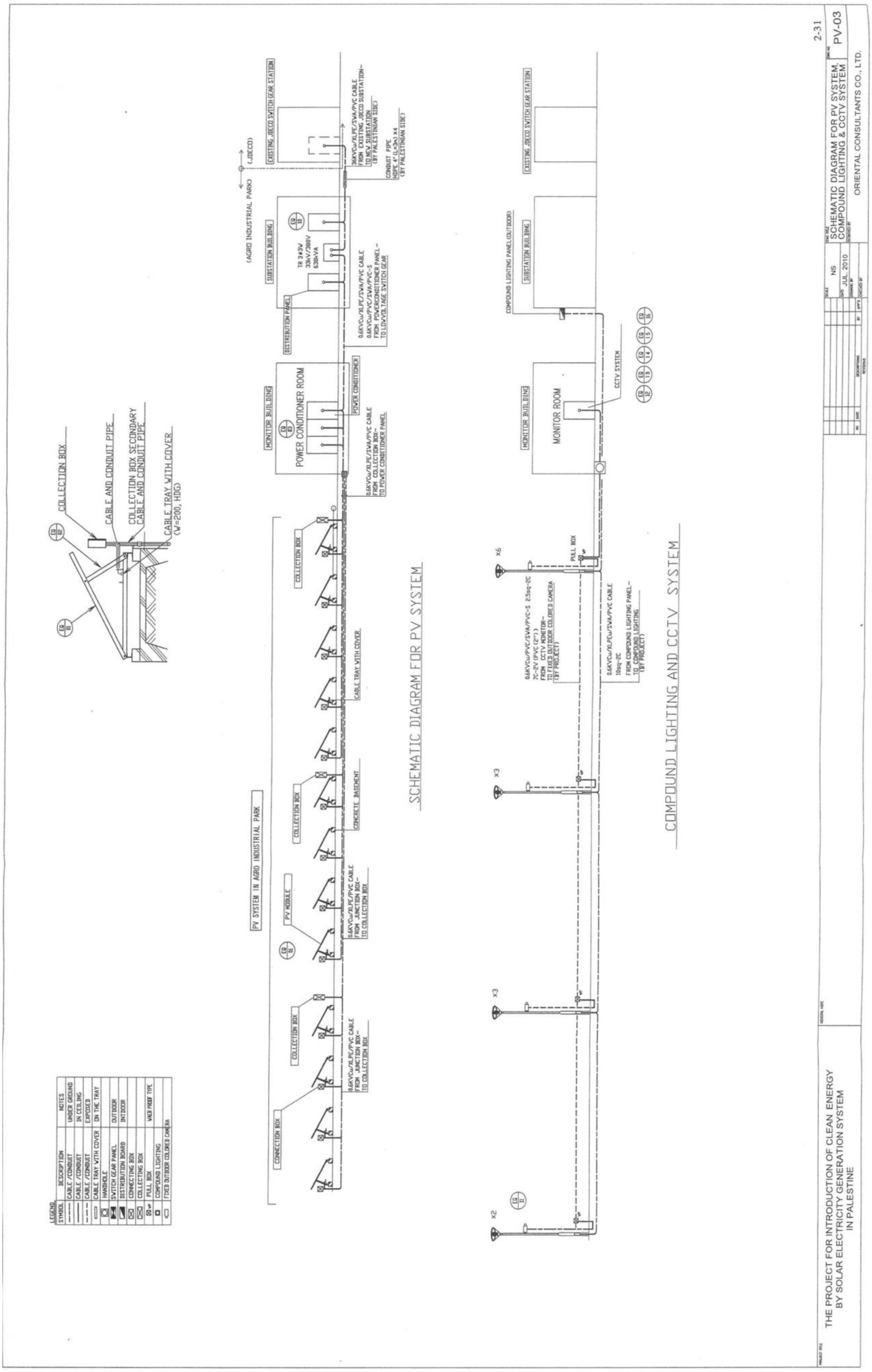
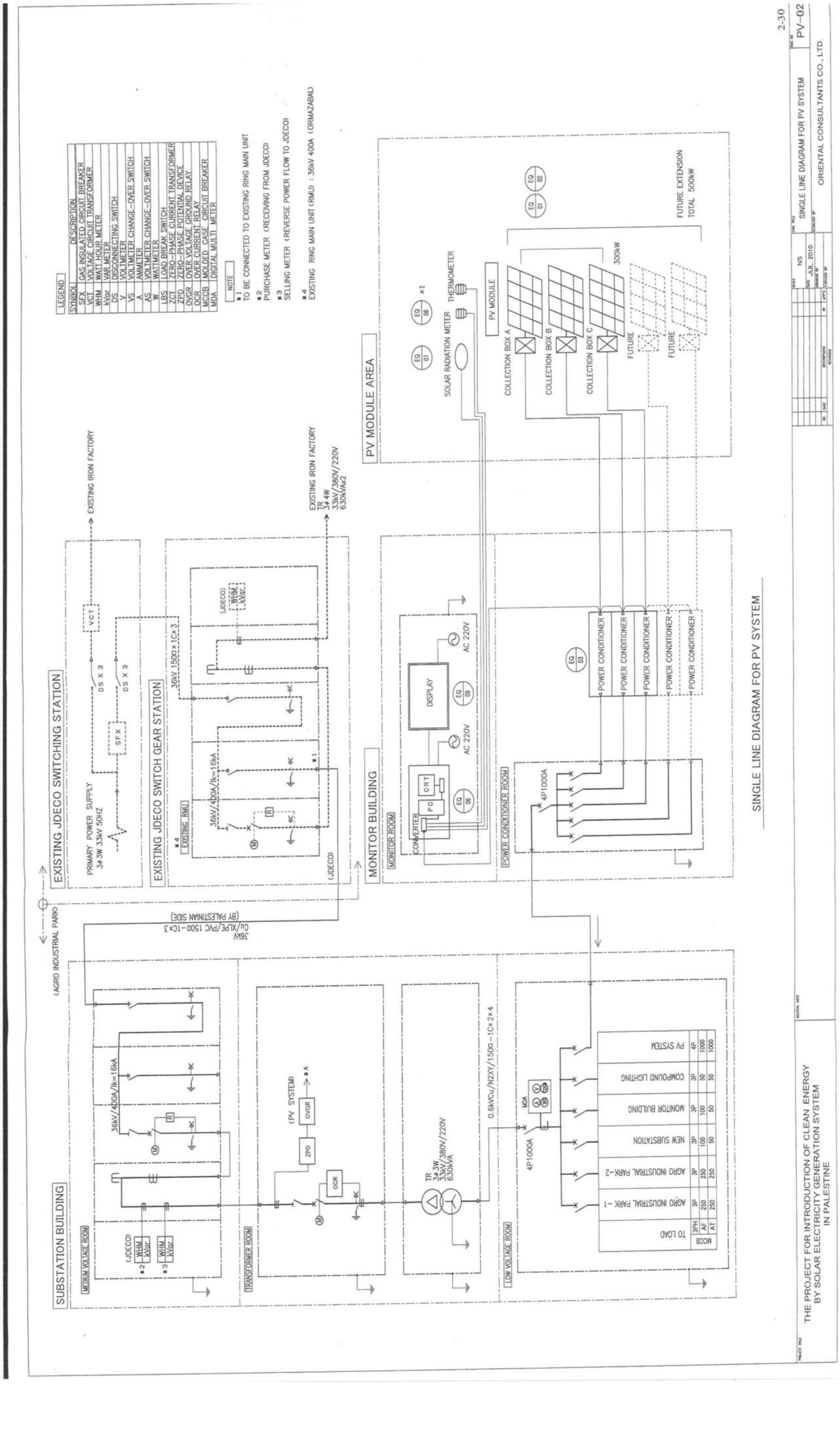
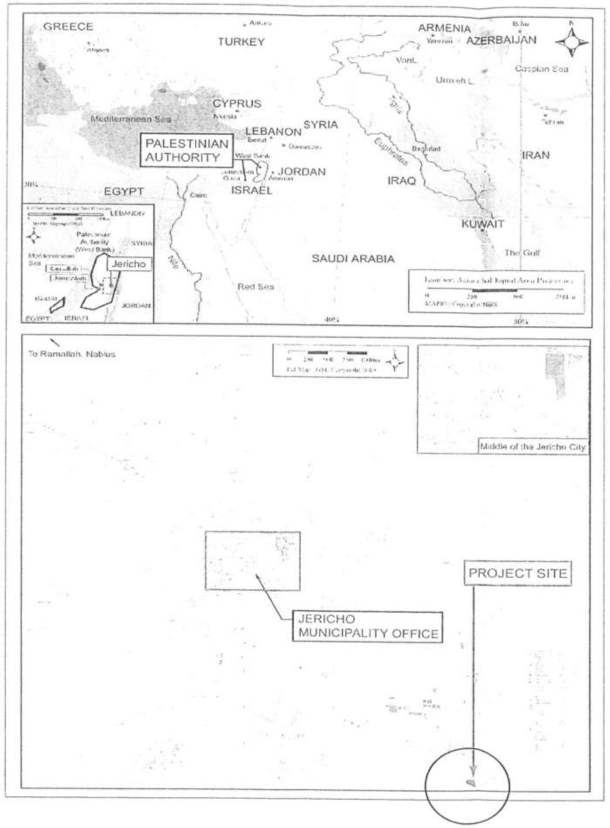
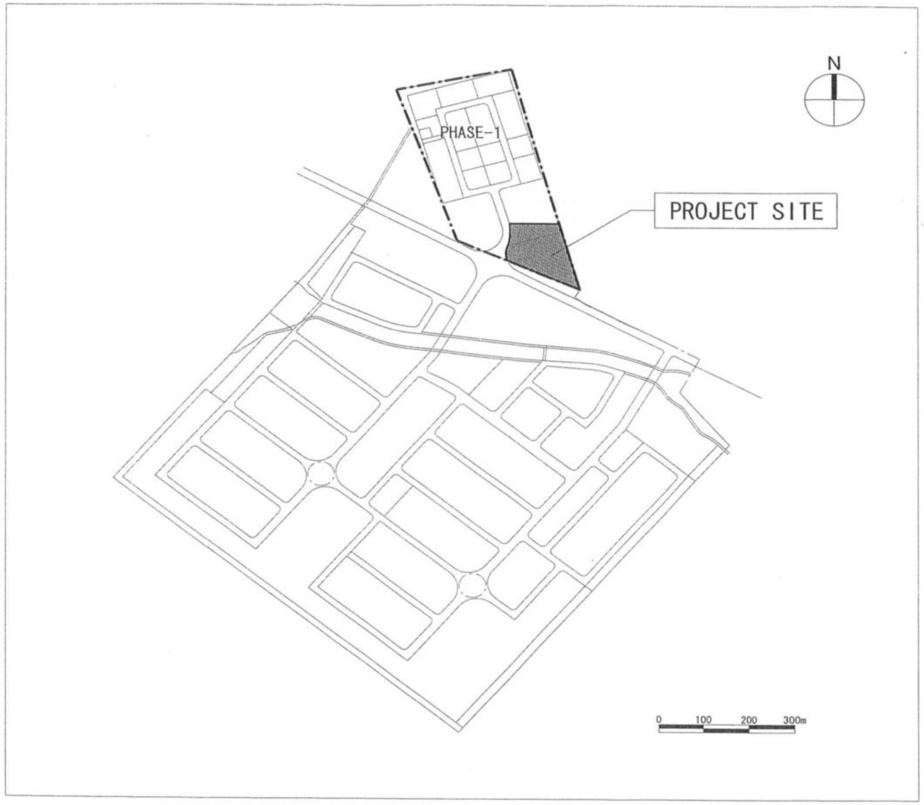

SCHEMATIC DIAGRAM FOR PV SYSTEM
COMPOUND LIGHTING AND CCTV SYSTEM
POWER CONDITIONER ROOM
MONITOR ROOM
COLLECTION BOX
CABLE AND CONDUIT PIPE
COLLECTION BOX SECONDARY CABLE AND CONDUIT PIPE
CABLE TRAY WITH COVER (W=200, HDG)
THE PROJECT FOR INTRODUCTION OF CLEAN ENERGY BY SOLAR ELECTRICITY GENERATION SYSTEM IN PALESTINE
SCHEMATIC DIAGRAM FOR PV SYSTEM, COMPOUND LIGHTING & CCTV SYSTEM
ORIENTAL CONSULTANTS CO., LTD.
NS
JUL 2010
PV-03
2-31


SUBSTATION BUILDING
MEDIUM VOLTAGE ROOM
TRANSFORMER ROOM
LOW VOLTAGE ROOM
EXISTING JDECO SWITCHING STATION
PRIMARY POWER SUPPLY 3φ3W 33kV 50HZ
EXISTING IRON FACTORY
EXISTING JDECO SWITCH GEAR STATION
EXISTING RMU
36kV/400A/Ik=16kA
36kV 150□×1C×3
(JDECO)
WHM
kVar
TR 3φ4W 33kV/380V/220V 630kVAx2
36kV Cu/XLPE/PVC 150□-1C×3 (BY PALESTINIAN SIDE)
(AGRO INDUSTRIAL PARK)
MONITOR BUILDING
MONITOR ROOM
CONVERTER
PC
CRT
DISPLAY
AC 220V
POWER CONDITIONER ROOM
4P1000A
POWER CONDITIONER
PV MODULE AREA
SOLAR RADIATION METER
THERMOMETER
PV MODULE
COLLECTION BOX A
COLLECTION BOX B
COLLECTION BOX C
FUTURE
300kW
FUTURE EXTENSION TOTAL 500kW
(PV SYSTEM)
ZPD
OVGR
OCR
TR 3φ3W 33kV/380V/220V 630kVA
0.6kVCu/N2XY/150□-1C×2×4
MDA
TO LOAD
AGRO INDUSTRIAL PARK-1
AGRO INDUSTRIAL PARK-2
NEW SUBSTATION
MONITOR BUILDING
COMPOUND LIGHTING
PV SYSTEM
MCCB 3PH AF AT
LEGEND
SYMBOL DESCRIPTION
SFX GAS INSULATED CIRCUIT BREAKER
VCT VOLTAGE CIRCUIT TRANSFORMER
WHM WATT HOUR METER
kVar VAR METER
DS DISCONNECTING SWITCH
V VOLTMETER
VS VOLTMETER CHANGE-OVER SWITCH
A AMMETER
AS VOLTMETER CHANGE-OVER SWITCH
W WATTMETER
LBS LOAD BREAK SWITCH
ZCT ZERO-PHASE CURRENT TRANSFORMER
ZPD ZERO-PHASE POTENTIAL DEVICE
OVGR OVER VOLTAGE GROUND RELAY
OCR OVER CURRENT RELAY
MCCB MOLDED CASE CIRCUIT BREAKER
MDA DIGITAL MULTI METER
NOTE
※1 TO BE CONNECTED TO EXISTING RING MAIN UNIT
※2 PURCHASE METER (RECEIVING FROM JDECO)
※3 SELLING METER (REVERSE POWER FLOW TO JDECO)
※4 EXISTING RING MAIN UNIT (RMU) : 36kV 400A (ORMAZABAL)
SINGLE LINE DIAGRAM FOR PV SYSTEM
THE PROJECT FOR INTRODUCTION OF CLEAN ENERGY BY SOLAR ELECTRICITY GENERATION SYSTEM IN PALESTINE
SINGLE LINE DIAGRAM FOR PV SYSTEM
ORIENTAL CONSULTANTS CO., LTD.
NS
JUN. 2010
2-30
PV-02

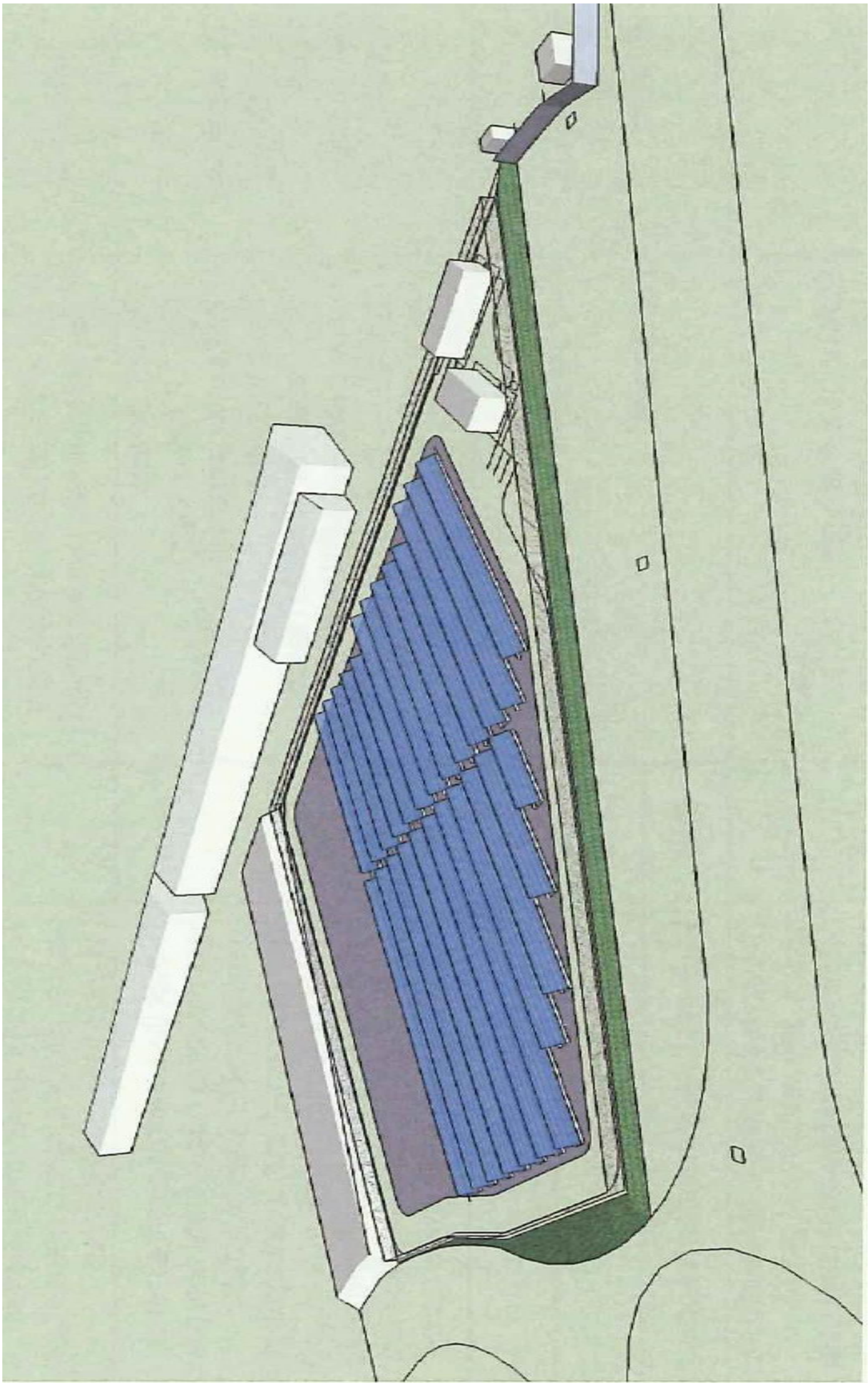


LOCATION MAP



JERICHO AGRO-INDUSTRIAL PARK (PLANNING)

THE PROJECT FOR INTRODUCTION OF CLEAN ENERGY BY SOLAR ELECTRICITY GENERATION SYSTEM IN PALESTINE	NS JUL. 2010	SITE MAP ORIENTAL CONSULTANTS CO., LTD.	2-28 PV-00



Appendix (D) Grid Code for Electrical Connection (Technical Requirements)

D.1 Connection Standards

D.1.1 A connection to the Distribution System may be by means of an overhead line, an underground cable or a combination of both. The network configuration at the Connection Point may take a number of forms suitable to the nature of the load and network arrangements.

D.1.2 All equipment in an installation connected to the Distribution System shall be designed, manufactured, tested and installed in accordance with all applicable statutory obligations and shall conform to the relevant Palestinian Standards current at the time of the connection of the installation to the Distribution System.

D.1.3 If there is no relevant Palestinian Standards, such other relevant International Standards or National Standards which are in common use, as current at the date of the User's applicable Connection Agreement, shall apply. If the Disco considers it necessary, however, the Disco may notify Users that supplemental specifications and/or standards shall be complied with, in which case User Plant and Apparatus shall so comply.

D.1.4 All equipment in an installation connected to the Distribution System shall be suitable for use at the operating frequency of the Distribution System and at the voltage and short-circuit rating of the Distribution System as shown in Table 2, at the Connection Point. The Disco may require certification that the equipment has been designed and installed in a satisfactory manner. The Disco may also seek evidence that the equipment has been tested for conformance with the standards.

D.1.5 For Users connected at Low Voltage, installations shall comply with the Electrical Installation Code and any other rules and regulations issued by the Authority from time to time. Users complying with these rules and regulations shall be deemed to comply with the requirements of the Distribution Code as regards design and safety. The Disco may seek evidence that the equipment has been tested for compliance with standards.

D.1.6 Before entering into a connection agreement it will be necessary for the Disco to be reasonably satisfied that the User's System at the boundary with the Distribution System shall comply with the appropriate requirements of the Distribution Code.

D.2 Protection Requirements

D.2.1 Users shall ensure that faults in the User's Plant and Apparatus do not unreasonably cause disturbances to the Distribution System or to other Users. Without limiting this obligation, a User shall prior to connection of the User's Installation to the Distribution System, install the protection equipment specified in Section D.2.4.

D.2.2 Faults on the Distribution System can cause damage to User’s Plant and Apparatus. These faults could result in a loss of a phase, over Voltage, or under Voltage. The User shall take account of the established practices of the particular network to which a connection is to be made, and ensure that protection installed is compatible with that used by the Disco. The adequacy of the protection installed by the User is the User's responsibility.

D.2.3 The User's Protection arrangements at the Ownership Boundary, including types of Equipment and Protection settings, shall be compatible with existing system conditions and the Distribution System protection practice as specified by the Disco at the time of application. In particular:

(a) The maximum clearance times (from fault current inception to arc extinction) shall be within the limits established by the Disco in accordance with Protection and Equipment short circuit rating policy adopted for the Distribution System.

(b) In connecting to the Distribution System the User should be aware that fast and slow speed automatic reclosing is a feature of Power System operation. This is characterised by sudden de/re-energisation of the power supply. *{Dead times are typically 0.3s, 1s and 10s at Medium Voltage and 3s and 60s on 33kV systems.}*

(c) Users should also be aware that disconnection of one or two phases only of a three phase system may be effected by Distribution Protection arrangements for certain types of faults.

D.2.4 The minimum protection required for a User Installation connected to the Distribution System will vary according to type, size, and method of connection (loop/tail/tee) and earthing of the User System. Low Voltage Customers shall comply with the Electrical Installation Code. Other User installations will vary. It is anticipated that a new connection may require all or some of the following protection facilities:

(a) Three phase Overcurrent

(b) Earth fault protection (suited to the local supply system)

(c) Distance

(d) Intercropping

(e) Other

D.2.5 Where interface circuit breakers are used they shall be fitted with relays of a type acceptable to the Disco. These relays shall have three phase Overcurrent elements and one earth fault element and shall have time-current characteristics complying with standard types A, B and C of IEC 255. Maximum permissible relay settings at the ownership boundary, necessary to provide selectivity with Distribution equipment, will be provided by the Disco, and these settings may be reviewed at any time in the future by the Disco. Distribution protection aims to minimise the impact of faults including voltage dip duration and must not be adversely affected by customer's protection limitations.

(a) In order to ensure satisfactory operation of the Distribution System, Protection systems, operating times, discrimination, and sensitivity at the Ownership boundary shall be agreed between the Disco and the User during the application for connection process, and may be reviewed from time to time by the Disco.

(b) In order to cover a Circuit Breaker, or equipment having similar function, failing to operate correctly to interrupt fault current on the System, back-up protection by operation of other circuit breakers or equipment having a similar function shall normally be provided.

(c) Unless the Disco advises otherwise, it is not acceptable for Users to limit the fault current in feed to the Distribution System by the use of Protection and associated Equipment if the failure of that Protection and associated Equipment to operate as intended in the event of a fault, could cause Equipment owned by the Disco to operate outside its short-circuit rating.

D.2.6 Protection relays shall be commissioned on site by the User who shall ensure that the settings are below the maximum permitted levels. In certain cases the Disco may wish to witness these tests and it shall be the responsibility of the User to ensure that sufficient notice is given to the Disco in such cases. Users shall ensure that the protection settings remain below the maximum permitted levels. This may require regular testing of the relays.

D.3 Earthing

D.3.1 Earthing of the part of the User's Installation that is connected to the Distribution System shall comply with the requirements of Distribution Planning Code Section 4.3.

D.3.2 The arrangements for connecting the User's Installation with earth shall be designed to comply with relevant international and Palestinian standards. For Low Voltage Users the Electrical Installation Code applies. For Medium Voltage Users and for High Voltage Users *{the Disco will specify conditions governing connection to the Distribution System at MV and HV and Embedded Generators at LV, MV and HV and annex these to this Distribution Code}.*

D.3.3 The method of earthing the Distribution System, for example, whether it is connected solidly to earth or through an impedance, shall be advised by the Disco. The specification of associated equipment shall meet the voltages which will be imposed on the Equipment as a result of the method of earthing.

D.3.4 Users shall take precautions to limit the occurrence and effects of circulating currents in respect of neutral points connected with earth where there is more than one source of energy.

D.4 Voltage Regulation and Control

Extensions or connections to the Distribution System shall be designed such that they do not prevent the necessary control of voltage on the Distribution System. Information on the voltage regulation and control arrangements shall be made available by the Disco if requested by the User.

D.5 Short-Circuit Levels

D.5.1 The short circuit rating of User's Equipment at the connection point shall not be less than the design Fault Level of the Distribution System as shown in Table 2 below. The choice of Equipment for connection at Low Voltage may take into account attenuation in the service lines. The Disco shall take into account the contribution to Fault Level of the User’s connected System and Apparatus in the design of its System.

TABLE 2: SHORT CIRCUIT RATINGS

{Values to be provided by Disco}

Connection Voltage	Short Circuit Level (RMS Symmetrical) Normally	Short Circuit Level (RMS Symmetrical) Certain Designated Areas
LV (Domestic)		
LV (Ind/Comm)		
11kV		
20kV		
33kV		

D.5.2 The User's incoming supply shall be controlled by a main circuit breaker which shall be in accordance with a recognised international standard acceptable to the Disco.

D.6 Insulation levels

D.6.1 The design of an operators equipment connected to the Distribution System shall be such as to enable it to withstand, under test, the AC and impulse (1.2/50 µS) voltages indicated in Table 3 below.

TABLE 3 : INSULATION LEVELS

{Values to be verified by Disco}

Voltage of Equipment	AC Withstand Level	Impulse Level
LV	3kV	
11kV	50kV	125kV
20kV	50kV	125kV
33kV	105kV	250kV

D.7 Capacitive and Inductive Effects

D.7.1 The User shall, when applying to make a connection, provide the Disco with information as detailed in Distribution Planning Code Section 4. Details shall be required of any capacitor banks and reactors connected at High Voltage, which could affect the Distribution System and which it is proposed to connect if agreed with the Disco. When requested by the Disco, details shall also be provided of distributed circuit capacitance and inductance. Sufficient detail is required for the following:-

(a) to verify that controlling Equipment of the Distribution System is suitably rated;

(b) to show that the performance of the Distribution System will not be impaired; and

(c) to ensure that arc suppression coils on the Distribution System neutral are correctly installed and operated.

D.8 Voltage Disturbances

D.8.1 Users of the Distribution System should not generate voltage disturbances at a level that would affect other Users. Users should in their own interest select equipment that is capable of functioning satisfactorily in the presence of disturbances at the levels permitted by *{EN 50160}*.

D.8.2 It is a condition of connection that equipment connected directly or indirectly to the Distribution System shall conform to the requirements of *{EU Directive 89/336/EEC (the EMC Directive)}* as amended.

D.8.3 Loads and installations shall comply with the following emission limits. Special conditions for generators are outlined in Section 9.6.1

(a) Voltage Flicker *{Disco to verify values shown in tables etc}*

(i) Frequency of occurrence: 0.22 per min – 600 per min

Voltage Level	P_{st}	P_{lt}
33kV, MV, LV	0.7	0.5

P_{st}: Short Term Flicker Severity - an index of visual severity evaluated over a 10 minute period.

P_{lt}: Long Term Flicker Severity - an index of visual severity evaluated over a 2 hour period.

(ii) Frequency of occurrence: 0.02 per min – 0.22 per min

Magnitude of up to 3% is permitted.

(iii) Frequency of occurrence: =< 0.02 per min

Magnitude of up to 5% is permitted.

(b) Harmonic Distortion *{Disco to verify values shown in tables etc}*

(i) Individual Harmonic Orders:

% Harmonic Voltage Distortion

(rms voltage as a % of rms value of the fundamental component)

Harmonic Order	LV	MV	33kV
2	0.70	0.50	0.25
3	0.75	0.50	0.25
4	0.70	0.50	0.25
5	2.00	1.00	0.50
6	0.50	0.50	0.30
7	2.00	1.00	0.50
8	0.50	0.50	0.30
9	0.50	0.50	0.25
10	0.50	0.75	0.25
11	1.50	1.50	0.75
12	0.50	0.50	0.30
13	1.50	1.50	0.75
14	0.50	0.50	0.50
15	0.50	0.75	0.25
16	0.75	0.75	0.25
17	0.75	0.75	0.50
18	0.50	0.50	0.25
19	1.00	0.50	0.25

(ii) Total Harmonic Distortion

Voltage Level	% Harmonic Voltage Distortion
LV	2.5
MV	2.0
33kV	1.5

(c) Unbalance *{Disco to verify parameter}*

The unbalance caused by the connection of an individual installation shall not exceed 1.3% at the Point of Common Coupling (PCC).

D.8.4 Under fault and circuit switching conditions the rated frequency component of voltage may fall or rise transiently. The rise or fall in voltage will be affected by the method of earthing of the neutral point of the Distribution System and voltage may fall transiently to zero at the point of fault. *{Sections 2 and 3 of EN 50160}*, as amended from time to time, contains additional details of the variations and disturbances to the voltage which shall be taken into account in selecting Equipment from an appropriate specifications for installation on or connected to the System.

D.9 Power Factor and Phase Balance

D.9.1 The customer shall take all reasonable steps to operate the Plant and the Facility to keep the power factor of the total load at the Connection Point for imported electricity between 0.90 lagging and unity and for exported electricity between 0.95 lagging and unity. Wind generators must keep power factor between 0.92 and 0.95 lagging. For the purpose of this code, lagging power factor refers to the absorption of reactive power. These are minimum requirements. In certain instances specific requirements may apply in order to ensure that the Disco can comply with the requirements of the Grid Code.

D.9.2 Disco Phase Balance requirements are covered in *{EN50160}*.

جامعة النجاح الوطنية

كلية الدراسات العليا

الآثار الفنية لآنظمة الخلايا الشمسية المربوطة على شبكة شركة كهرباء محافظة القدس حالة دراسة (خطوط تغذية اريحا والجيب)

إعداد

رامي ياسر محمد دسة

إشراف

أ. د. مروان محمود

د. أسامة العمري

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة وترشيد الاستهلاك بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

2013م

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الملخص

باستخدام برنامج المحاكاة (Power World Simulator) ، تمت محاكاة وتحليل حالة الدراسة على الضغط المنخفض لشبكة التوزيع الكهربائية لقرية الجيب، وقد تم اسقاط أنظمة خلايا شمسية مربوطة على الشبكة 5 ك.و حسب المبادرة الوطنية الفلسطينية على الشبكة الكهربائية. ومن ثم تمت زيادة ومضاعفة قدرتها وبحث ومحاكاة نسب مختلفة 25%، 50%، 75%، 100%، من قيم مشاركة (مساهمة) الخلايا الشمسية في الشبكة، وذلك بواسطة تمثيل وتحليل المخطط الاحادي والخلايا الشمسية باستخدام برنامج المحاكاة لاختبار الآثار الفنية الخاصة بجودة المصدر المغذي.

لوحظ أنه ومع زيادة نسبة مشاركة الخلايا الشمسية المربوطة على الشبكة بنسبة فوق 50 % من قيمة حمل المحول ، فان محولات التوزيع ستعاني من قيم معامل قدرة منخفضة جدا وسريان تيار عكسي باتجاه المصدر مما يتسبب في ان تصبح الشبكة مصدرا للطاقة المراكسة (الخيالية) فقط، وهذا بالاضافة الى قيم معامل القدرة المنخفضة مما سيتسبب في قلة كفاءة أجزاء وعناصر الشبكة ، وتوليد حرارة ناتج عن سريان الطاقة المراكسة التي ستعمل على تخفيض العمر الزمني لعناصر وأجزاء الشبكة.

وعلى الرغم من أن فواقد الخطوط تقل مع زيادة نسبة مشاركة الخلايا الشمسية وتتحسن قيم الجهد عند نسبة مشاركة 25 % ،، لكن ارتفاع في الجهد يظهر فوق القيم المسموح بها والمقبولة حسب المواصفة العالمية ال IEC وقوانين الشبكات بعد تجاوز نسبة مشاركة 50 % ، وخاصة

على مغذيات المناطق الريفية الطويلة ذات المقاومات المرتفعة والحمل المنخفض. كما أن تأرجحا هاما في التيار يحدث عند نسبة مشاركة 80%.

في حالة الدراسة على الضغط المتوسط لشبكة أريحا ومحطة الطاقة الشمية لأريحا فان الآثار الفنية لنسبة المشاركة الحالية وهي قدرة محطة الطاقة الشمسية الحالية وتساوي 300 ك.و، كانت غير ملحوظة ومهملة. كما تم اختبار نسب مختلفة من مشاركة الخلايا الشمسية على شبكات الضغط المتوسط بواسطة الزيادة التدريجية لقدرة المحطة الشمسية وذلك بتمثيل الخلايا الشمسية المربوطة على الشبكة والقيم الحقيقية والواقعية لبيانات ومعلومات الشبكة باستخدام برنامج المحاكاة (Power World Simulator) لشبكة أريحا ومحطة الطاقة الشمسية ولم تظهر اشارت على وجود قيم جهد مرتفعة في أي من نسب المشاركة للخلايا الشمسية ، ولكن أيضا لم يكن هناك اي تحسن ملحوظ على نقاط الربط ذات قيم الجهد المنخفضة، معامل القدرة على نقطة الربط للمصدر انخفض بشكل ملحوظ مع زيادة نسبة مشاركة قدرة محطة الخلايا الشمسية المربوطة على الشبكة ، كما أنه لم يكن هناك اي تاثير ملحوظ على تحسن قيم فواقد الخطوط لكل نسب مشاركة الخلايا الشمسية التي اختبرت. وحدث تارجح هام للتيار فوق نسبة مشاركة 50% .

فيما يتعلق بحالة الدراسة على الضغط المتوسط فانه يوصى وحسب وجهة نظر الباحث ومن خلال نتائج الدراسة بانه كان من الافضل اختيار موقع أخر أقرب للحمل السكني (محطة المغطس)، وهذا الموقع الجغرافي الجديد تم اختباره وتحليله بواسطة برنامج المحاكاة وكانت النتائج لقيم الجهد والفاقد أفضل.

على حالة الدراسة للضغط المنخفض ، فان التوصيات لتقليل الآثار الفنية السلبية لمولدات الخلايا الشمسية المربوطة والموزعة على الشبكة التقليدية هي :

1- استخدام أنظمة الشبكات الذكية لمراقبة أداء الشبكة الساعي والتحكم في أوقات تبادل الطاقة وازالة الآثار السلبية وزيادة الفوائد

2- تحديد نسب مشاركة الخلايا الشمسية على الشبكة بنسبة 40 % بواسطة منظم الشبكة لزيادة الأمان. أو تحديد نسبة المشاركة للخلايا الشمسية بقيمة الحد الادنى لقيمة حمل المغذي.

3- دراسة نظام تخزين على الشبكة ليعمل كمنطقة عازلة.

4- تقليل نسبة مشاركة الخلايا الشمسية على الشبكة (خط التغذية) لتصبح مساورية لقيمة اقل حمل على خط التغذية نتيجة لارتفاع الجهد مع فرض عدم حدوث تغير في قيم الرتب لمحول الضغط المنخفض/الضغط المتوسط.