An-Najah National University

Faculty of Graduate Studies

The Techno - Economical Impact of PV On-Grid Systems on the Security of Palestinian Electrical Supply (Jericho PV system - Case study)

By

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Supervisor

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Dedication

To my father, mother, brother and sisters...………………..

To my wife and sons……………………………………………..

To all friends and colleagues…………………………………

To everyone works in this field……………………………..

To all of them,

I dedicate this work

Acknowledgment

I would like to thank my family for constant love and support that have always given me.

My furthermost appreciation goes to my supervisor, Dr. Imad Ibrik for his exceptional guidance and insightful comments throughout the duration of this project.

Thanks go also to all my friends and fellows graduate Students.

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الإقرار

أنا الموقع أدناه، مقدم الرسالة التي تحمل العنوان:

The Techno - Economical Impact of PV On-Grid Systems on the Security of Palestinian Electrical Supply (Jericho PV system - Case study)

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة كاملة، أو أي جزء منها لم يقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

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

Student's Name:	**اسم الطالب:**
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Date:	**التاريخ:**

List of Abbreviations

AC	Alternative current
DC	Direct current
kWh	Kilo watt hour
STC	Standard Test Condition
PSH	Peak sun hour
PV	Photovoltaic
FIT	Feed in Tariff
GTI	Grid Tie Inverter
PWM	Pulse Width Modulation
LCC	Life Cycle Cost
AW	Annual Worth
PW	Present worth
PEA	Palestinian Energy Authority
PERC	Palestinian Electricity Regulatory Council
PSI	Palestinian Solar Initiative
SCADA	Supervisory Control and Data Acquisition
MPPT	Maximum Power Point Tracker
SPBP	Simple Pay Back Period
LV	Low Voltage
MV	Medium Voltage
Wp	Watt peak
CER	Certified Emission Reduction

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The Techno - Economical Impact of PV On-Grid Systems on the Security of Palestinian Electrical Supply
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Abstract

This research based on modeling the grid tie PV power system using Matlab Simulink software program in order to study the techno-economic performance analysis of building these systems according to our environmental conditions such as temperature, solar radiation and wind speed.

The main objective of research is to design a grid tie PV system by using Matlab Simulink program and apply this system on Jericho PV power plant as a case study. To achieve this objective we should study the mathematical models which characterize each part of grid tie PV power system such as PV module, MPPT controller, transformer, and then convert the mathematical models to Simulink models.

Furthermore, we should investigate the design connection topologies for all components of grid tie PV system in order to study the operation of system for different environmental conditions.

Current predictive models are very useful for a grid tie system, which is limited to operate at the maximum power point. These models accurately predict the power output of different PV On grid tie system based on data specification.

The program is dynamic, and fit with the changes of parameters, which are related to the reduced power output caused by increased temperature, as well as the effect of non-linear absorption of solar radiation on power output. Data was collected and analyzed as a case study for Jericho PV power plant.

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 kWp.

On the low voltage case study, it is recommended to minimize the negative technical impact of the distributed PV generators on the conventional grid by using smart grid systems to monitor the grid performance hourly and control the energy exchange times.

Regarding the L.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 limiting the PV penetration level on the grid to 15% or to equal the minimum load of the feeder by the regulator for more safety.

Based on the economic evaluation, the cost of energy generated by Jericho PV power plant were studied is 0.18 (US$/kWh) while the cost of energy generated by conventional supply is 0.19 (US$/kWh).

Introduction

Solar energy is one of the most abundant energy resources on earth. Photovoltaic (PV) technology converts this natural energy (solar radiation) into electricity creating no pollution with consuming no conventional fossil fuels, and lasting for decades with relatively little maintenance efforts. The use of a widely available and reliable energy source, the sun, makes this related technologies highly promising.

Indeed, numerous examples of deployed systems are already successfully available in the world. In addition, the scalable nature of the technology lends itself well to varying power requirements from the smallest autonomous platforms to infrastructure-based systems.

PV module represents the fundamental power conversion unit of a PV generator system. The output characteristics of PV module depends on the solar insolation, the cell temperature and output voltage of PV module. Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications. Almost all well-developed PV models describe the output characteristics mainly affected by the solar insolation, cell temperature, and load voltage.

PV On – grid systems has the ability to provide 24-hour electricity to the load. This system offers a better reliability, efficiency, flexibility of planning and environmental benefits compared to the standalone system.

Each kilowatt-hour (kWh) generated from solar systems saves the environment from the burning of fossil fuels. The diesel –fired and the natural-gas-fired power generators produce 1.2 Kg and 0. 5307 Kg carbon dioxide, respectively, to generate 1 kWh electricity [1].

The main scope of thesis is to study the medium voltage level PV generation system station. The study case of this thesis investigates a techno-economic study of the Jericho PV generation station in Jericho, West Bank with total installed capacity 300 kWp.

Structure of Thesis

The work carried out in this thesis has been summarized in seven chapters

Chapter 1: Renewable Energy Strategy in Palestine

This chapter illustrates renewable energy potential in Palestine, Photovoltaic (PV) Implemented Projects in Palestine, and energy strategy in Palestine by 2020.

Chapter 2: Solar Energy Systems

This Chapter describes the main elements of PV systems, types of PV systems, Policy of on-grid PV systems (Feed in Tariff, Net Metering), and renewable energy policy in Palestine.

Chapter 3: Design of PV On-Grid Systems

This chapter describes the selection of the capacity of PV modules, selection of grid tie inverters, grid connection, and configuration of monitoring system.

Chapter 4: Modeling On-Grid PV Systems

This chapter describes mathematical modeling and Simulink of grid tie PV system and designs a grid tie PV system by using Matlab Simulink and observes how the system works with a dynamics behavior of changing solar radiations and temperature.

Chapter 5: Techno - Economical Impact of PV On-Grid Systems

This chapter studies the evaluation of techno economical impact of Jericho grid tie PV system, Levelized Cost of Energy (LCOE), Environment impact of grid tie PV system.

Chapter 6: Performance Analysis of Jericho PV System

This chapter introduces some information about Jericho PV power plant, potential of solar energy, also, sizing the elements of the grid tie system for this plant and simulation results in different conditions such as solar radiation and temperature.

Chapter 7: Conclusions and Future Scope of Work

This chapter describes the main conclusions about grid tie PV system and future scope of work.

Chapter One

Renewable Energy Strategy in Palestine

1.1 Renewable Energy Potential in Palestine

Introduction

Palestine is located between 34º:20´ - 35:30´ E and 31º: 10´ - 32º:30´ N , It consists of two separated areas from one another , the Gaza Strip is located on the western side of Palestine adjacent to the Mediterranean Sea and the West-Bank which extends from the Jordan River to the center of Palestine .

Palestine's elevation ranges from 350 m below sea level in Jordan Valley, to sea level along Gaza Strip sea shore and exceeding 1000 m above sea level in some mountains sites in the west-Bank.

Climate conditions in Palestine vary widely, the coasted climate in Gaza Strip is humid and hot during summer and mild during winter. These areas have low heating loads, while cooling is required during summer.

The daily average temperature and relative humidity vary in the ranges: (13.3 – 35.4) C° and (67 – 75) % respectively.

In the hilly areas of the West-Bank, cold winter conditions and mild summer weather are prevalent. Daily average temperature and relative humidity vary in ranges: (8 – 23) Cº and (51 – 83) % respectively. In some areas the temperature decline below 0 Cº. Hence, high heating loads are required, while little cooling is needed during summer.

In Jericho and Jordan Valley, almost no heating is needed during winter while high cooling during summer is needed [2].

Renewable energy is energy that is derived from natural processes that are replenished constantly. In its various forms, it derives directly or indirectly from the sun, or from heat generated deep within the earth.

Included in the definition is energy generated from solar, wind, biomass, geothermal, hydropower, ocean energy, bio-fuels and hydrogen derived from renewable resource.

The main renewable energy sources considered to have potential in Palestine are wind energy, biogas and solar energy.

1.1.1 Wind Resource

The wind speeds in the West Bank are low or moderate, varying between 2-5 m/s, depending on the site and altitude. Which can be translated to an average wind potential of 150 kWh/m^2 yr in the Jordan valley, 300-450 kWh/m^2 yr in most of the West Bank and in some spots (like in the northern and southern parts) it could reach up to 600 kWh/m^2 yr, as shown in figure 1.1. However, these figures were based on estimates and theoretical calculations without any wind measurements or real data from the field. Thus, an analysis with real measurements covering different parts of the West Bank was still needed and is presented [3].

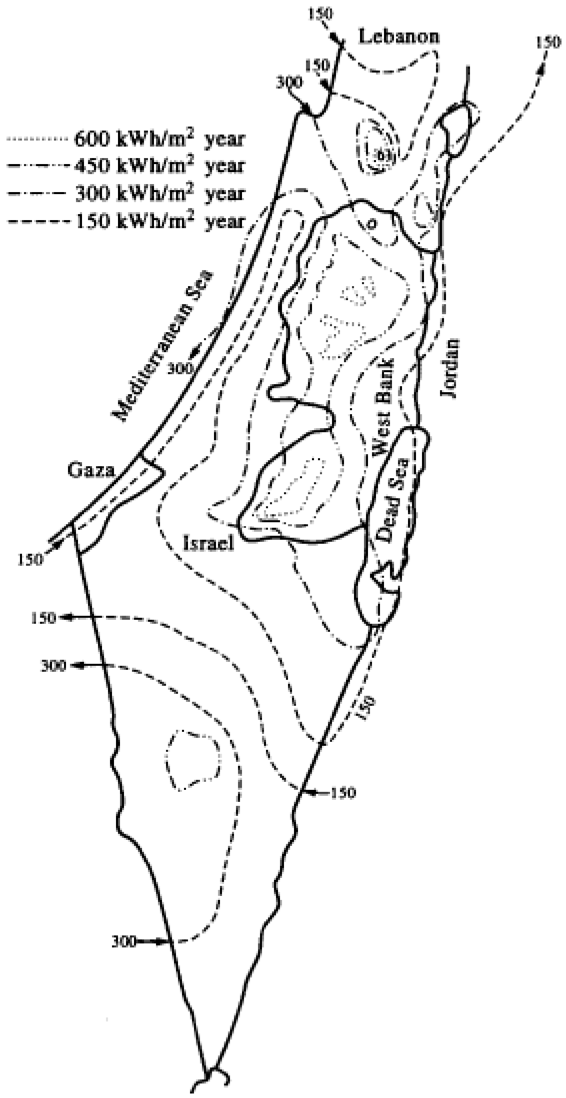

Figure (1.1): Wind potential in Palestine

However, based on previously available metrological data from various stations (around the West Bank taken before the year 2000 from the national meteorological stations) average wind speed is moderate, see table 1.1.

Table 1.1 - Wind Speed (measured at 10m height) and Potential in some areas of the West Bank

Location	Elevation (m)	Wind Speed (m/sec)	Wind Potential (kWh/m^2)		
			10 m	20 m	40 m
Jenin	140	3.7	285	431	626
Jericho	-280	3.3	146	286	505
Ramallah	874	4.8	407	659	1013
Jerusalem	757	4.1	334	541	831

1.1.2 Biogas Resource

In Palestine there are many people living from the agriculture in rural areas. Therefore animal solid waste resources appear as a useful and viable input for electricity generation. Moreover, recently the informal deposit of solid waste has been forbidden. As a consequence, three large landfills had planned to build in the West Bank. This assessment analyzes the potential of these two sources of energy to produce biogas used for electricity generation through the following applications:

- Animal waste distributed digester (50 kW)
- Landfill waste centralized digester (6 MW) [4]

1.1.3. Solar Resource

Palestine has high potential of solar energy. It has around 3000 sunshine hours / year and high annual average solar energy radiation which is about 5.45 kWh/m^2 - day.

The lowest average solar energy is in December which is about 2.84 kWh/m^2 - day and the highest one is in June which is about 8.245 kWh/m^2 - day **[2].**

These figures are encouraging to exploit the solar energy for different applications such as water heating, drying of crops, vegetables, and fruits, water desalination, water pumping, and electrification of remote locations far from the electrical networks, and also for distributed generation of electricity for shaving peak demand as a DSM tool .

In order To Know the Potential of solar energy in Palestine, we must study and measure two elements.

1- Solar Radiation (w/m^2)
2- Ambient Temperature (C)

1.1.3.1 Solar Radiation

Solar irradiation data can be obtained mainly in two different ways: from ground meteorological stations or by satellites (geostationary or polar-orbiting). Some well-known available online web applications such as PVGIS**1** use data from ground measurements in their first databases, which are then interpolated until they cover the desired surface resolution. New databases that are being incorporated in such applications come from satellite databases like Meteosat. Satellite data is not as accurate as ground measurements but it offers the best coverage and regular calculations for large territories.

Satellite data covering Palestine territories comes from Meteosat satellites, which are treated into different solar databases. One of the available databases is Helioclim**2**, produced using the Heliostat 2 processing models from Meteosat images. Since data comes from satellite images, data precision depends on their resolution, which in turn depends on the latitude and longitude of the site.

Monthly averages from ground stations have been compared with data values from the Helioclim databases. Furthermore, in order to strengthen the data analysis, measurements have also been compared with the irradiation data provided by the PVGIS tool. PVGIS data also comes from the Helioclim databases, but provides only the average monthly irradiation data from the last few years [5].

Figure 1.2 depicts the graphical result of the correlation data analysis of Kardallah ground station.

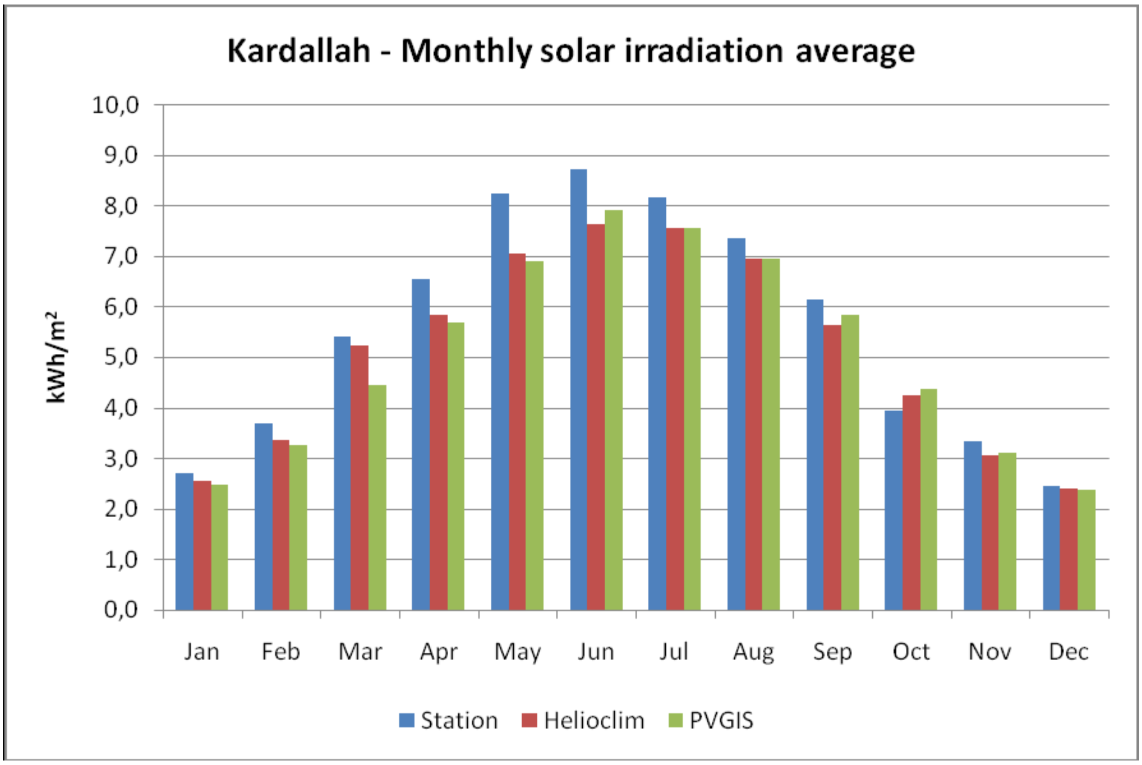

Figure (1.2): Kardallah monthly solar irradiation average

It is clear that the different series of data do not present significant differences. The data analysis shows that the average difference is lower than 10%.

In conclusion, on average Palestine has a solar Global Horizontal Irradiation of 5.2 kWh/m²/day, which yearly stands for about 1900 kWh/m²/year.

Figure 1.3 depicts the relation between the Global Horizontal Irradiation used for the photovoltaic technology, and the Direct Normal Irradiation used for the CSP plants, at the Jericho area using Meteonorm databases. As expected, DNI irradiation is higher than Global Horizontal Irradiation, especially in winter.

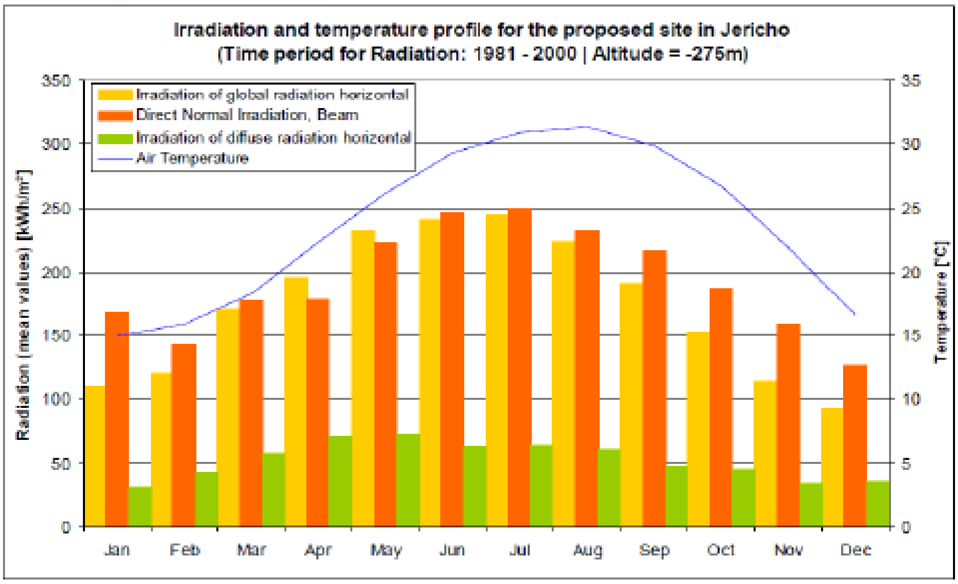

Figure (1.3): Irradiation and temperature profile at the Jericho area

1.1.3.2 Ambient Temperatures

Ambient temperature affects the PV generators efficiency.

The relation between efficiency and ambient temperature is inversed.

The shown data is the average of five days measurement in June 2013. The original Measurements are done on a 5 - minute interval basis.

Table 1.2: The daily ambient temperature 23-7-2013

Hours	Ambient temp.(°C)	Hours	Ambient temp.(°C)
01:00	22	13:00	32
02:00	22	14:00	32
03:00	22	15:00	31
04:00	21	16:00	31
05:00	21	17:00	29
06:00	22	18:00	28
07:00	22	19:00	27
08:00	23	20:00	25
09:00	24	21:00	24
10:00	27	22:00	24
11:00	28	23:00	23
12:00	31	00:00	22

Figure (1.4) shows the daily curve of the ambient temperature drawn from the data table (1.1). It shows that the maximum temperature occurs around noon time (32°C), and the minimum temperature occurs in the early morning (21°C).

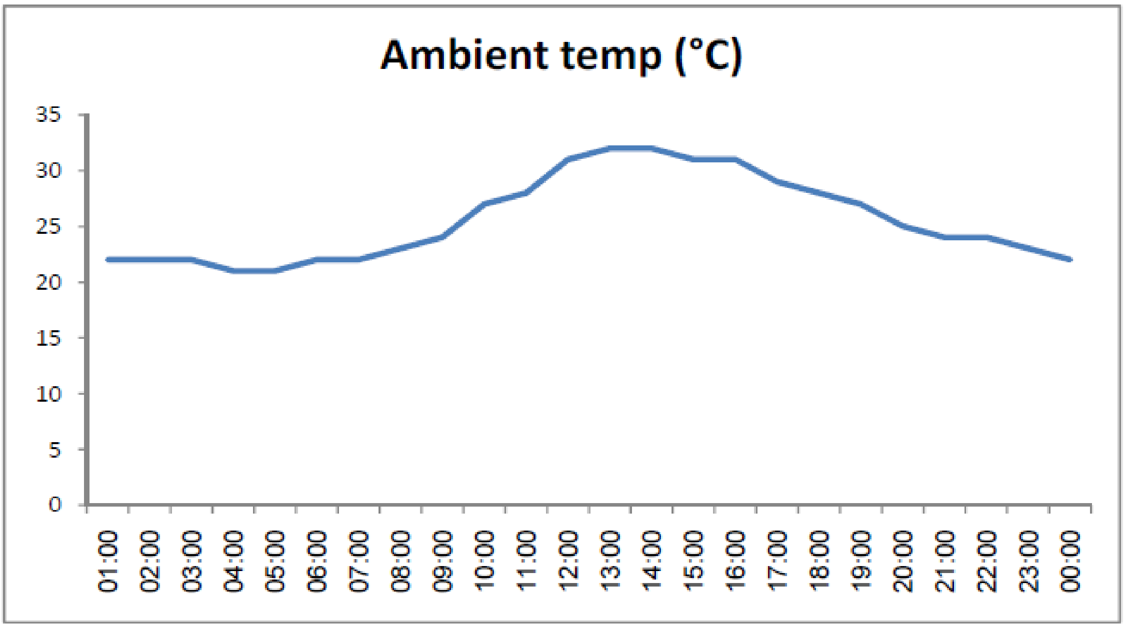

Figure (1.4): The daily ambient temperature 23-7-2013

1.2 Solar Energy Applications in Palestine:

Photovoltaic electrification in isolated rural villages and communities in Palestine is considered feasible and effective compared with other alternatives like electrical grid and diesel generators.

The PV electrification could be using the decentralized stand alone and centralized systems, depending to the nature of the load and the distribution of houses.

Photovoltaic electrification is limitedly used in different rural areas in Palestine mainly for schools, clinics, Bedouins communities, agricultural and animal farms, and private homes.

The most important solar energy projects in Palestine are:

1. **Atouf** (Tubas) project by PV centralized power system; the village includes 25 houses, school, and clinic with power capacity about 12 kWp.
2. **Imnezel** (south Hebron) project by PV centralized power system.
3. **Al-Saed** (Yaebd-Jinin) project by PV centralized power system.
4. **Al-Mikhal** (Yaebd-Jinin) project by PV centralized power system.
5. **Yerza** (Tubas) project by PV decentralized power system.
6. **Ibziq** (Tubas) project by PV decentralized power system.
7. Electrifying a **Palestinian School Rabood** (south Hebron) by PV decentralized power system.
8. Electrification of **Alisteqlal center for media and development** by PV decentralized power system.

9. Electrification of **Um-Alkher**, **Almajaz** and **Aldaqiqa** villages in south of Hebron by PV decentralized power system.
10. **The applied research institute-Jerusalem (ARIG)**, implemented some PV projects such as:

- Utilization of Solar Energy in lighting **Jub-Altheib** Village in the West Bank (Southeast Bethlehem).
- Utilization of Solar Energy in lighting **Al-Bierh Children Happiness Center** (Albira).
- Utilization of Solar Energy in lighting the emergency entrance of the clinic of **Medical Charitable Society** (Toque- Bethlehem).
- Installed 500 watt solar system at the **Applied Research Institute** to power the external lighting system of ARIJ and to assist in establishing a research center for renewable energy [6].

11. **Palestinian solar and sustainable energy society (Psses)**, implemented project for Streetlights of Wadi El-Nar (the road connects Hebron with Bethlehem) by Solar energy [7].
12. **Renewable energy Unit- Hebron University**.

    Research and development of exploitation of wind energy and solar energy for lighting of the University and its facilities by two stages, First stage; lighting the green room at the University, Second stage; street lighting for the University [8].
13. **Action Against Hunger Foundation (ACF)**. Implemented some Projects to supply electricity to the Nomadic areas in Yatta, **Khirbet Altaban** and **Alfkhit** (South of Hebron) using solar energy [9].

14. **SATCO Company**. Implemented project of Street Lighting using Solar Energy; this project was executed in December 2010 in Jericho city, to light the Amman-AL-Karama Bypass Street in Jericho [10].

15. **Palestinian Energy Authority** implemented some PV projects such as:

    Jericho PV project - This project provides the Palestine with Photovoltaic Power Generation system of 300 kW output of grid tied type in Jericho Governorate; this project was funded by Japanese Government, with the support of the Japanese development cooperation (JICA).

    Tubas PV project - This project provides the Palestine with Photovoltaic Power Generation system of 120 kW output of grid tied type in Tubas Governorate; this project was funded by Czech Republic, with the support of the Czech Development Agency.

16. **Authority of Water and House of Water and Environment (HWE) and An-Najah National University** implemented Water pumping project in the Palestinian village **Beitillu** (Ramallah) by using solar energy, this project was funded by UNDP_ GEF\SGP [11].

17. **Palestinian Hydrology Group for water and environmental resources development (PHG)** –Gaza, Implemented lighting project. The main aim is to provide electricity for Gaza Valley Bridge by solar energy; this project was funded by Global Environmental Facility - Small Grant Program, and UNDP [12].

1.3 Energy Strategy by 2020 in Palestine

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. Its energy is not provided through domestic means but rather provided through Israel which controls the quantity and quality of energy imported.

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.

One of the main obstacles that most of the government in the developing countries encounter is how to improve the efficiency and the degree of reliability of energy supplied while making modern energy services available to all people and affordable at the same time, and because of the huge unmet demand for energy and the volatility of energy prices in the recent period, ensuring the availability and security of energy supplied at reasonable prices has become the core issue in the development of energy policy.

Accordingly, the Palestinian Energy Authority has prepared a strategy for renewable energy as an important part of the resources matrix, where Palestine needs clean and more secure supply of electrical power. The Palestinian Energy Authority has developed a clear goal for the year 2020 is as follows:

To attain 240 GWh gradually (at least) to generate electricity from different renewable resources which is equivalent to 10% of the power that will be produced locally by 2020, according to the strategic plan of the energy sector.

The estimated exploitation of renewable resources (thermal) is about 18% of the total current energy consumption in Palestine, which represents 2287 GWh (of the power produced) which will be used in particular in heating and thus, the dependence on renewable energy will reach 25% of the power produced by the year 2020 [13].

To achieve this goal, this strategy requires:

- Apply the necessary regulations and legislations for the development and promotion of the use of this technology.
- Securing funding sources to cover the required costs and provide incentives for private sector investors.
- Approving a plan to develop local human resources to be capable of manufacturing, installing and managing the renewable energy systems.
- Applying the Palestinian solar initiative (PSI) for the period between 2012-2015.
- Adopting a development plan for the renewable energy resources until 2020.

Based on the assessment studies of renewable energy resources conducted by the energy authority, the required technology needed have been identified in terms of application and investment until 2020.

Table 1.3: Energy Strategy by 2020 in Palestine

Technology used	2020 (MW)
On Ground PV	25
Rooftops PV (Palestinian Solar Initiative)	20
Concentrated solar power plants	20
biogas from landfills	18
biogas from animal waste	3
Small-scale wind	4
Wind Farms	40
Total	130

It is noted from the table above that the dependence on solar energy sources represented 50% of total capacity, so this strategy contained the initiative of solar energy in order to disseminate and promote the use of renewable solar energy technology to generate electricity [13].

Chapter Tow

Solar Energy Systems

2.1 Elements of PV Systems

Photovoltaic systems (PV system) use solar panels to convert sunlight into electricity. A system is made up of one or more solar panels, usually a controller or power converter, and the interconnections and mounting for the other components. A small PV system may provide energy to a single consumer, or to an isolated device like a lamp or a weather instrument. Large grid-connected PV systems can provide the energy needed by many customers. Generally, PV panel, Power conditioner (inverter), batteries, distribution board and junction box can be counted as typical components of PV systems.

- PV panel: photovoltaic panels convert sunlight to direct current (DC) electricity which can be used to charge batteries or to supply loads.
- Charge controller: This manages the efficient charging of the batteries using the DC energy from the PV panels.
- Batteries: DC energy is stored in deep cycle lead-acid batteries, which give back the electricity as needed, especially when no charging energy is being produced. Energy put into batteries over a period of time can be taken out more quickly when needed. Lead –acid batteries need to be quickly 100% re-charged to remain in good condition. To maintain a good lifespan, they should not be drawn down below 50% charge.
- Inverter: The inverter converts the DC energy from the batteries or panels to 220 volts AC for standard house loads [14].

2.2 Types of PV Systems

PV systems can be mostly classified as standalone (off-grid) system and grid-connected (on-grid) system by applications of the power connection. Various applications could be available according to a combination of facilities on site and each project. Figure-2.1 and figure-2.2 show each schematic.

2.2.1 Off-Grid PV Systems

An off-grid system does not have a connection to the electricity "mains" (grid). Standalone systems vary widely in size and application from wristwatches or calculators to remote buildings or spacecraft. If the load is to be supplied independently of solar irradiance, the generated power is stored and buffered with a battery. In non-portable applications where weight is not an issue, such as in buildings, lead acid batteries are most commonly used for their low cost and tolerance for abuse.

A charge controller may be incorporated in the system to: a) avoid battery damage by excessive charging or discharging and, b) optimizing the production of the cells or modules by maximum power point tracking (MPPT).

However, in simple PV systems where the PV module voltage is matched to the battery voltage, the use of MPPT electronics is generally considered unnecessary, since the battery voltage is stable enough to provide near-maximum power collection from the PV module. In small devices (e.g. calculators, parking meters) only direct current (DC) is consumed. In larger systems (e.g. buildings, remote water pumps) AC is usually required. To convert the DC from the modules or batteries into AC, an inverter is used [14].

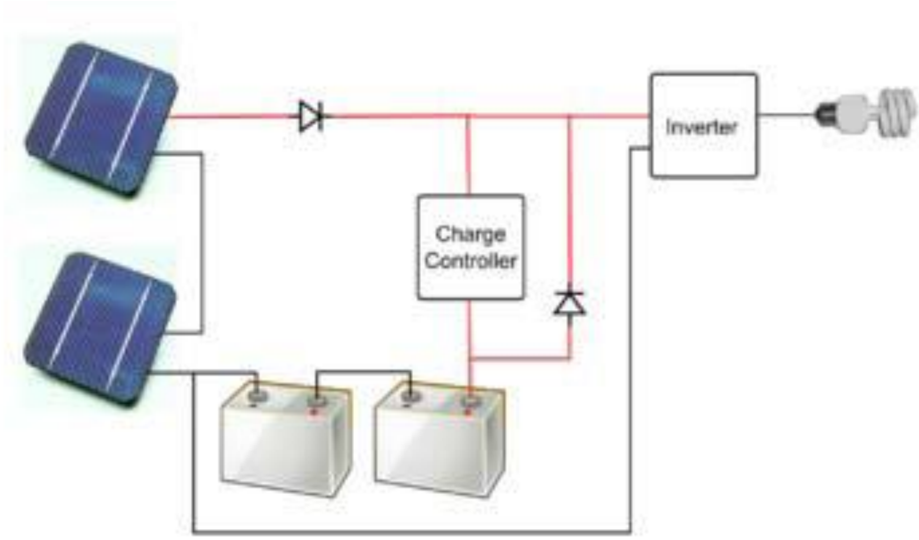

Figure (2.1): Schematic of off-grid PV systems

2.2.2 Grid-Connected PV Systems

A grid connected system is connected to a large independent grid (typically the public electricity grid) and feeds power into the grid. Grid connected systems vary in size from residential (2-10 kWp) to solar power stations (up to 10s of MW_p). This is a form of decentralized electricity generation. In the case of residential or building mounted grid connected PV systems, the electricity demand of the building is met by the PV system. Only the excess is fed into the grid when there is an excess. The feeding of electricity into the grid requires the transformation of DC into AC by a special, grid-controlled solar inverter [14].

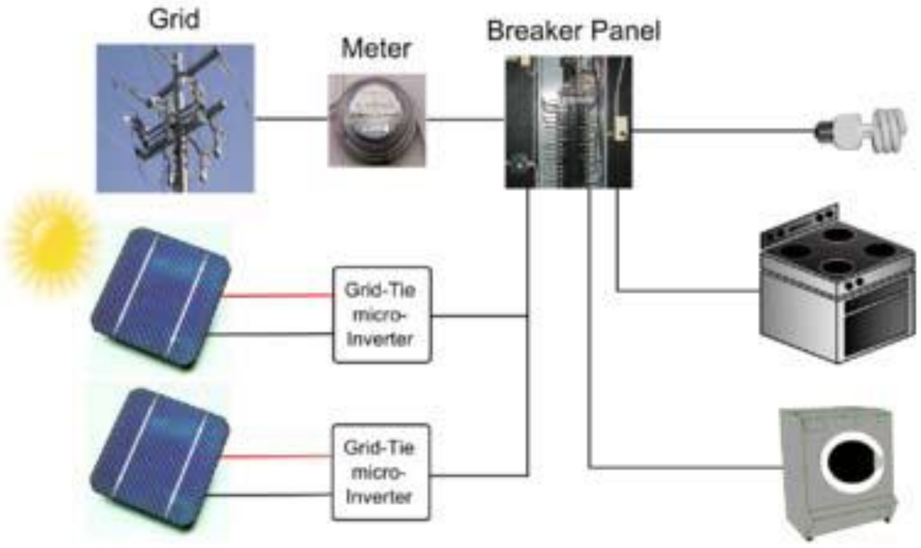

Figure (2.2): Schematic of grid-connected PV systems [14]

2.3 Policy of On-Grid PV Systems

2.3.1 Feed in Tariff (FIT)

Since the power generation costs of different RE technologies vary, a successful FIT design should provide technology-specific tariff levels. The following factors influence the power generation costs and therefore should be taken into account when the tariff levels are determined:

- Investment for the plant
- Other costs related to the project, such as expenses for licensing procedures
- Operation and maintenance (O&M) costs
- Fuel costs (in the case of biomass and biogas)
- Return on/of capital
- Other potential revenues (for instance, CER selling)
- Financial constraints commonly employed by financing institutions (DSCR6, etc.)

- According to the expected amount of electricity generated and the estimated lifetime of the power plant, a level of remuneration can be fixed [15].

2.3.2 Net Metering

Net metering policies and programs may serve as an important incentive for consumer investments in renewable energy generation.

Net metering shall be available to any Palestine consumer who generates electricity from a renewable source (wind, solar, water or biomass), using equipment of maximum cumulative output up to 100 kW.

One of the key aspects for this mechanism is the settlement of the guidelines to implement this system. Below are listed the main steps:

- Contact with the local utility company for obtaining a net metering agreement.
- An authority shall be appointed and entitled of inspect and approve net metering equipments.
- Determine the size system.

Such net metering arrangements may involve separate sets of unidirectional meters for recording the electricity received and supplied to the utility by the power producer, or special bidirectional meters capable of instantaneously recording net power transfers.

This facility would be particularly suitable for incentivizing dispersed small scale RE generation, such as rooftop PV panels, helping optimize their utilization and payback rates and obviating the need for expensive on site storage batteries.

The suited approach for Palestine should be similar than the EU methodology, purchasing electricity at retail prices and selling their own power output at feed in tariff price settled depending on the characteristics of the generation technology and size.

The settlement of a net metering approach similar than United States require an upfront subsidy which, at the end of the day, result at least the price rate established for that technology. This type of net metering is considered simplest that the proposed approach [15].

2.4 Renewable Energy Policy in Palestine

2.4.1 The Palestinian Solar Initiative (PSI)

The first phase will include an unprecedented initiative to spread the concepts of solar energy which is called the Palestinian Solar Initiative (PSI). This initiative consists of three phases over a period of three years from the mid-2012 until mid-2015. This initiative aims to set up small businesses with a capacity up to 5 kW for each project to be installed on the roofs of homes to achieve 1/2 MW from the 100 homes in first half and expand the project up to generate one and a half MW during the following year. In the last year of the project it will generate 3 MW extra to reach a total of 5 MW at the end of three years. Nearly 1,000 homes, distributed 30%, 40% and 30% in northern, central, and southern West Bank, respectively, in addition to 400 homes in the Gaza Strip when it is possible.

Every citizen shall install this system in his home will attain a preferable electricity tariff produced from solar cells [15].

2.4.2 Feed in Tariff for the Palestinian Solar Initiative

The concept of the Palestinian solar Initiative has been drafted as part of the renewable energy strategy for PEA and PERC.

The initiative aims to achieve a 5 MW of solar energy renewable by 2015, through the installation of solar cells on the roofs of 1000 houses throughout the West Bank. And it will be distribute 5 MW of renewable solar energy in different regions of the West Bank according the following table:

Table 2.1- PSI geographic distribution

MW	Location
1.5	North WB
2	Center WB
1.5	South WB

The reasons behind the Palestinian solar initiative are as follows:

- Increase technology awareness
- Attaining international support especially from the communities that are interested in renewable energy
- To encourage the Palestinians on the use of renewable energy technologies
- reduce carbon dioxide emission in Palestine
- Political benefits, to get independence from the Israeli power sources
- Increase the knowledge of the Palestinians in the field of renewable energy [15].

The PSI is supported by financial incentives that facilitate the initiative and shorten the pay-back period by more than one half.

- The Palestinian solar power initiative will be supported by subsidies and rebates that aim at encouraging people to install PV panels on their rooftops.
- Through the PSI, PENRA aims at shortening the pay-back period by more than one half for people installing PV panels. This means that the average 20 to 25-year pay-back period of regular PV installations will be reduced to around seven to eight years.
- Two kinds of subsidies were set in place to support the PSI; rebates and feed-in tariffs (FIT). The table below depicts the rebates and FIT's that are planned for the period between 2012 and 2014.
- The PSI will be subsidized by a 47% subsidy (approximately USD 7.5m) and the participants will contribute the remaining 53% (approximately USD 8.5m).
- It's worth noting that the planned rollout of the PSI is 100 households in the first year (2012), 300 households in the second year and 600 in the third year. The expected PV production within the rollout is 750 MWh in 2012 going up to 7500 MWh in 2014 as the rollout period ends [15].

Table 2.2- PSI First Three Year Rollout Plan

Year	MW	Cumulative MW	Household Rollout	Cumulative Households	PV Production MWh	Rebate (USD in 000's)
2012	0.5	0.5	100	100	750	750
2013	1.5	2	300	400	3,000	2,250
2014	3	5	600	1000	7,500	4,500
Total	5		1000		11,250	7,500

Chapter Three

Design of PV On-Grid Systems

3.1 Selection the Capacity of PV Modules

The PV generator is composed by the total photovoltaic panels responsible of generating electricity by transforming solar energy. Opposite to off grid applications were dimensioning must fit the requirements of energy consumption of a specific village, community or even a single house, On ground PV installations are supposed to produce as much energy as possible, since the goal is to sell energy to the grid and make profit with it. The only or the most limiting factor of plant size is the amount of money that the project developer wants to invest. Large photovoltaic installations as a consequence have a wide range of kWp of power, typically starting from few kWp such as 50 kWp, up to 97 MW (biggest PV plant constructed). Unlike off grid installations, On ground PV installations need big areas of terrain being this another typical constraint.

The PV generator part of these installations represents the main component while considering the amount of material needed and as a consequence, the highest cost. Since the feasibility of the project will depend on the amount of energy sold to the grid, and this to the electricity that the PV generator is capable to produce, it is important to take into account some basic considerations during the projection of it [16]:

- **Shadows**

Photovoltaic panels decrease their productivity if they have a partial or total shadow over them to the level that depending on the model of the panel, it can just not produce any energy. Solar panels in a generation park are divided in groups of several rows working together. Hence, the fact that one or more panels do not work because of shadowing over them (or any other reason), affects the overall performance of the group and even the generator park in terms of energy produced instantly. Shadows usually are produced either by external elements of the generator park (these can be from some elements like trees which are possible to modify, to other like buildings or mountains), or by internal elements (usually the panels itself makes shadows over other nearby ones). In some cases we will be able to modify the elements that can produce permanents shadows over the generating solar system (such as trees), other cases help determine the area where the generator park is placed (such as mountains or buildings), and other affect directly the design of the generator park itself (shadows between panels). Whichever the case, shadows are an important factor to consider and avoid since it affects directly the performance of the installation.

- **Land**

Since PV on-grid installations can be really big installations, it may need a considerable amount of land, so sometimes it can also be a limiting factor or at least condition the site of the installation. While evaluating the approximate amount of land needed, it can be taken as a reference that only considering the surface of the panels, for 1 kWp of power around 6-7 m^2 are required. However, as mentioned it is important to consider the shadows that panels can produce to each other, the ratio commonly used in order to avoid shadows can increase project size to 15 to 20 m^2 for 1 kWp of power. These ratios are given as a valid reference for a pre-design.

Configuration

PV Large installations can vary significantly in size. This means that different configuration strategies in terms of wiring the panels are needed.

Solar panels especially in medium-big installations are divided in several arrays that work together. Each array (which might be composed of several strings of panels from a generating park), is connected to an inverter. The number of arrays and the number of panels that conforms each array depends on the characteristics of each installation and the characteristics of the inverters used.

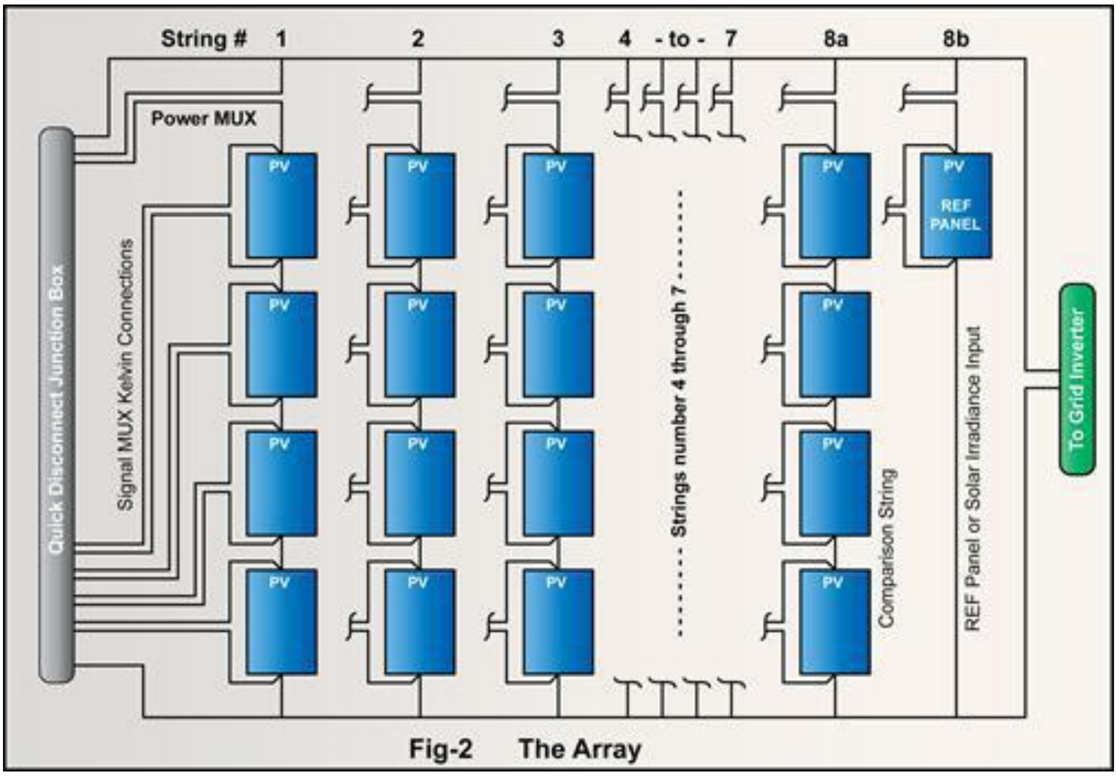

Figure (3.1): Array of PV panels divided in strings

Dividing the panels into different arrays gives the installation a better reliability (if there is a problem with one inverter the other ones can still continue generating energy) and design (if a single inverter can hold a limited number of panels depending of the voltage and current produced by the group). However, usually this configuration is recommended, but it makes the project more expensive because more equipment is needed.

For powers above 50 kW three-phase inverters are used.

- **Technology**

Different technologies exist nowadays depending on how the panel is manufactured and that affect both, the performance and the final price of it. The most common technologies while considering On ground PV installations are mono-crystalline, poly-crystalline and thin-film, having the first a slightly higher performance than the second and third one but also being more expensive. The final decision will depend on the criteria of the engineering team.

More than the technology the tolerance percentage that the modules have over their peak power capacity designed by the manufacturer should also be considered.

Other aspects to keep in mind while selecting solar panels are the following:

- ✓ Codes
- ✓ Resistance to weather conditions
- ✓ Electrical connection box [16]

- **Distance to grid**

On grid installations obviously need to be connected to the grid in order to feed the generated electricity. Sometimes and especially in areas not highly electrified, the nearest grid point of connection can be far from the emplacement of the generation park. This is important because of two main reasons:

- ❖ Having a long distance to the grid will increase dramatically the final cost of the project (prices of medium voltage grid extension in the Distributed PV section are highlighted).
- ❖ Energy transport always is associated with energy losses. This means that for bigger generating parks the technical energy transportation losses will have to be compensated, again increasing the final cost of the project [16].

Orientation

While considering the PV generator park configuration, it is important to determine the panels' orientation, since this also affects directly the final performance of the park and emplacement configuration. Panels obtain a better performance while being orientated directly to the south for installations at the northern hemisphere and to the north for installations at the southern hemisphere. Usually there is a relative tolerance of about ±10 degrees.

Emplacement

Medium to big size installations must be placed on the ground, however, smaller size installations can also be placed over the roofs (usually on industrial buildings, supermarkets, farm building, etc.). The decision of placing the installation on the ground or over a roof depends firstly on the availability of each case and the characteristics of each installation and secondly on the regulation laws of a particular country.

Performance

PV panels have different performance in function of the radiation and temperature, among other factors. These are not really factors that determine a configuration or emplacement of any installation, since such do not vary much inside a country itself especially if it is a small one. However, these factors are important when designing the installation in particular weather conditions [16].

Figure 3.2 shows the effects of irradiation (top) and temperature (bottom) to the performance of PV cells.

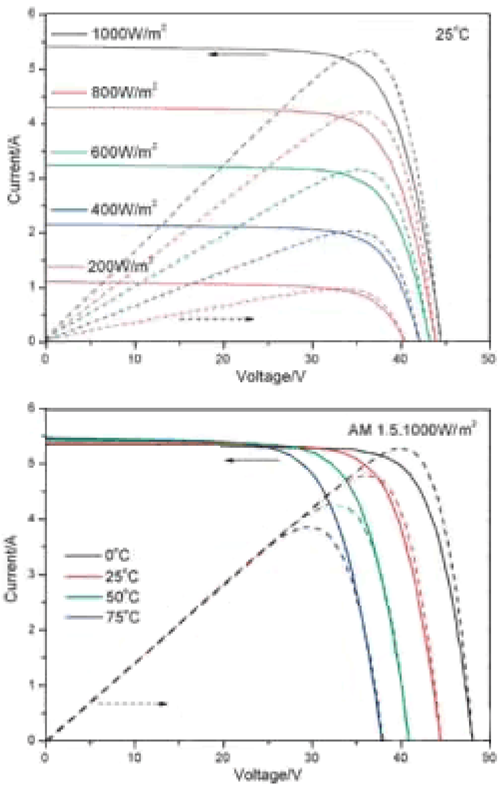

Figure (3.2): Irradiation and temperature influence to PV cells performance

3.2 Selection of Grid Tie Inverters

The inverter is responsible of transforming electricity from DC to AC. It must adapt the electricity to the needed characteristics in order to be injected to the grid: 230/400 V pure sine wave with a 50 Hz frequency.

The inverter is also responsible of monitoring the grid for anti-islanding protection, which in such case the inverter should disconnect the PV system from the grid **[17]**.

Islanding operation mode will be performed when Supply and/or Energize the PV power to loads and/or grid (transmission/distribution lines) under the following condition:

- ❖ A part of grid is disconnected from the ordinary utility power sources.
- ❖ The part of grid is energized by the PV power only.
- ❖ The loads connected with the said grid is supplied the PV power only.

Main characteristics of common inverters are the following ones:

- Self-commutated
- Provided with automatic maximum power point tracking (MPPT) system of the photovoltaic farm
- Anti-islanding protection and automatic connection and disconnection
- Galvanic isolation between the DC and AC inverter’s circuits
- Protections against shorts in AC
- Inverter’s manual starting/stopping control
- Performance over 90% when working over 25% of load

- Power factor over 0.97 when working over 25% of load
- Auto consumption in night mode below 0.5 W
- Temperatures range between -15 and +45 ºC
- Environmental humidity range between 0 to 90%
- Internal measurement of impedance of the grid deactivated

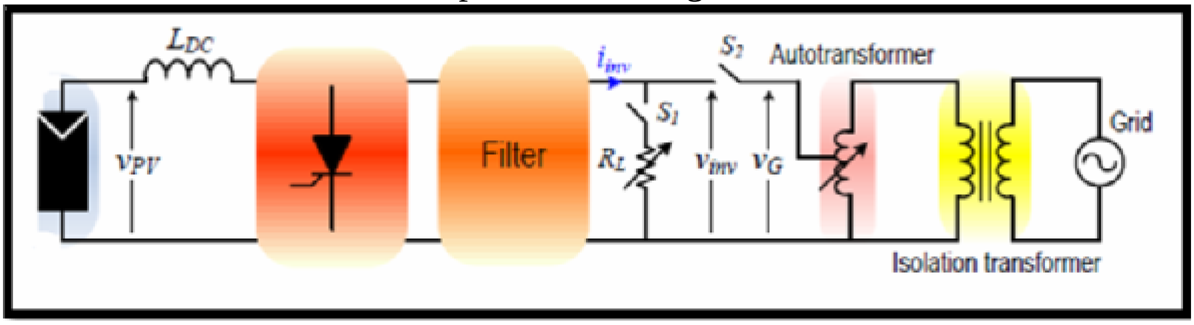

Figure (3.3): Grid tie inverter

The selection of the inverter for the installation will depend on:

- the energy output of the array
- the matching of the allowable inverter string configurations with the size of the array in kW and the size of the individual modules within that array
- whether the system will have one central inverter or multiple (smaller) inverters [17].

3.2.1 Multiple Inverters

- If the array is spread over a number of rooves that have different orientations and/or tilt angles then the maximum power points and output currents will vary. If economic, installing a separate inverter for each section of the array which has the same orientation and angle will maximize the output the total array.

This could also be achieved by using an inverter with multiple maximum power point trackers (MPPTs).

- Multiple inverters allow a portion of the system to continue to operate even if one inverter fails.
- Multiple inverters allow the system to be modular, so that increasing the system involves adding a predetermined number of modules with one inverter.
- Multiple inverters better balance phases in accordance with local utility requirements.

The potential disadvantage of multiple inverters is that in general, the cost of a number of inverters with lower power ratings is generally more expensive [17].

3.2.2 Inverter Sizing

Inverters currently available are typically rated for:

- maximum DC input power i.e. the size of the array in peak watts
- maximum DC input current
- maximum specified output power i.e. the AC power they can provide to the grid.

The maximum power of the array is calculated using the following formula:

Array Peak Power = Number of modules in the array × the rated maximum power (P_{mp}) of the selected module at STC.

The designer shall follow the manufacturer's recommendation when matching the peak power rating of the array to that of the inverter.

Many manufacturers provide the maximum rating of a solar array in peak power for a specific size inverter. Accredited designers shall follow the recommendations of the manufacturer.

If the manufacturer does not provide recommendations then the designer shall match the array to the inverter allowing for the de-rating of the /array.

The typical PV array output in watts is de-rated due to:

- ❖ manufacturers tolerance of the modules
- ❖ dirt and temperature [17].

Inverter with crystalline modules

Based on figures of:

- ✓ 0.97 for manufacture
- ✓ 0.95 for dirt
- ✓ 0.825 for temperature (based on ambient of 35°C).

The de-rating of the array is: $0.97 \times 0.95 \times 0.825 = 0.76$

Inverter with thin film modules

The temperature effect on thin film modules is less than that on crystalline modules. Assuming the temperature coefficient is only 0.1% then the temperature de-rating at ambient temperature of 35°C is 0.965

Based on figures of:

- ✓ 0.97 for manufacturer
- ✓ 0.95 for dirt
- ✓ 0.965 for temperature (based on ambient of 35°C).

The de-rating of the array is: $0.97 \times 0.95 \times 0.965 = 0.889$

3.3 Grid Connection

Energy produced by the photovoltaic generator, once it is transformed from DC to AC must be adapted to the voltage of the grid where it is going to be injected. On-grid photovoltaic plants are usually connected to medium voltage grids due to the capacity of the grid (usually it will be able to absorb all the energy produced by the PV generator) and the fact that normally these kinds of installations are far from urban centers. As a consequence the closest lines are in medium voltage. In the case of small on-grid installations however, which are more flexible in terms of emplacement and the grid probably arrives at the same place where the installation is placed, would be able to connect to the low voltage grid (these could be for example the case of roof photovoltaic installations). In both cases it is important to ensure that the grid offers the necessary stability (frequency, voltage) and capacity (cable section) to support the injection of all the energy produced by the photovoltaic plant.

In a common On ground PV installation configuration it is necessary to transform and transport the generated energy to the adequate point where the distribution electric company of the area can absorb it.

The transformation center will be placed closed to the photovoltaic installation in order to minimize the technical losses. The transformation center will keep the transformers and all the security equipment necessary to connect to the medium voltage grid.

Usually the transformation center is built with pre-manufactured concrete allowing a fast and economic assembly. It is important to consider the necessary ventilation for the transformers to function properly while designing the transformation center and all the security measures that medium voltage installations need according to the local codes.

From the transformation center to the electrical distribution company substation usually aerial grid extension are used, however in some cases buried lines would fit better since they have a lower visual impact and due to the characteristics of the area it could be difficult to extend aerial lines. Moreover if the line needs to go through the photovoltaic panels it could shade them, affecting the energy production.

3.4 Configuration of Monitoring System

Distributed photovoltaic applications analyzed are those suitable for urban areas mainly rooftop photovoltaic installations in buildings (but can also be integrated systems in car parks or in other ways). Building photovoltaic applications analyze the case where all the produced energy is sold to the grid. Typically two scenarios fit the configuration described in this application:

- **Generate energy to sell to the grid.** This is the common feed in tariff scenario where user(s) can sell the produced energy at a fixed price for a guaranteed period established by the government.

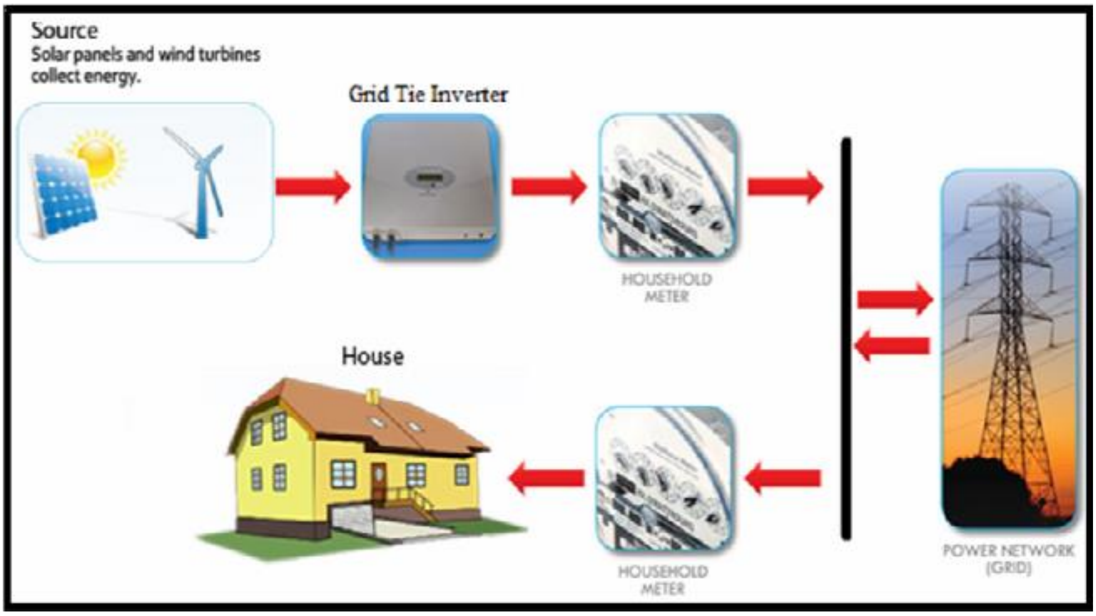

Figure (3.4): Grid tie feed in tariff

- **Net-metering scenario.** In this case the user would consume the produced energy, selling to the grid only the surplus.

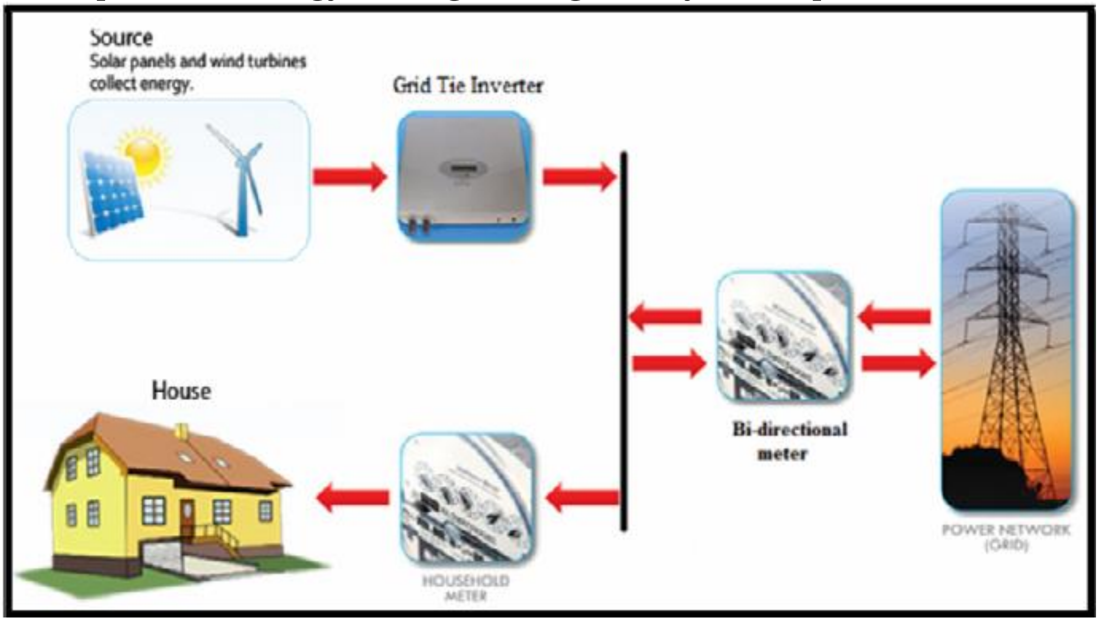

Figure (3.5): Grid tie net metering tariff

Distributed PV installations characteristics are similar to Large Grid PV power plants differing obviously in size. As well a bi-directional meter is required to measure electricity taken and being fed into the grid.

Chapter Four

Modeling On-Grid PV Systems

4.1 Configuration of Grid Tie PV System

The configuration of grid tie PV system under study is shown in figure (4.1).

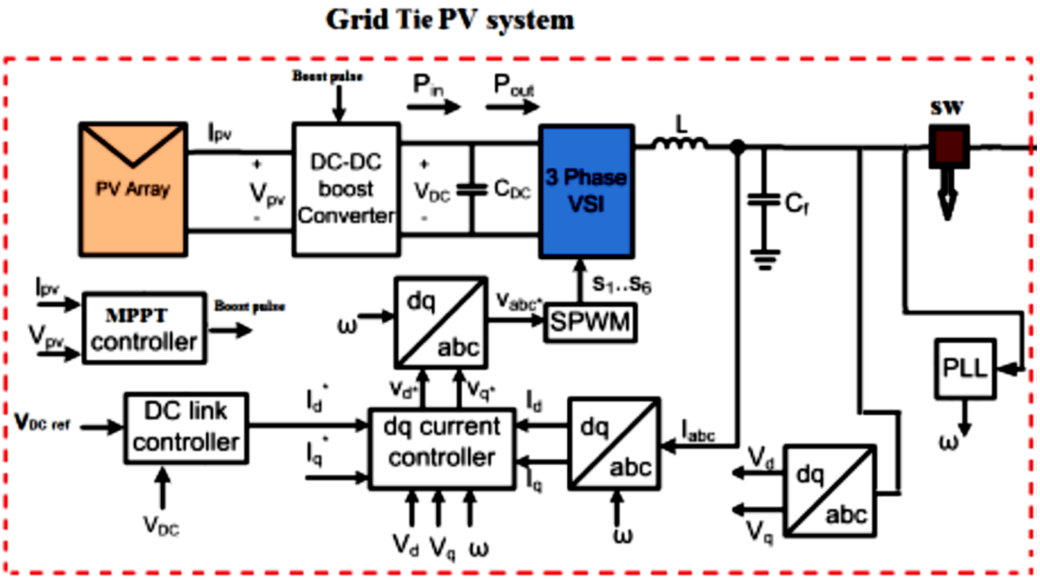

Figure (4.1): Simulink model of PV system [18].

Figure (4.1) shows the Simulink model of grid tie PV system which consists of photovoltaic Array, DC-DC Boost converter, maximum power point tracking controller, three phase voltage source inverter, system controller and LC filter.

For grid tie PV system the output of the PV array is connected to DC-DC boost converter that is used to perform MPPT functions and increase the array terminal voltage to a higher value so it can be interfaced to the distribution system grid.

A DC link capacitor is used after the DC converter and acts as a temporary power storage device to provide the voltage source inverter with a steady flow of power. The capacitor’s voltage is regulated using a DC link controller that balances input and output powers of the capacitor.

The voltage source inverter is controlled in the rotating *dq* frame to inject a controllable three phase AC current into the grid. To achieve unity power factor operation, current is injected in phase with the grid voltage. A phase locked loop (PLL) is used to lock on the grid frequency and provide a stable reference synchronization signal for the inverter control system, which works to minimize the error between the actual injected current and the reference current obtained from the DC link controller.

RL load are connected to the grid to simulate some of the loads that are connected to a distribution system network.

An LC low pass filter is connected at the output of the inverter to attenuate high frequency harmonics and prevent them from propagating into the power system grid [18].

4.2 Mathematical Modeling of Photovoltaic Array

The PV uses semiconductor cells (wafers), each of which is basically a large area p-n diode with the junction positioned close to the top surface. PV results in the generation of direct voltage and current from the Sun's (light) rays falling on the cell. To achieve higher voltage and current, multiple cells are used as needed.

The PV cell can be represented by a simple equivalent circuit shown in Figure 4.2. The output current is a function of solar radiation, temperature, wind speed and coefficients that are particular to the cell technology.

The PV current $\mathbf{I_{pv}}$ is a function of the array output voltage V_{pv} (V-I) characteristic of the array) which is given in Figure 4.3 The maximum power output is obtained when the array operates at point M on the V-I characteristic.

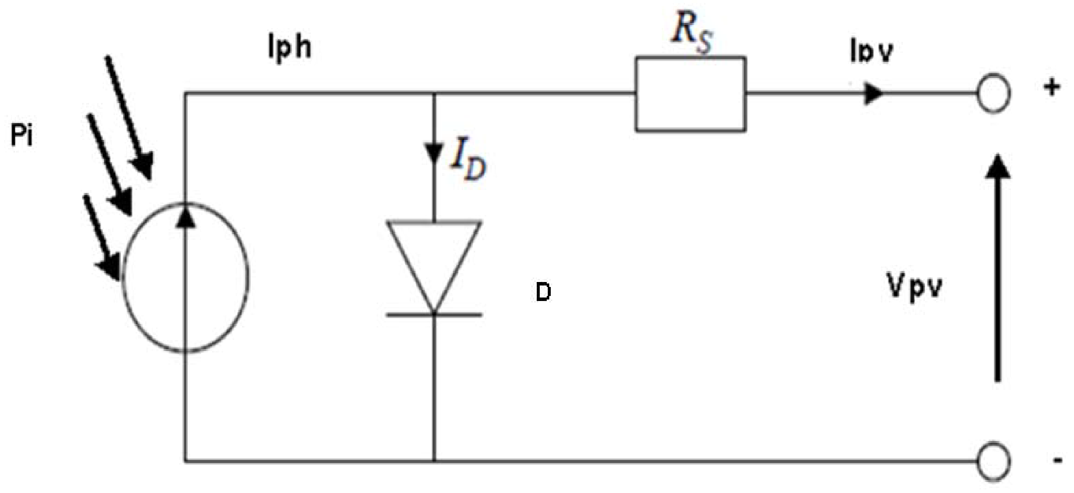

Figure (4. 2): PV cell equivalent circuit (Lorenzo, 1994)

The model contains a current source I_{ph}, one diode and a series resistance Rs, which represents the resistance inside each cell and in the connection between the cells. The net current is the difference between the photocurrent I_{ph} and the normal diode current $\mathbf{I_D}$.

$$I = I_{ph} - I_D = I_{ph} - I_0(\exp\frac{e(V + IR_S)}{mkT_c} - 1) \tag{4.1}$$

where:

m– idealizing factor

k – Boltzmann’s constant ($1.38*10^{-23}$ J/K)

T_c– the absolute temperature of the cell

e – electronic charge ($1.6*10^{-19}$ Cb)

V – the voltage imposed across the cell

I_o – the dark saturation current (strongly depends on temperature)

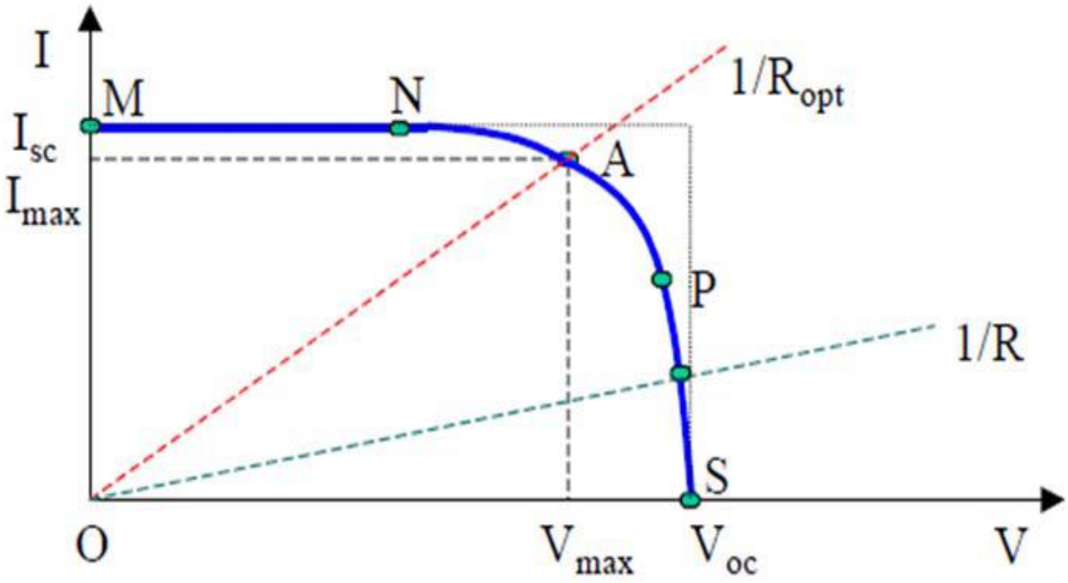

Figure (4.3): A typical I-V, P-V Characteristics of a solar cell

In the above representation of I-V characteristic, a sign convention is used, which takes as positive the current generated by the cell when the sun is shining and a positive voltage is applied on the cell's terminals.

A real solar cell can be characterized by the following fundamental parameters:

A. **<u>Short circuit current</u>:** It is the greatest value of the current generated by a cell. It is produced under short circuit conditions: V = 0

B. **<u>Open circuit voltage</u>** Corresponds to the voltage drop across the diode (p-n junction), when it is traversed by the photocurrent I_{ph} (namely $I_D=I_{ph}$) when the generator current is I = 0. It reflects the voltage of the cell in the night and it can be mathematically expressed as:

$$V_{oc} = \frac{mkT_c}{e} \ln\left(\frac{I_{ph}}{I_0}\right) = V_t \ln\left(\frac{I_{ph}}{I_0}\right) \tag{4.2}$$

where:

V_t - known as thermal voltage and T_c is absolute cell temperature

C. **Maximum power point** Is the operating point A (Vmax, Imax) at which the power dissipated in the resistive load is maximum: $P_{max} = I_{max} * V_{max}$

D. **Maximum efficiency** Is the ratio between the maximum power and the incident light power.

$$\eta = \frac{P_{max}}{P_{in}} = \frac{I_{max} V_{max}}{A\, G_a} \tag{4.3}$$

where G_a is the ambient irradiation and A is the cell area.

E. **Fill factor** is the ratio of the maximum power that can be delivered to the load and the product of I_{sc} and V_{oc}:

$$FF = \frac{P_{max}}{V_{oc} I_{sc}} = \frac{V_{max} I_{max}}{V_{oc} I_{sc}} \tag{4.4}$$

The fill factor is a measure of the real I-V characteristic. Its value is higher than 0.7 for good cells. The fill factor diminishes as the cell temperature is increased.

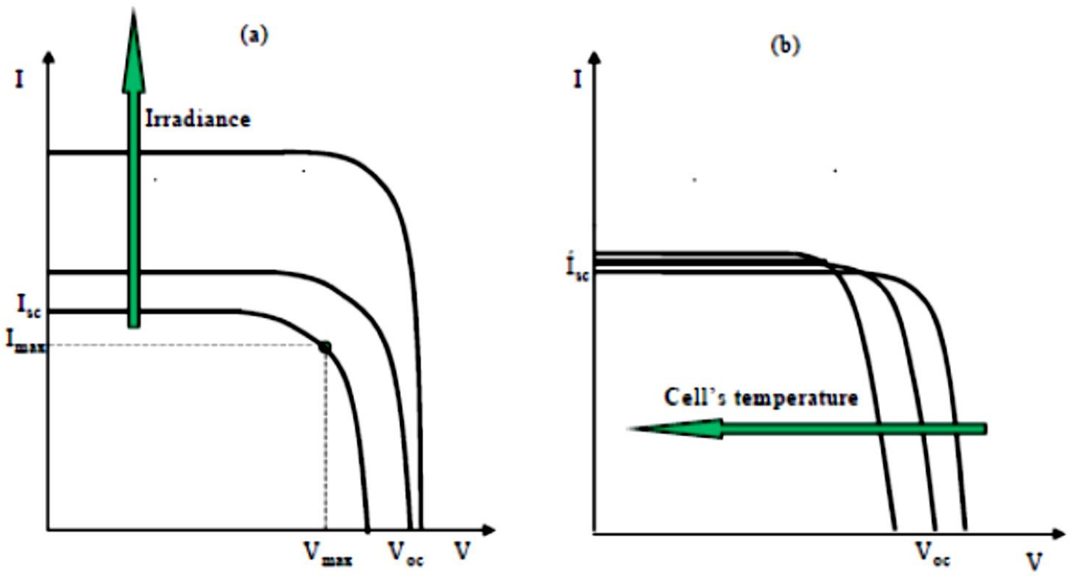

Figure (4.4): Influence of the ambient irradiation on the PV cell – a); and of the cell temperature on the cell characteristics – b).

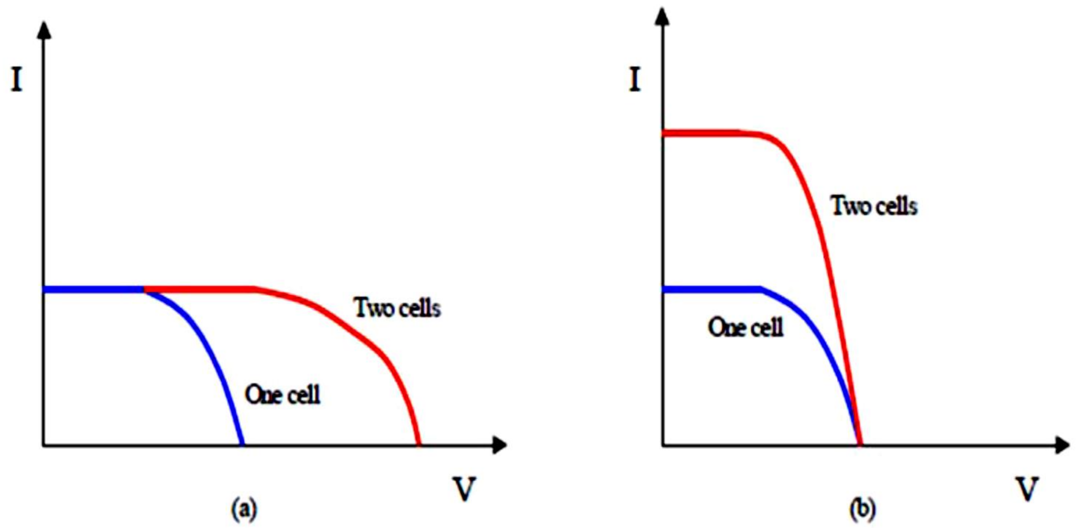

Figure (4.5): Series (a) and parallel (b) connection of identical cells

In current practice, the performance of a module or another PV device is determined by exposing it at known conditions. The module characteristics supplied by the manufacturer are usually determined under special conditions, as for example nominal or standard conditions (Lorenzo, 1994) – see Table below:

Nominal and standard conditions.

Nominal conditions	Standard conditions
Irradiation: $G_{a,ref}$=800 W/m^2	Irradiation: $G_{a,0}$=1000 W/m^2
Ambient temperature: $T_{a,ref} = 20^\circ C$	Cell temperature: $T_0^C = 25^\circ C$
Wind speed: 1 m/s	

In Figure 4.6 the series resistance R_s represents the internal losses due to the current flow, whereas the shunt resistance R_{sh} corresponds to the leakage current to the ground and it is normally ignored. For an ideal PV cell (no series loss and no leakage to ground, i.e., $R_S = 0$ and $R_{SH} = \infty$, respectively). The equivalent circuit of a PV module, which consists of a combination of series and parallel-connected cells are the same.

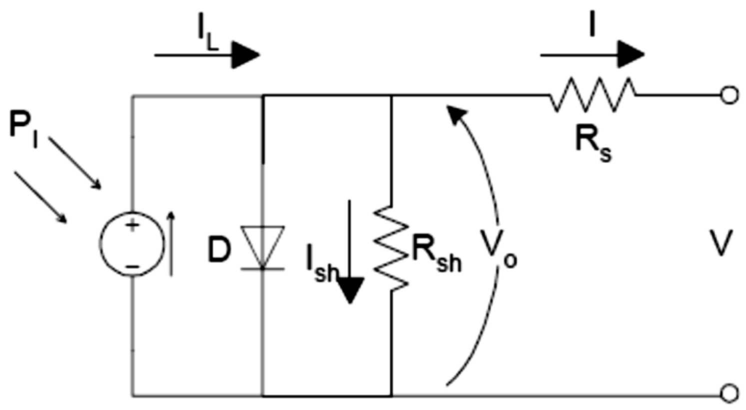

Figure (4.6): PV module Equivalent Circuit

The governing equations of the equivalent circuit are:

$$V = V_0 - R_s I \tag{4.5}$$

$$I = I_L - I_D(e^{\frac{qV_0}{AkT}} - 1) - I_{sh} \tag{4.6}$$

$$I_{sh} = \frac{V_0}{R_{sh}} \tag{4.7}$$

$$I_L = I_{sc1}\left(\frac{P_I}{1000}\right) \tag{4.8}$$

Where:

V, I – output voltage and current

q – electron charge ($1.6*10^{-19}$ Cb)

k – Boltzmann constant ($1.38*10^{-23}$ J/K)

T – temperature in K

A – quality factor (constant)

ID – reverse saturation current of the diode

I_L – photocurrent, dependent on T

P_I – insolation level in W/m^2

I_{sc1} – short circuit current at 1000 W/m^2 solar radiation

The PV cell characteristics also depend on external factors including temperature and solar irradiation level. To incorporate these effects into the model, two additional relations are used.

Output current varies with solar irradiation and temperature through [16]:

$$I = \left(I_n + K_I \Delta T\right)\frac{G}{G_n} \tag{4.9}$$

Where

I_n**:** is the nominal PV cell output current (at 25 °C and 1000 W/m^2).

K_I**:** is the current/temperature variation coefficient (A/°C).

ΔT: is the variation from the nominal temperature (25°C).

G_n: is the nominal solar irradiation (1000 W/m^2).

The value of K_I is relatively small and this makes the cell output current linearly dependent on solar radiation level more than temperature.

Temperature, however, has a strong effect on the reverse saturation current, I_0 in equation

$$I_0 = \frac{I_{sc,n} + K_I \Delta T}{\exp(q(V_{oc.n} + K_V \Delta T) / akT) - 1} \qquad (4.10)$$

Where

$I_{sc,\,n}$**:** is the nominal short circuit current of the PV cell.

$V_{oc,\,n}$**:** is the nominal open circuit voltage.

K_I and K_V**:** are the current and voltage temperature variation coefficients, in A/°C and V/°C, respectively.

A PV module is the result of connecting several PV cells in series to order to increase the output voltage. The characteristic has the same shape except for changes in the magnitude of the open circuit voltage.

The PV array is composed of several interconnected photovoltaic modules. The modeling process is the same as the PV module from the PV cells. The same parameters from the datasheet are used. To obtain the required power, voltage and current, the PV modules are associated in series and parallel the number of modules connected in series and connected in parallel must be calculated the number of modules modifies the value of resistance in parallel and resistance in series. The value of equivalent resistance series and resistance parallel of the PV array are:

$$R_{s,array} = \frac{R_{s,module} \cdot N_{ss}}{N_{pp}} \qquad (4.11)$$

$$R_{p,array} = \frac{R_{p,module} \cdot N_{ss}}{N_{pp}} \qquad (4.12)$$

N_{ss} - is the total quantity of modules within the series.

N_{pp} - is the amount of modules in parallel.

After extending the relation current voltage of the PV modules to a PV array, the new relation of current voltage of the PV array is calculated in by [20].

$$I = I_{ph} N_{pp} - I_0 N_{pp} \left[exp\left(\frac{V + R_s \left(\frac{N_{ss}}{N_{pp}} \right) I}{V_t a N_{ss}} \right) - 1 \right] - \frac{V + R_s \left(\frac{N_{ss}}{N_{pp}} \right) I}{R_p \left(\frac{N_{ss}}{N_{pp}} \right)} \qquad (4.13)$$

Where

I_0, I_{ph}, V_t are the same parameters used for a PV modules.

This equation is valid for any given array formed with identical modules.

The photovoltaic array will be simulated with this equation. The simulation circuit must include the number modules series and parallel. Figure (4.7) shows the circuit model of the PV array.

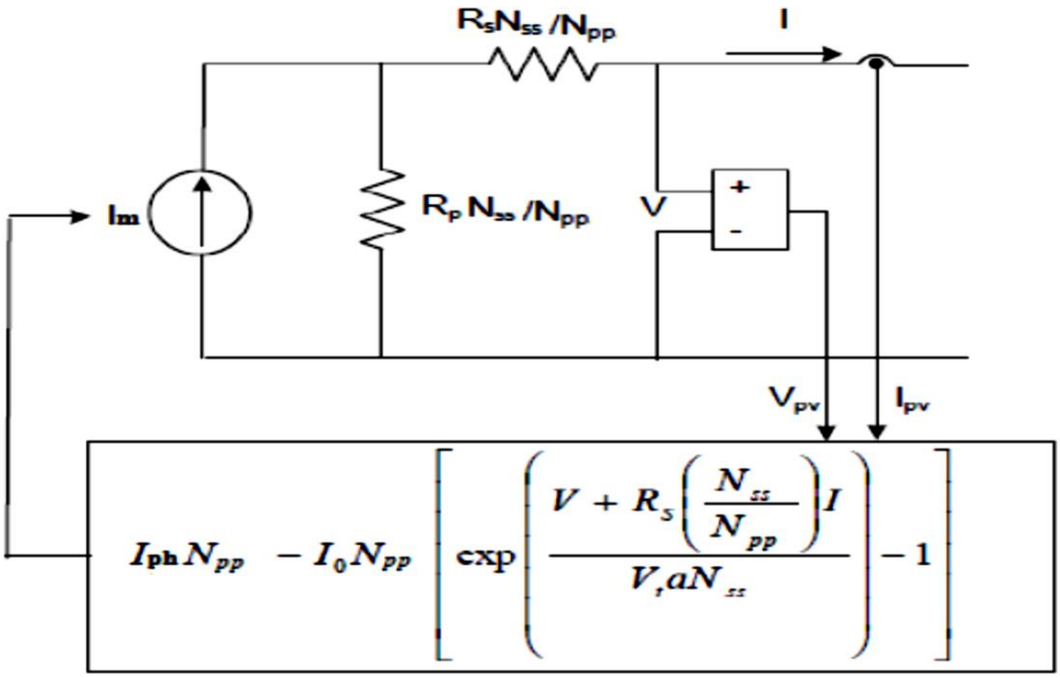

Figure (4.7): Model structure of the photovoltaic array [19]

4.3 Simulink Modeling of the Photovoltaic Array

The PV characteristics from data sheet are used to generate the file necessary for R_s, R_p and other parameters for the maximum power point.

The initial setup is used to obtain the I-V curve characteristics of the PV array and show the maximum power point of the PV. The model of the PV is used with the boost converter to determine the performance of the maximum power point tracker.

The model of the photovoltaic array has been implemented in Simulink as shown in figure (4.8). The temperature and the irradiance are specified. The simulation allows having the curve I-V and P-V characteristics.

The Simulink model uses a current source and the value of the resistance in series and parallel of the PV.

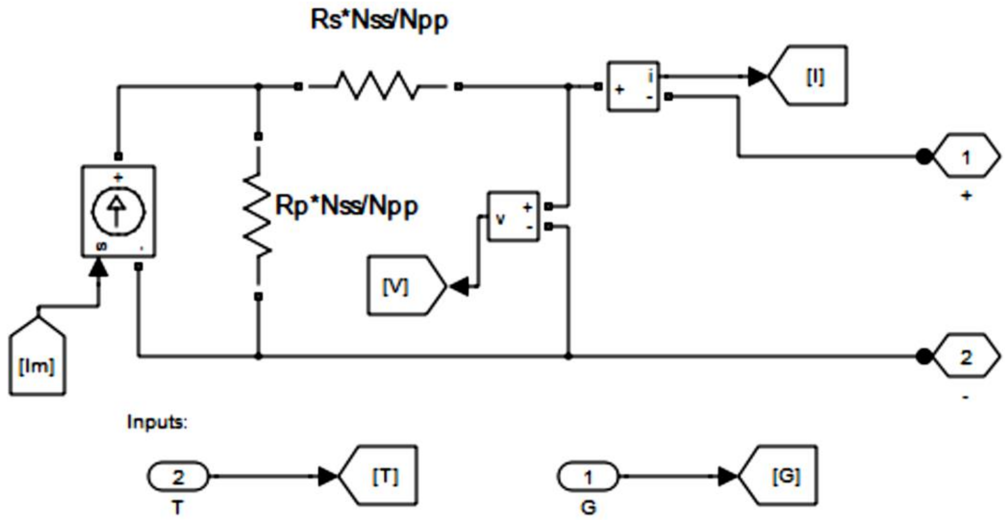

Figure (4.8): Simulation of the PV module

The number of modules in series and parallel are set with N_{ss} and N_{pp}. The I_m result is used for the Simulink block as a current source to obtain the voltage and current delivered from the PV.

Figure (4.9) shows the Simulink model for the reverse current saturation (I_o) at the reference temperature which is given by the equation:

$$I_0 = \frac{I_{sc,n} + K_I \Delta_T}{\exp\left(\frac{V_{oc,n} + K_V \Delta_T}{aV_t}\right) - 1} \tag{4.14}$$

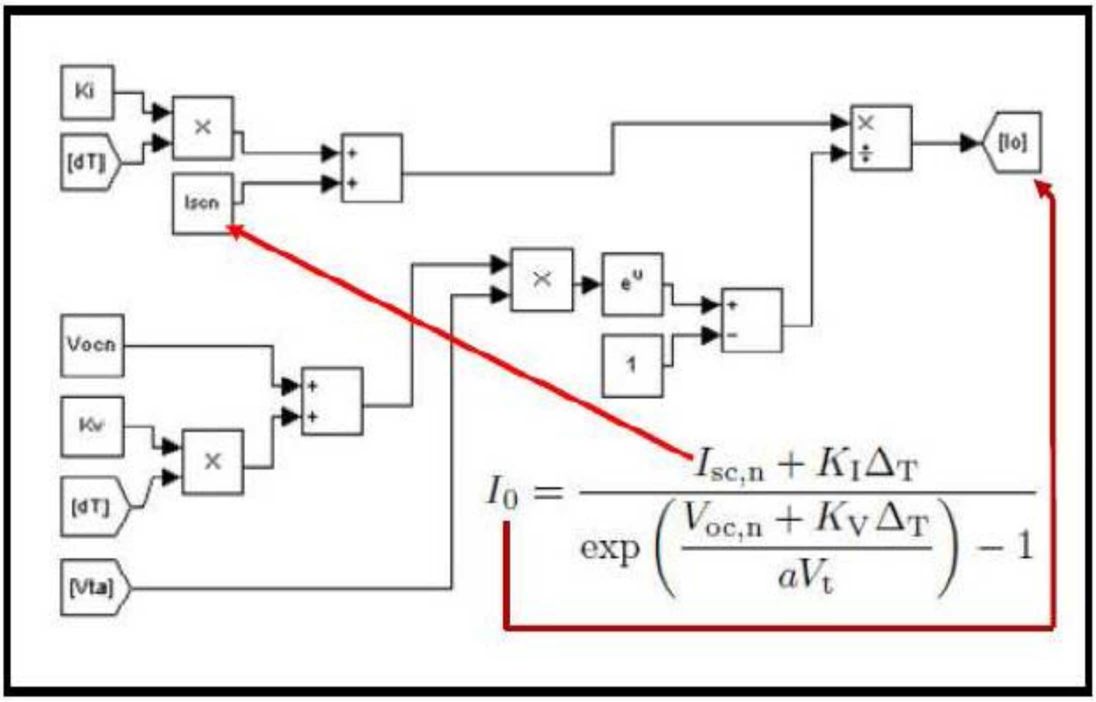

Figure (4.9): Simulink modeling implementation for Io.

Figure (4.10) shows the Simulink model for the light generated current of the photovoltaic cell which depends linearly on the influence of temperature and solar radiation as given by the equation:

$$\mathbf{Iph} = (\mathbf{I}_{\mathbf{ph,n}} + \mathbf{K_I \Delta T})\frac{\mathbf{G}}{\mathbf{Gn}} \tag{4.15}$$

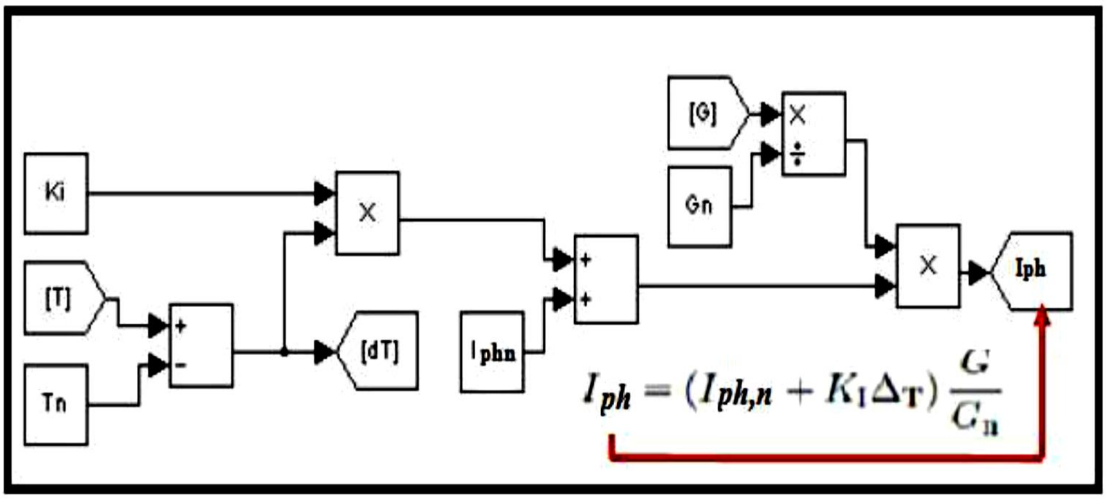

Figure (4.10): Simulink modeling implementation for I_{ph}.

Figure (4.11) shows the Simulink model for the model current I_m which given by the equation:

$$I_m = I_{ph} - I_0 \left[\exp\left(\frac{V + Rs\,I}{Vt\,a} \right) - 1 \right] \tag{4.16}$$

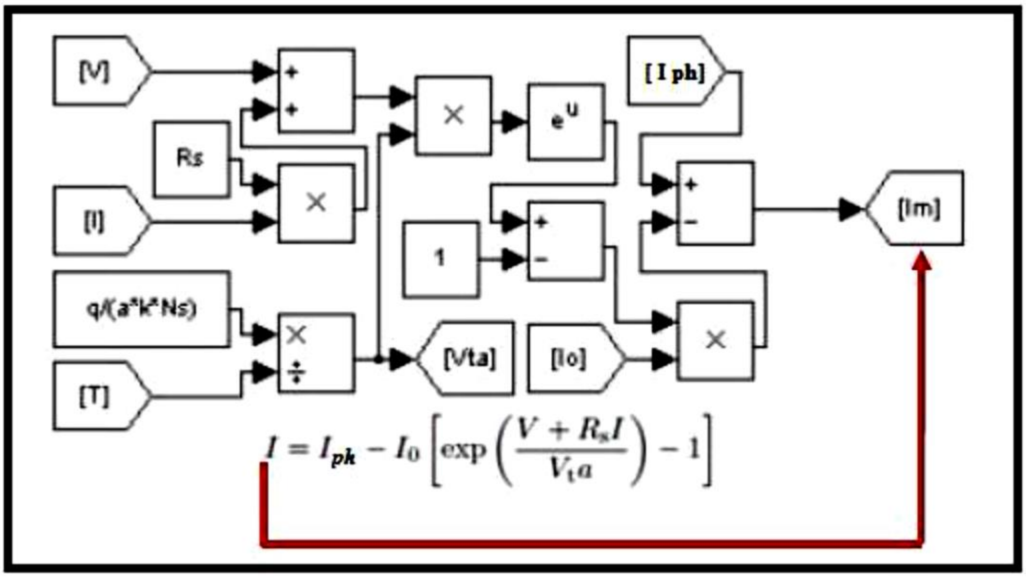

Figure (4.11): Simulink modeling implementation for Im

Figure (4.12) depicts the PV array modeling.

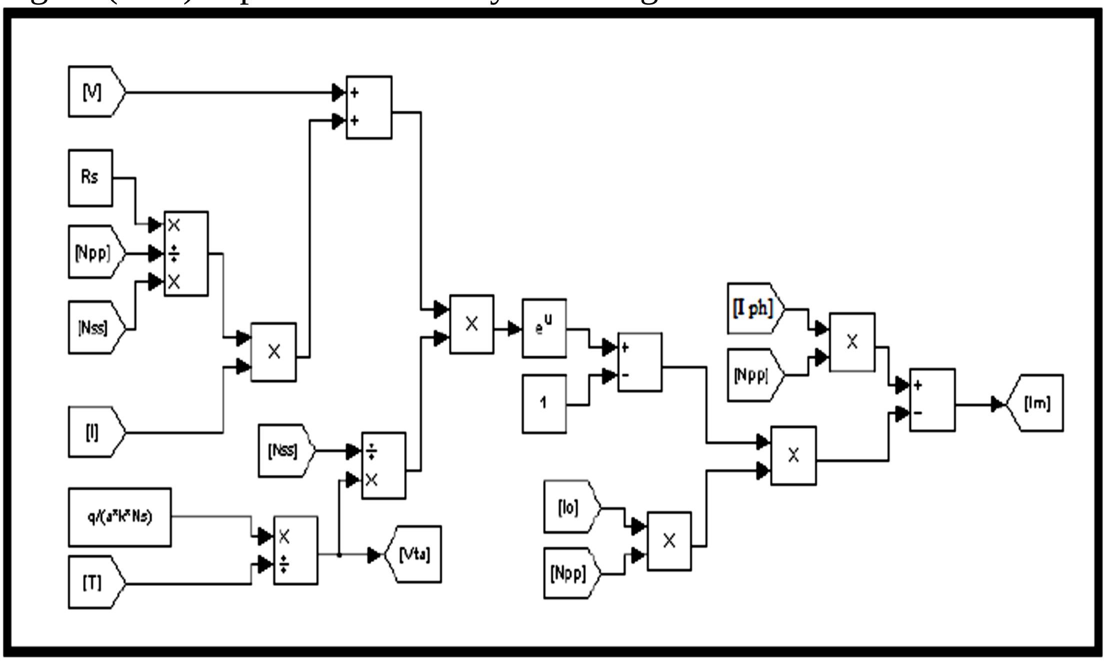

Figure (4.12): PV array modeling.

4.4 Validation of PV Simulink Model

In order to validate the PV model, I substituted the PV model parameters from a real PV module (MSX-50), then PV model simulated under different temperatures and radiations. As a result, I achieved the same curves from the simulation model and from data sheet PV module as shown in figure (4.14) to (4.19).

Table (4.1): Electrical characteristics data of the MSX-50 solar at 25 °C, 1.5AM 1000W/m^{2}taken from the datasheet

Electrical Characteristics	
Maximum Power (Pmax)	50W
Voltage at Pmax (Vmp)	17.1V
Current at Pmax (Imp)	2.92A
Open-circuit voltage (Voc)	21.1V
Short-circuit current (Isc)	3.17A
(K_I)Temperature coefficient of Isc	(0.0032±0.015)%/°C
(K_V) Temperature coefficient of Voc	− (80±10)mV/°C
NOCT	47±2°C

Figure 4.13 depicts Validation of PV Module Model for Different Temperatures.

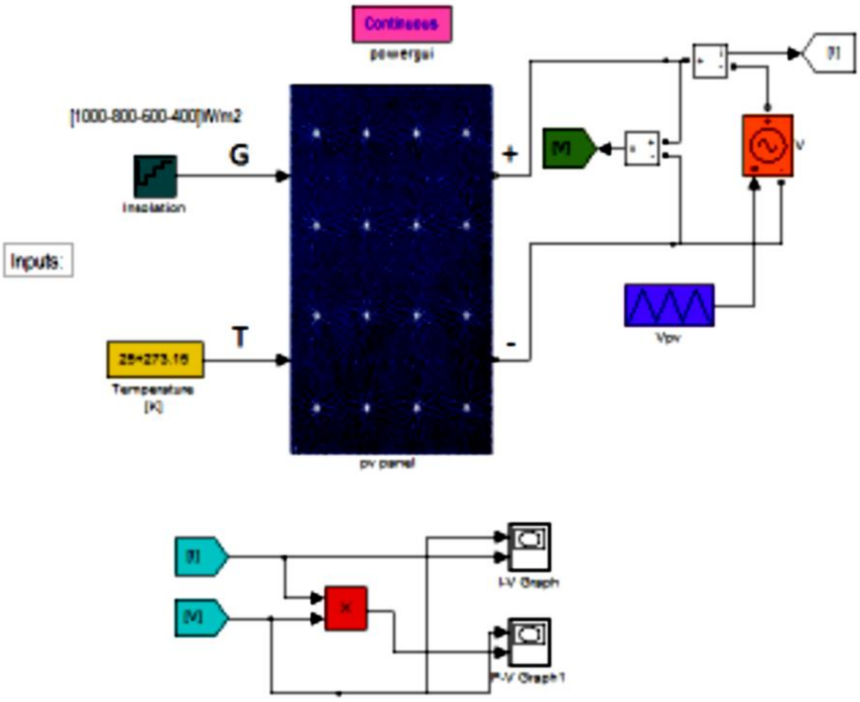

Figure (4.13): PV model simulation at different temperatures.

Figures (4.14), (4.15) show the main effect of temperature on the PV module voltage by simulink and by data sheet, which decreases when the temperature increases.

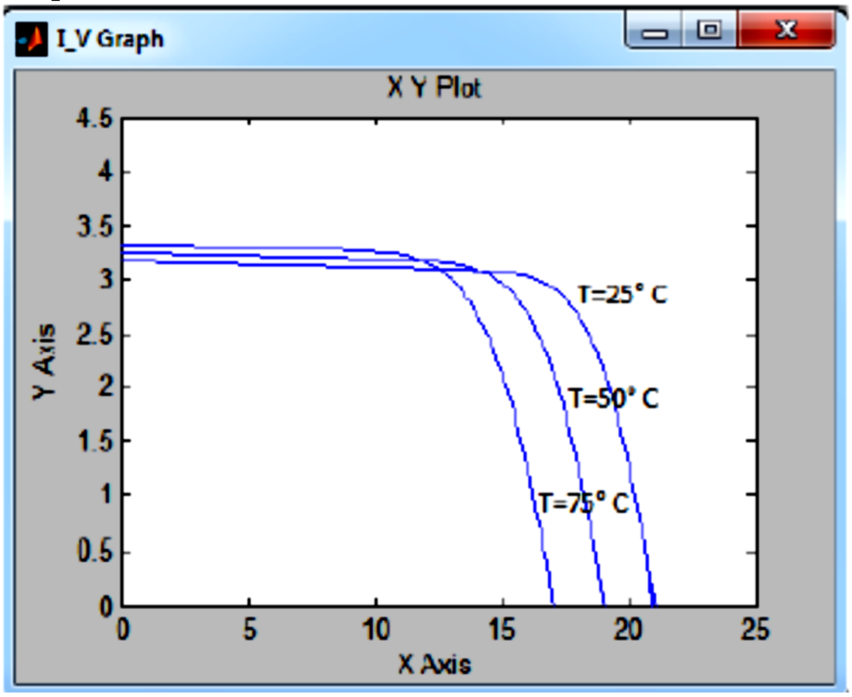

Figure (4.14): Simulink IV characteristic curves for different temperatures.

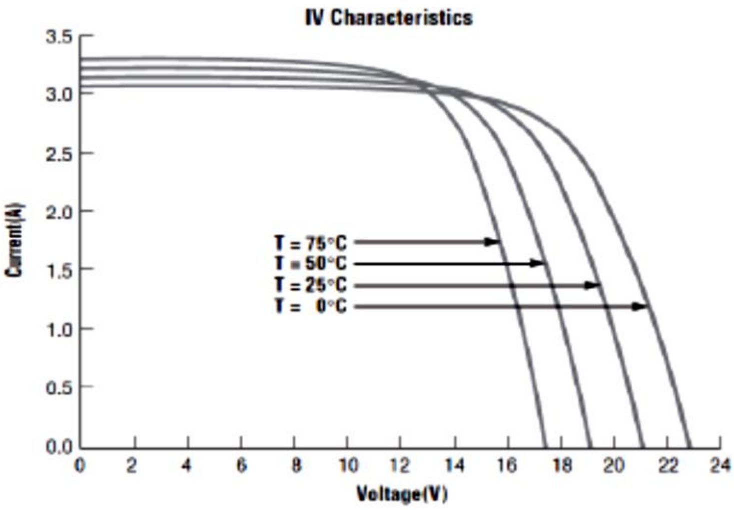

Figure (4.15): Datasheet IV characteristic curves for different temperatures.

Figure 4.16 depicts Validation of PV Module Model for Different radiations.

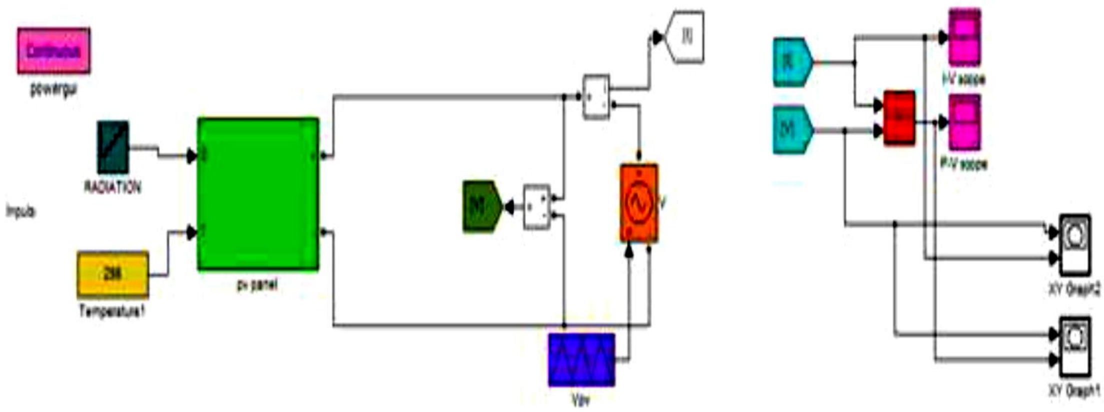

Figure (4.16): PV model simulation at different radiations.

Figures (4.17), (4.18) show the main effect of radiation on the PV module current, which decreases when the radiation decreases.

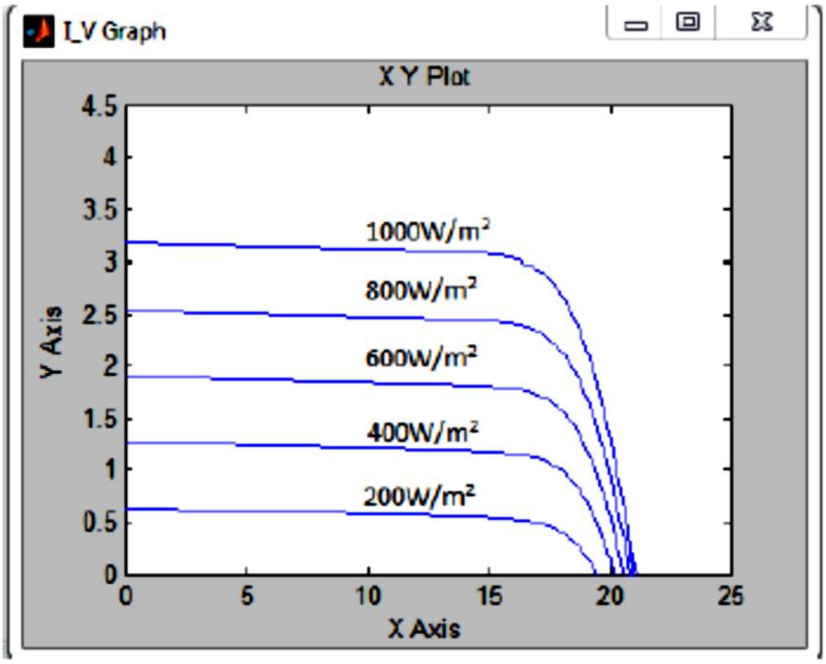

Figure (4.17): Simulink IV characteristic curves for different radiations.

Figure (4.18) shows the effect of temperature on the PV module power, which decreases when the temperature increases.

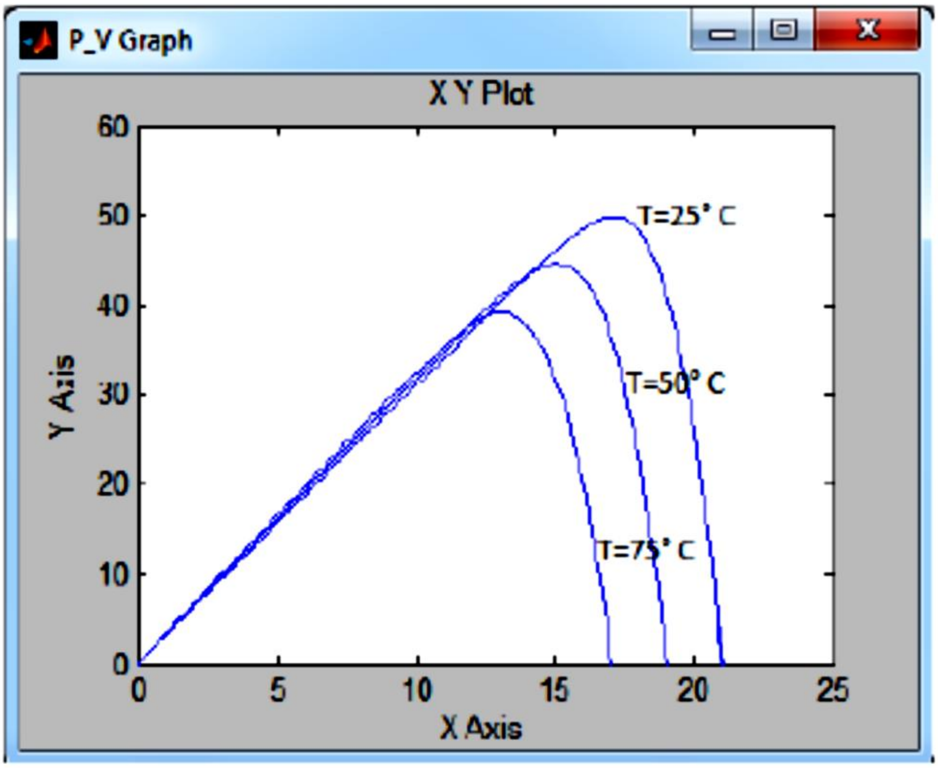

Figure (4.18): Simulink P-V characteristic curves for different temperatures.

Figure (4.19) shows the effect of radiation on the PV module power, which decreases when the radiation decreases.

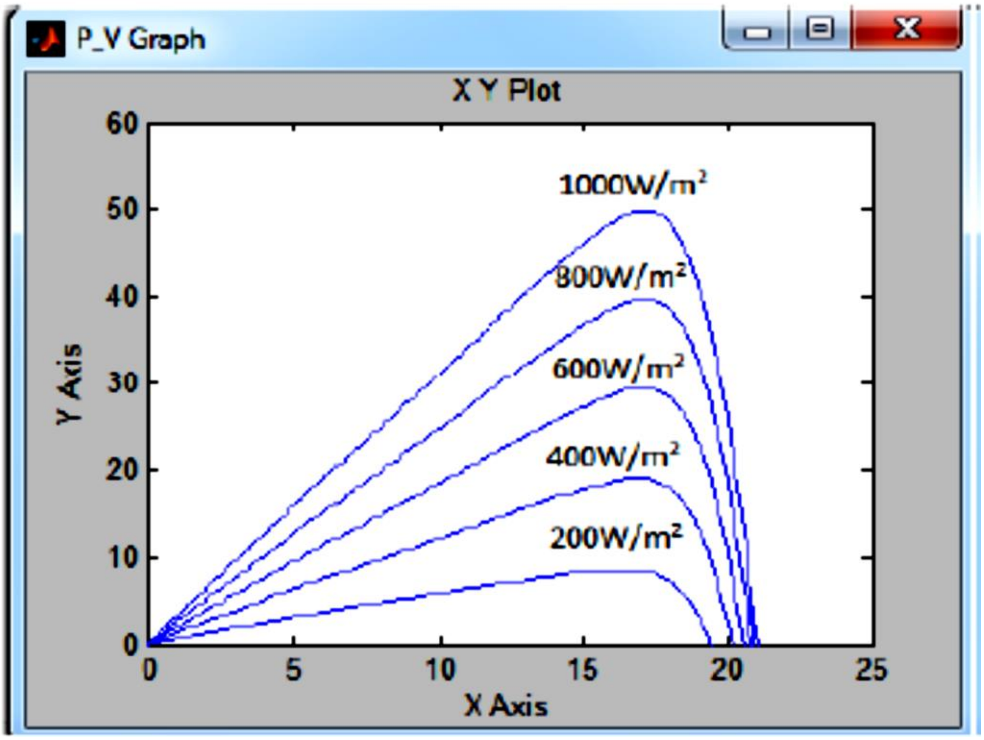

Figure (4.19): Simulink P-V characteristic curves for different radiations.

4.5 Impact of Shading on I-V Characteristic Curve of Photovoltaic Module

Solar PV panel is a power source having non-linear internal resistance. A major challenge in using a PV source containing a number of cells in series is to deal with its non-linear internal resistance. The problem gets all the more complex when the array receives non-uniform insolation. Cells under shade absorb a large amount of electric power generated by cells receiving high insolation and convert it into heat. This heat may damage the low illuminated cells under certain conditions. To relieve the stress on shaded cells, bypass diodes are added across the module.

The bypass diodes' function is to eliminate the hot-spot phenomena which can damage PV cells and even cause fire if the light hitting the surface of the PV cells in a module is not uniform. The bypass diodes are usually placed on sub-strings of the PV module. This configuration eliminates the creation of hot-spots and enables the PV modules to operate with high reliability throughout their lifetime [20].

The destructive effects of hot-spot heating may be circumvented through the use of a bypass diode. A bypass diode is connected in parallel, but with opposite polarity, to a solar cell. Under normal operation, each solar cell will be forward biased and therefore the bypass diode will be reverse biased and will effectively be an open circuit. However, if a solar cell is reverse biased due to the a mismatch in short-circuit current between several series connected cells, then the bypass diode conducts, thereby allowing the current from the good solar cells to flow in the external circuit rather than forward biasing each good cell.

In practice, however, one bypass diode per solar cell is generally too expensive and instead bypass diodes are usually placed across groups of solar cells. Figure-4.20 shows an outline of the bypass diode in a PV system.

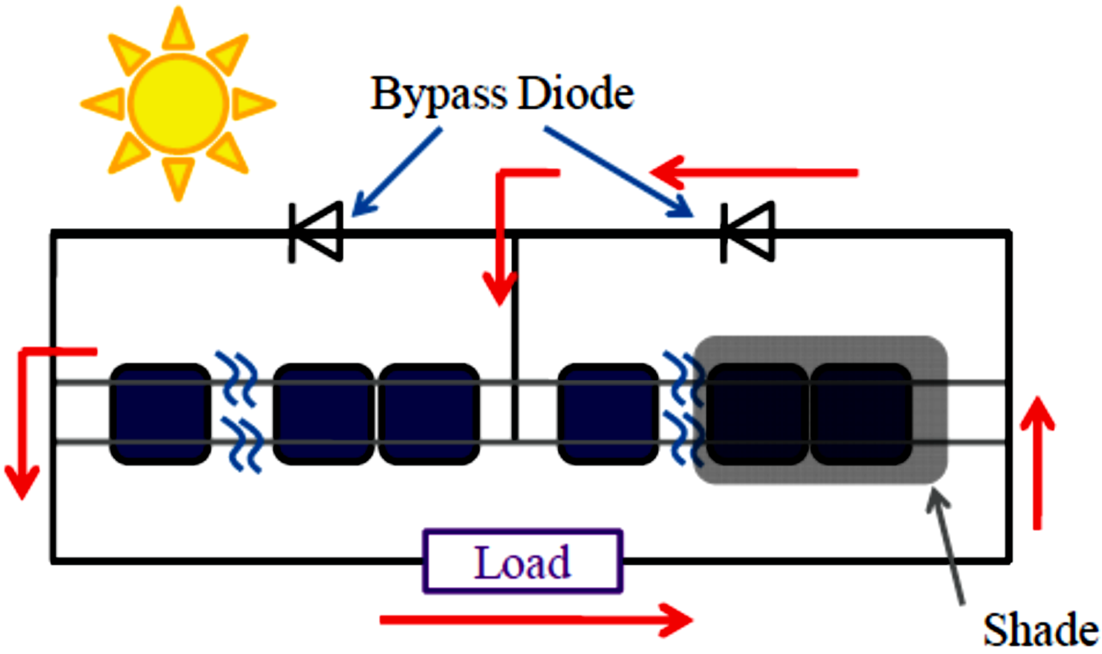

Figure (4.20): PV modules with bypass diodes

Blocking diodes are installed between parallel panel string and/or the entire array and the battery. They prevent current from flowing back into paralleled series strings or arrays that are acting as a power consumer, discharging all of the power produced by the other series strings and/or the power stored in the battery at night when the array is darkened.

When the sun shines, as long as the voltage produced by PV panels is greater than that of the battery, charging will take place. However, in the dark, when no voltage is being produced by the panels, the voltage of the battery would cause a current to flow in the opposite direction through the panels, discharging the battery, if it was not for the blocking diode in the circuit. Blocking diodes will be of benefit in any system using solar panels to charge a battery.

Blocking diodes are usually included in the construction of solar panels so further blocking diodes are not required. Figure-4.21 represents each position of bypass diodes and blocking diodes [20].

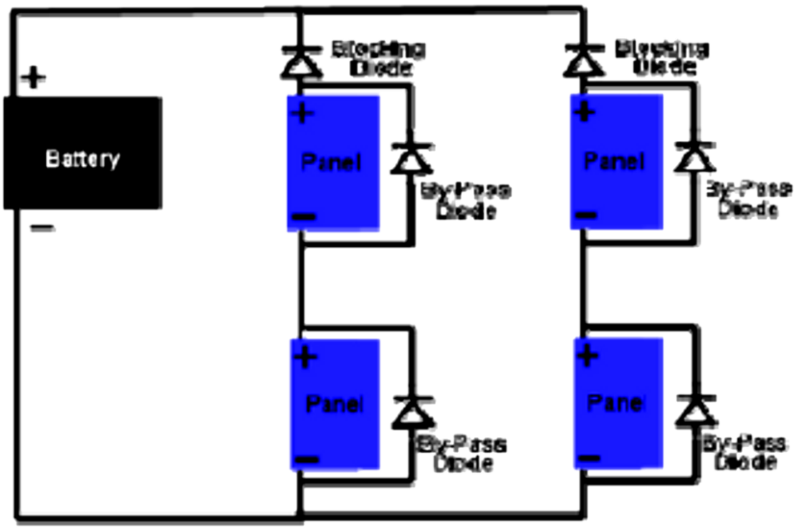

Figure (4.21): Each position of bypass diodes and blocking diodes

In figure (4.22) shows simulink model for two PV modules with series connection at variable irradiance at 1000 W/m^2 and 500 W/m^2 [21].

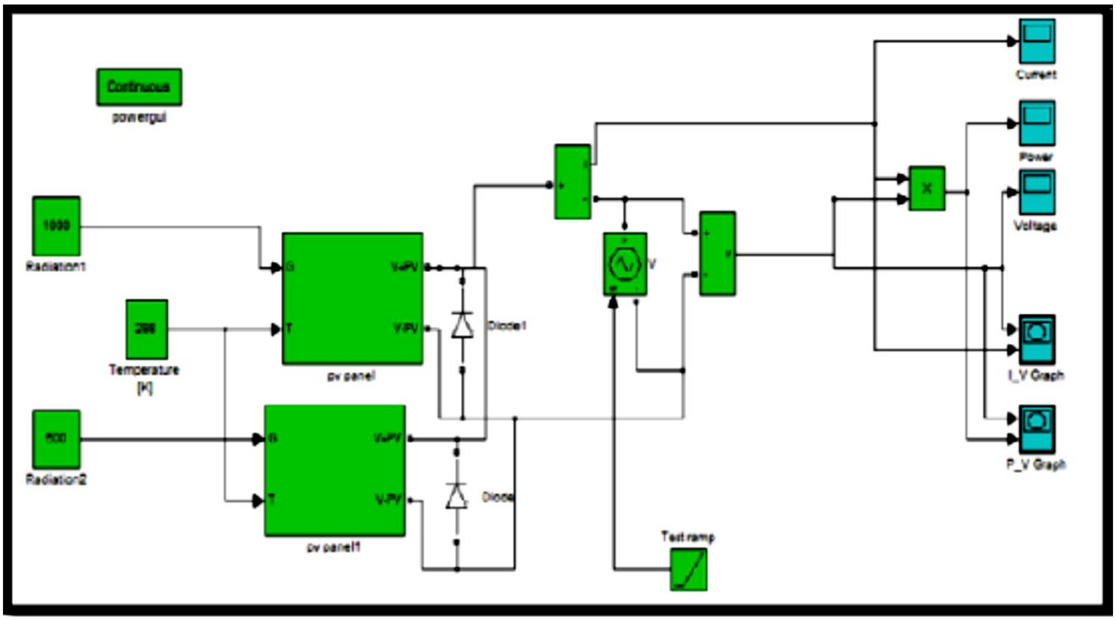

Figure (4.22): Two PV module with series connection at variable irradiance at 1000 W/m^2 and 500 W/m^2, by Matlab - Simulink.

The figures (4.23), (4.24) show the effect of shading in the I-V, P-V characteristic curve.

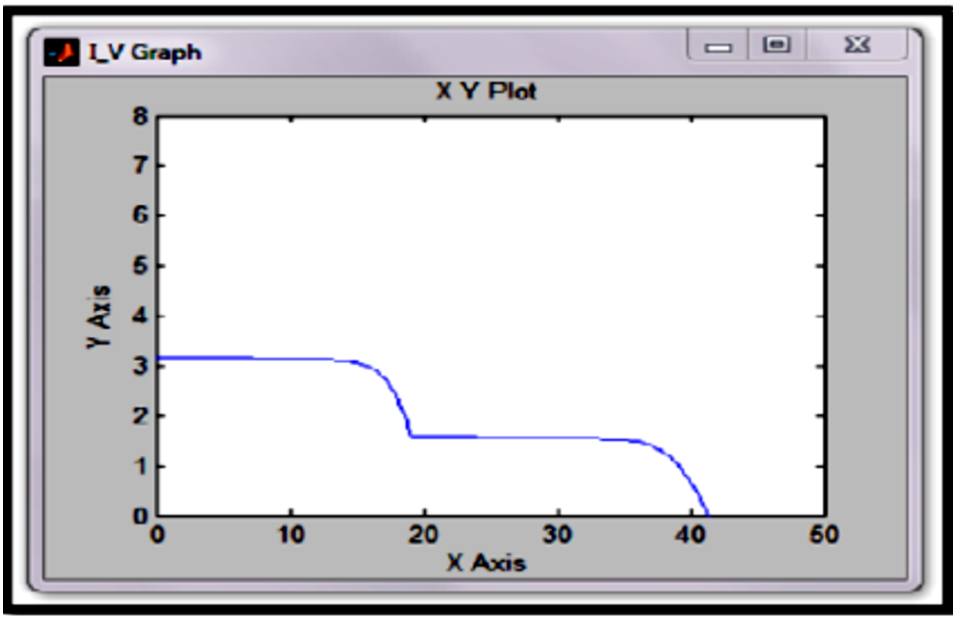

Figure (4.23): I-V characteristics at variable irradiance at 1000 W/m^2 and 500 W/m^2, by Matlab – Simulink [Y- axis: current (A), X –axis: voltage (volt)].

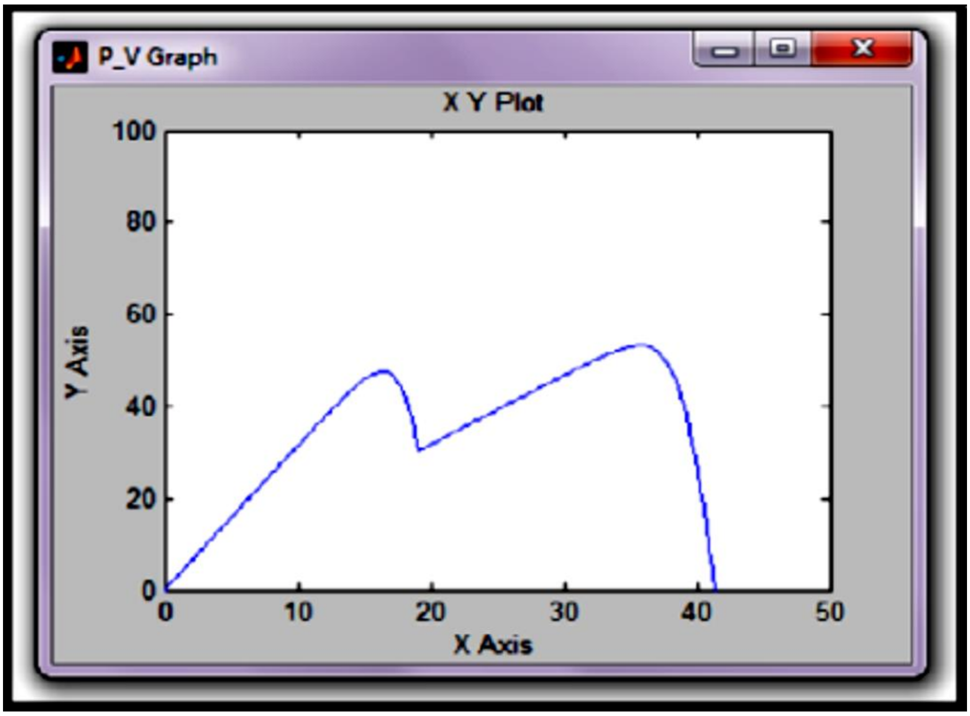

Figure (4.24): P-V Characteristics at variable irradiance at 1000 W/m^2 and 500 W/m^2, by Matlab – Simulink [Y- axis: power (watt), X –axis: voltage (volt)] [21].

4.6 Maximum Power Point Tracking (MPPT)

4.6.1 Incremental Conductance Based Maximum Power Point Tracking (MPPT)

As known from a Power-Voltage curve of a solar panel, there is an optimum operating point such that the PV delivers the maximum possible power to the load. The optimum operating point changes with solar irradiation and cell temperature.

This thesis deals with Incremental conductance MPPT algorithm method due to its simple approach.

In incremental conductance method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module.

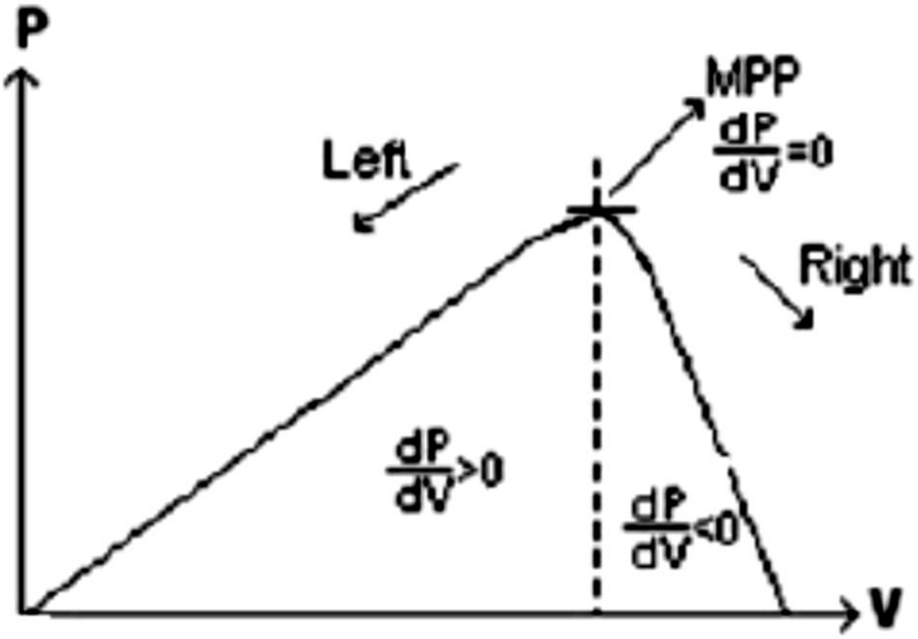

Figure (4.25): Basic idea of incremental conductance method on a P-V Curve of solar module

Figure (4.25) shows that the slope of the P-V array power curve is zero at The MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are as follows.

$$\frac{dI}{dV} = -\frac{I}{V} \quad \text{At MPP} \qquad (4.17)$$

$$\frac{dI}{dV} > -\frac{I}{V} \quad \text{Left of MPP} \qquad (4.18)$$

$$\frac{dI}{dV} < -\frac{I}{V} \quad \text{Right of MPP} \qquad (4.19)$$

Where I and V are PV array output current and voltage respectively. The left hand side of equations represents incremental conductance of P-V module and the right hand side represents the instantaneous conductance. When the ratio of change in output conductance is equal to the negative output conductance, the solar array will operate at the maximum power point [22].

4.6.2 Incremental Conductance MPPT Algorithm

This method exploits the assumption of the ratio of change in output conductance is equal to the negative output Conductance Instantaneous conductance. We have,

$$P = V\,I \qquad (4.20)$$

Applying the chain rule for the derivative of products yields to

$$\partial P/\partial V = [\partial\,(VI)]/\,\partial V \qquad (4.21)$$

At MPP, as $\partial P/\partial V=0$ (4.22)

The above equation could be written in terms of array voltage V and array current I as

$$\partial I/\partial V = - I/V \tag{4.23}$$

The MPPT regulates the PWM control signal of the dc – to – dc boost converter until the condition: $(\partial I/\partial V) + (I/V) = 0$ is satisfied. In this method the peak power of the module lies at above 98% of its incremental conductance. The Flow chart of incremental conductance MPPT is shown below [22].

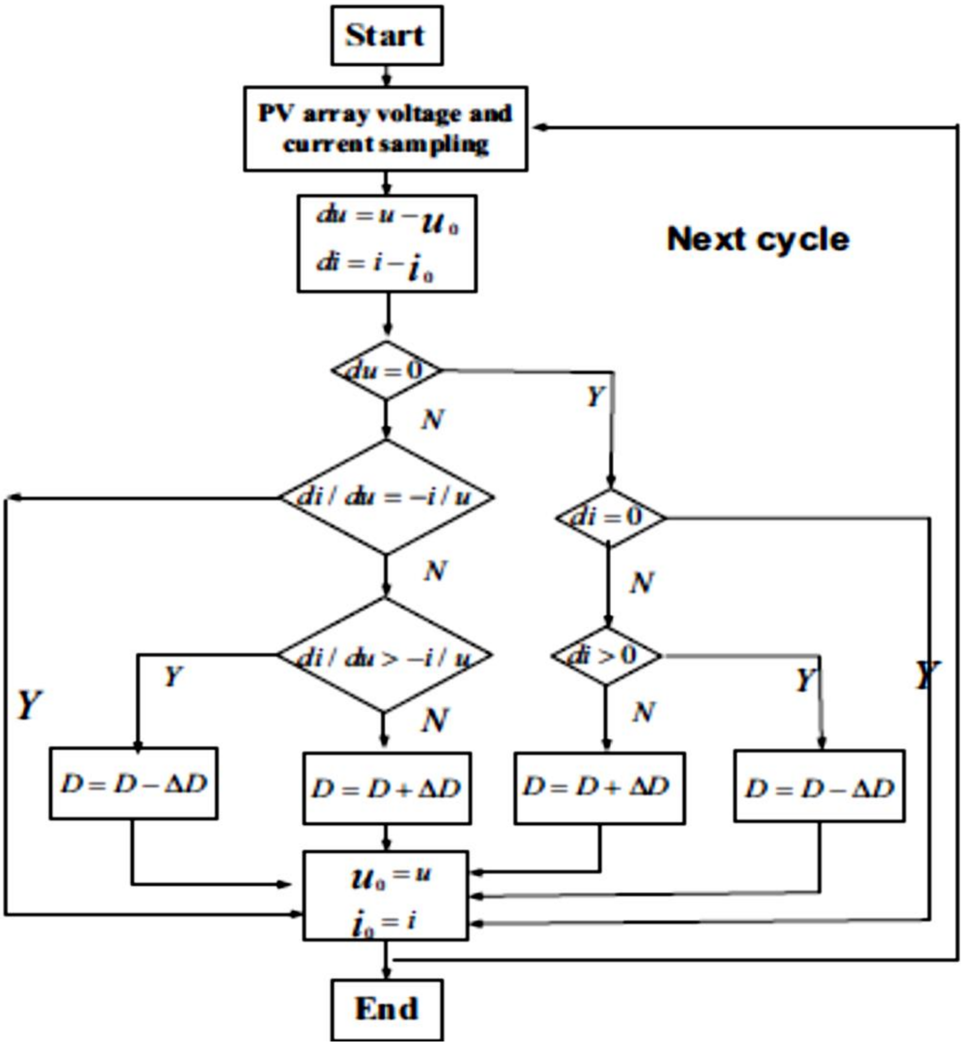

Figure (4.26): Incremental conductance MPPT Flow chart

Chapter Five

Techno - Economical Impact of PV On-Grid Systems

5.1 Determining the Cost of Producing One kWh from Grid Tie PV System

The economic analysis used in this thesis is based on the use of life cycle cost, cost annuity (NIS/kWh) and economic impact of grid tie PV system.

5.1.1 Life Cycle Cost (LCC)

The life cycle cost (LCC) is defined as the sum of the PWs of all the components. The life cycle cost may contain elements pertaining to original purchase price, maintenance costs, operation costs, and salvage costs or salvage revenues.

A) Initial cost of grid tie PV system

Initial cost includes purchasing equipment (PV-panels, grid tie inverter, transformer, wires and other components used in installation). Also includes labors and technicians costs for installation. These costs depend on the size and type of a component. All these costs are summed to give the overall initial cost.

$$\textbf{Initial cost} = \Sigma\ \textbf{Components cost} + \textbf{installation} \qquad (5.1)$$

Initial cost of photovoltaic modules

PV-modules are available in different sizes and types, the size of PV is characterized by their peak watt at STC (rated power).The price of peak watt is the same for mono or poly crystalline, but the installation or Structure cost will differ depending on the installed PV area. The (NIS/Wp) will decrease as the size of module increases.

Initial cost of grid tie PV inverter

The grid tie inverter available in different sizes and types .The price of the grid tied inverter depend on its capacity, efficiency, contain MPPT controller or not, protection and other parameters.

Other initial costs

Shipping costs and accessories needed for installation and system protection, wiring, rooms, should be also considered. These costs depend on the system size and vary with the kind of the project; if it for public use (may be land available free), or for private use.

B) Operation and maintenance cost of grid tie PV system

The operation costs considered are incurred after installation in order to run the system for a certain number of years (system life time).

C) Salvage value

The salvage value is considered as the value of the project elements after the system life time finishes.

Figure (5.1) shows the cash flow which represents the initial, maintenance cost and salvages revenue.

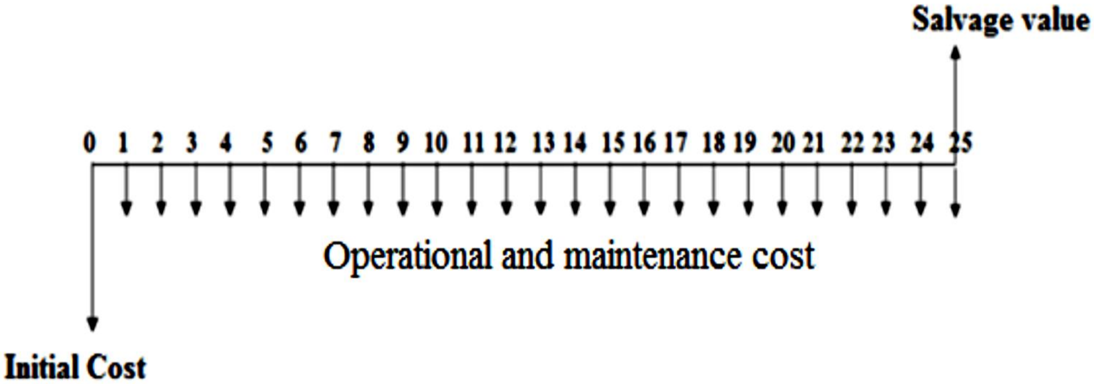

Figure (5.1): The cash flow which represent initial, operational cost and salvage revenue

5.1.2 Economic Factors

In order to calculate the equivalent uniform annual series (Aw) of cash flow in figure (5.1), the most important fact to remember is to first convert everything to a present worth.

The life cycle cost of grid tie system = initial cost of PV system + present worth of maintenance and operation – present worth of salvage value.

The life cycle cost of grid tie system = initial cost of the system + Operation and maintenance × (P/A, i, n) – salvage value × (P/F, i, n).

The term A (P/A, i, n) is called the uniform-series present worth factor.

This expression determines the present worth P of an equivalent uniform annual series A which begins at the end of year 1 and extends for n years at an interest rate i, and (P/A) can be found by equation (5.2):

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad i \neq 0 \tag{5.2}$$

The term F (P/F, i, n) is known as the single-payment present-worth factor, or the P/F factor. This expression determines the present worth P of a given future amount F after n years at interest rate i, and (P/F) can be found by equation (5.3):

$$P = F\left[\frac{1}{(1+i)^n}\right] \tag{5.3}$$

In order to simplify the routine engineering economy calculations involving the factors, tables of factors values have been prepared for interest rates from 0.25 to 50% and time period from 1 to large n values, depending on the interest value 10% and interest table in appendix (E).

The equivalent annual worth AW is obtained with appropriate A/P, as follow:

AW = PW (A/P, i, n)

Then the energy unit price calculated from equation (5.4)

$$(\text{NIS/kWh}) = \frac{\text{Aw}}{\text{Total yearly kWh produced}} \tag{5.4}$$

5.1.3 Cost of Producing One kWh from Grid Tie PV System for Jericho Power Plant

The price of the PV system and its installation are important factors in the economics of grid tied PV systems. These include the prices of PV modules, inverter, and all other auxiliaries as shown in table (5.1).

The cost of installation must be taken into consideration.

Table (5.1): Cost of elements and installation of grid tie PV system

Component Material or Work	Quantity	Price($)	Life time(Year)
PV Cells / Modules	2610	280789	25
Power conditioners (Inverters)	3	107612	25
Supporting structure for PV modules	2610	154244	25
Connection boxes	30	107636	25
Collection boxes	3	17938	25
Substation equipment	1	14348	25
Total		682567	

For the present PV system, the life cycle cost will be estimated as follows:

1- The lifecycle of the system components will be considered as 25 years.

2- The interest rate is about 10%.

The initial cost of the PV system = PV array cost + inverter cost + installation cost.

The initial cost of the PV system = 280789 + 107612 + (154244 + 107636 + 17938 + 14348) = 682567 $

The annual maintenance and operation costs are about 2% of initial cost which is equal to 13651 $/year, salvage value after 25 years is taken 15% from initial cost and it is equal to 102385 $.

The life cycle cost of PV system is obtained by drawing cash flow as in figure (5.2):

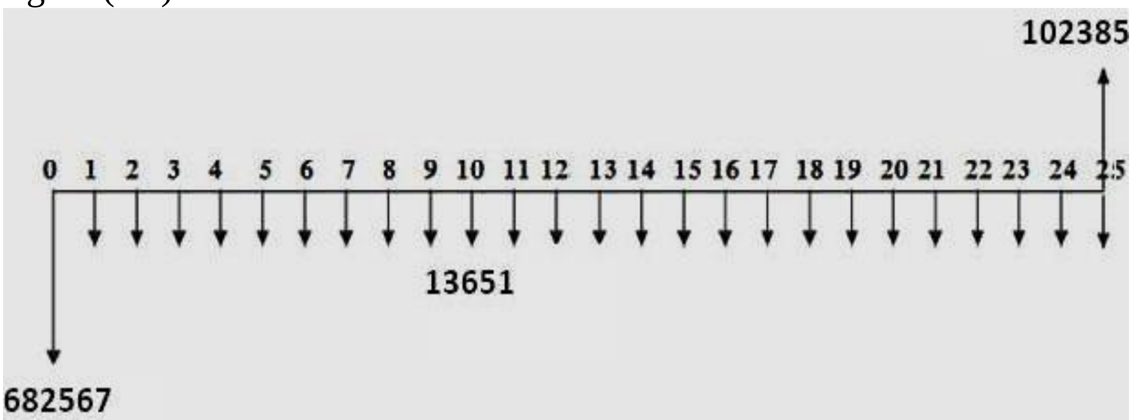

Figure (5.2): Cash flow of grid tie PV system for Jericho PV Power Plant

The life cycle cost of PV system = 682567 + 13651 (P/A, i, n) – 102385 (P/F, i, n).

PW = 682567 + 13651 (P/A, 10%, 25) – 102385 (P/F, 10%, 25).

The factors in the above equation are taken from appendix (E):

PW = 682567 + 13651 × 9.0770 – 102385 × 0.0923 = 797027 $.

AW = PW (A/P, i, n) = 797027 (A/P, 10%, 25).

From appendix (D), the term (A/P, 10%, 25) is equal to 0.11017, then:

AW = 797027 (A/P, 10%, 25)

AW = 797027 × 0.11017 = 87808 $.

The total energy yield from Jericho PV power station for the first year is equivalent to 480572 kWh.

The cost of 1 kWh from the PV generator = 87808 $ / 480572 kWh = 0.18 $/kWh.

5.2 Evaluation the Economic Impact of Jericho Grid Tie PV System

The following equation determines simple payback period which evaluate the economic impact for Jericho PV Power Station.

$$\mathbf{SPBP} = \frac{\mathbf{Investment}}{\mathbf{Saving}} \tag{5.5}$$

Annual saving money for Jericho Power System = Output Energy per year × Feed in Tariff/kWh

Saving = 480572 kWh/year × 0.19 $/kWh = 91309 $/year

SPBP = $\frac{682567\ \$}{91309\ \$/\mathrm{year}}$ = 7.5 Year

5.3 Levelized Cost of Energy (LCOE)

Since the LCOE ratio computes the total cost of the facility during its cycle of life dividing it for the energy produced for the same time, first we need to specify the energy produced by the 300 kW of Jericho power plant we are considering for this analysis.

In order to calculate the energy production for the whole lifecycle, the following values were considered (considering the irradiation characteristics of Palestine):

- Peak power: 339 kWp

- Performance Ratio (PR): 75 % (for the whole system)
- Peak irradiation hours per day: 5,5 h

Energy production can be calculated following the next formula:

Energy (kWh/year) = Power (kWp) * Peak hours (PH/day) * 365 * PR (%)

As a result, the energy produced yearly is about 510 MWh/year.

The Global Horizontal Irradiation GHI is about 5.2 peak hours per day. Considering tilted panels, the number of peak hours per day increases to 5.5 according to PVGIS results. A 5.5 hours peak irradiation per day has a production ratio of about 1500 kWh/kWp.

Considering the formula for calculating the LCOE ratio, for the case of the On ground PV installation described in the scenario proposed the following LCOE are obtained:

Table 5.2 - On ground PV LCOE

% subsidy to initial investment	0%	25%	50%	75%	100%
LCOE (USD/kWh)	**0,27**	**0,21**	**0,15**	**0,09**	**0,03**

Costs from photovoltaic installations are not expected to vary as much as the CSP case in non-mature markets since this is a less sophisticated technology. Sensitivity analysis for this case considers a variation of +10% over the initial costs in order to obtain a range of LCOE. Results are showed at the next table:

Table 5.3 - On ground PV LCOE sensitivity analysis

% subsidy to initial investment	0%	25%	50%	75%	100%
LCOE (USD/kWh)	0,29	0,23	0,16	0,09	0,03

5.4 Environment Impact of Grid Tie PV System

In the long term, environmental benefits may be the most important reason for the implementation of grid-tied PV systems. The environmental impact of PV is small when compared with all nonrenewable energy sources. Coal plants produce huge quantities of CO_2 as well as particulates and oxides of sulfur and nitrogen. Of course, CO_2 is inherent in the combustion process and cannot be avoided. Scrubbers can reduce, but not eliminate sulfur and particulate emissions. Gas fired plants are cleaner than coal plants, but still produce greenhouse gases. Atmospheric emissions from nuclear plants are negligible, but radioactive waste is an incessant problem with no clear cut solution.

The amount of CO_2 produced from conventional source using fossil fuel is 0.7 kg for 1 kWh, so if I consider Jericho Power Plant as a case study the reduction of CO_2 from energy yield 480572 kWh is 336.4 ton annually. [13]

Chapter six

Performance Analysis of Jericho PV On-Grid System

6.1 Introduction of Jericho PV On-Grid System

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.

Jericho station system has been designed and constructed as the grid-connected, with reverse power flow, and without storage batteries system.

This thesis aims to provide an understanding of PV integration to the medium distribution network from technical point of view [25].

The description of Jericho PV On-Grid system is the following:

- Rated Capacity = 300 kWp at 1,st stage, 550 kWp at 2,nd stage
- Number of Modules = 2610, 115 W
- Expected Yearly KWh = 422,000 kWh, Actual for the 1,st year = 552,657.8 kWh
- Area of Installation = 13,000 m^2
- Expected Amount of Reduction of Carbon Dioxide = 290.6 tons/year.

6.2 Elements of Jericho PV On-Grid System

This project provides the Palestine with Photovoltaic Power Generation system of 300 kW output of grid tied type in Jericho. The system comprises of PV module 115 W × 2610pcs, Power conditioners 100 kW × 3 no. and Substation.

The system generates power from sunlight and intended to supply 3-phase AC power rated 300 kW. One string consisted of 6pcs of PV modules in series supply rated DC 330 V, input to the power conditioner pass through junction box and collection box. Power conditioner converts from DC power to 3-phase 3-wire 202 VAC power which to be synchronized with grid line, insulation transformer makes step-up to 3-phase 4-wire 400 V power and supply to load. When output voltage of PV module is raised by increasing solar irradiance, power conditioner automatically starts operation.

When output voltage of PV module is fallen by decreasing solar irradiance, power conditioner automatically stops operation. Generated power and voltage are measured, indicated and recorded using by personal computer. And solar irradiance, air temperature and surface temperature of PV module are also measured, indicated and recorded [25].

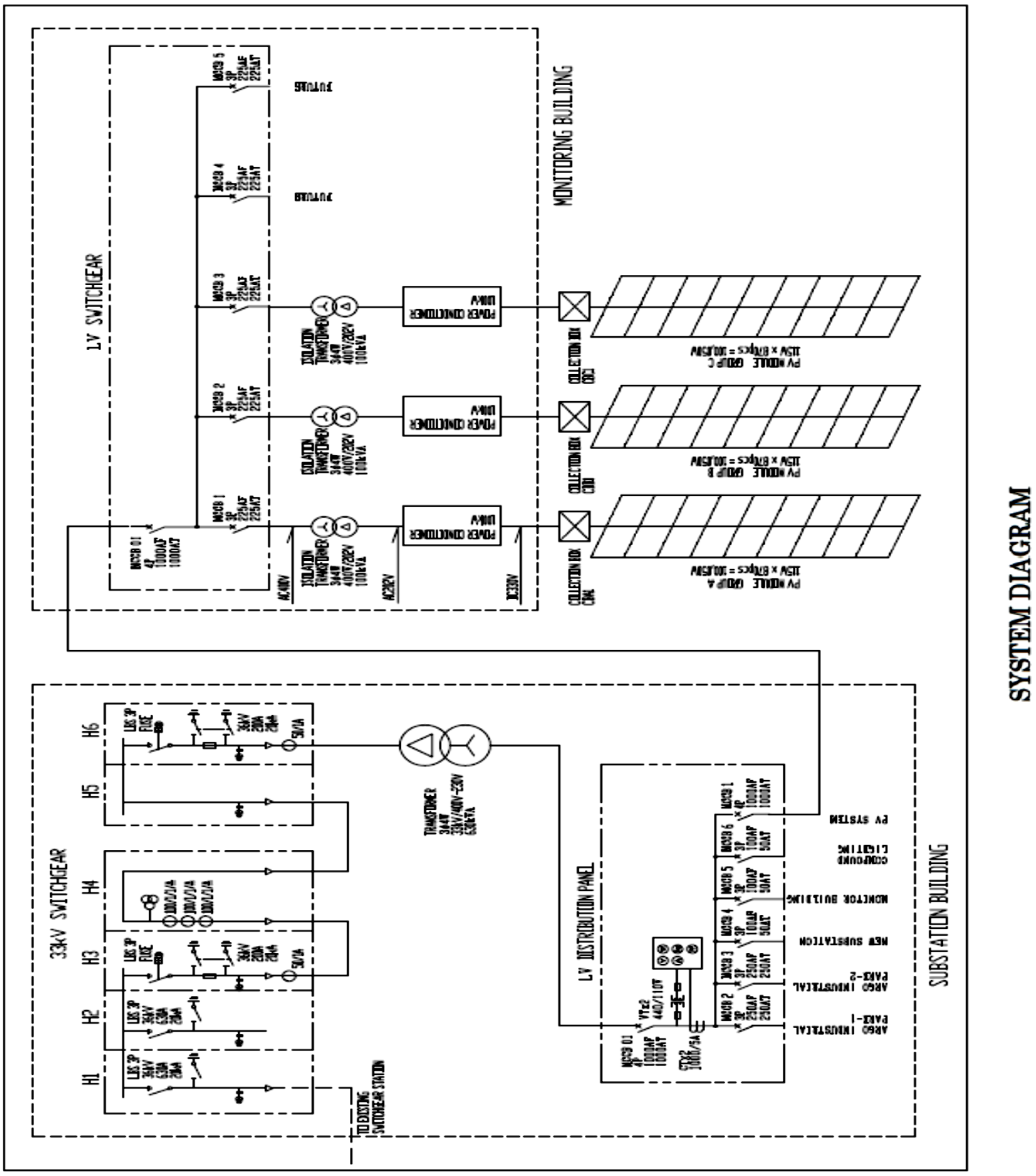

Figure (6.1): Jericho PV Station Single Line Diagram

6.2.1 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 (6.1).

Table 6.1: Kaneka PV Module's Datasheet

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 [25].

6.2.2 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 (6.2) shows the datasheet of the (P83B104R) inverter in grid connected operation mode.

Table 6.2: Grid Connected Inverter Datasheet

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%

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. The output power from the inverters is 300 kW (AC) three phase at output voltage rated 202 V as shown in table (6.2) [25].

6.2.3 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 202 V to 400 V. As we use three inverters, here we need a voltage transformer to each inverter.

6.2.4 LV/MV Transformer

After raising the voltage to 400 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 400 V to 33 KV, the transformation is from Star connection to Delta connection and the rated output power is 630 KVA [25].

6.2.5 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.

6.2.6 Main Monitoring System

In the main monitoring room at Jericho Solar Station, many screens which 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.

6.3 Performance Analysis of Jericho Solar PV Station

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 (6.3) [25].

Table 6.3: Solar Station Data from 8/2012 – 1/2013

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
CO2 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, the monitor system were not working from 2/2013 – 8/2013 due to technical malfunction.

It was observed 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%).

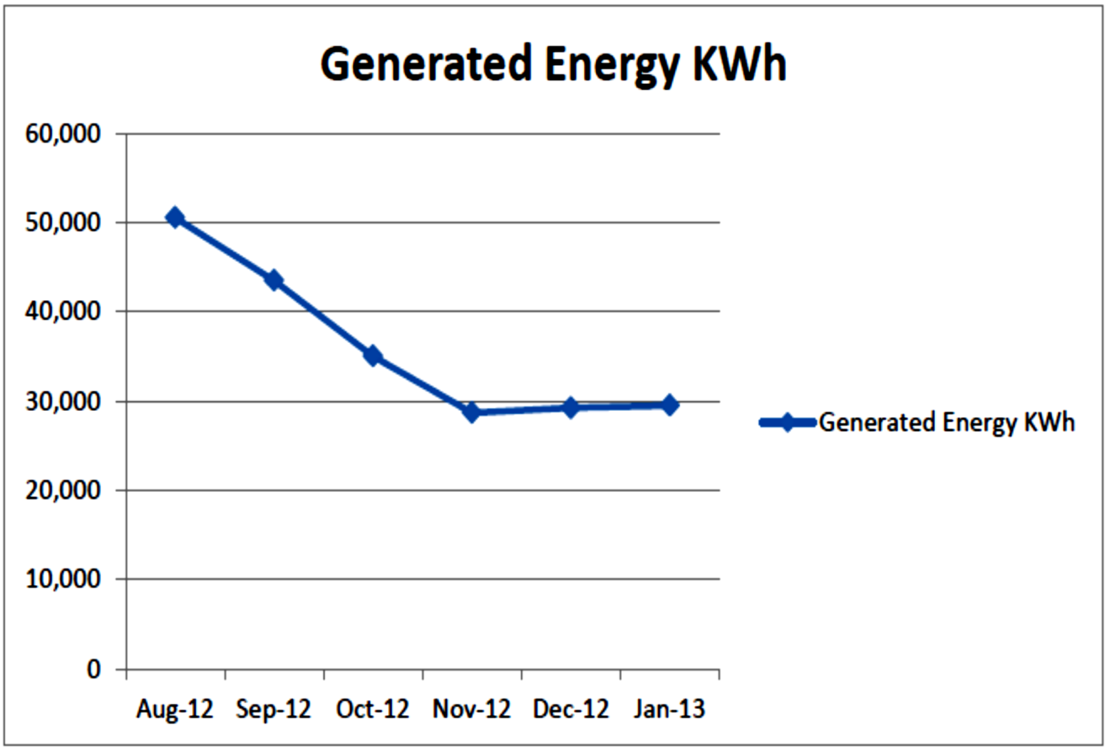

Figure (6.2): Generated KWh Units from Jericho Solar Station

The next figure and table, depicts 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

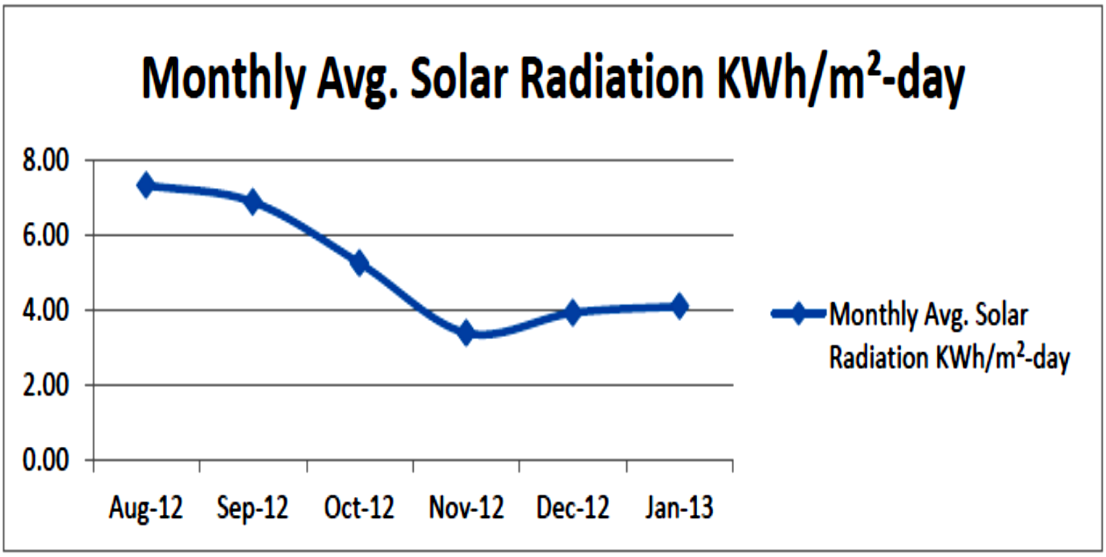

Figure (6.3): Monthly Average Solar Radiation in Jericho Station

Table 6.4: Generated KWh Units from Solar Station that counted by Grid [25]

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 * 0.105) = 531,032.06 KWh.

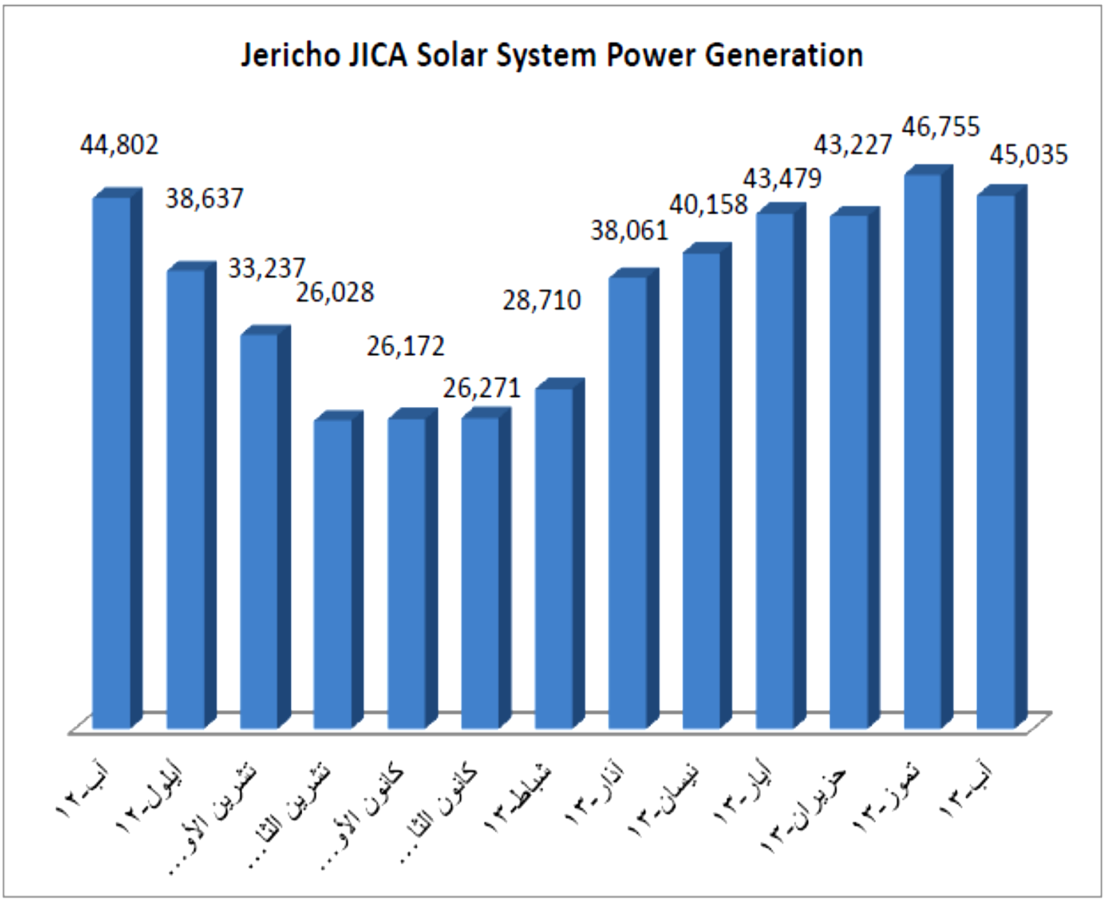

Figure (6.4): Generated kWh Units from Solar Station that seen by Grid [25]

6.4 Environmental Impact Assessment for 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) [25].
- The amount of generated energy from Jericho Solar Station by theoretical calculations is:

$$E = Wp * Average\ Solar\ Irradiance * pf * S.f * 365 \quad (6.1)$$

$$E = 300 * 5.4 * 0.9 * 0.9 * 365 = 478{,}953\ KWh$$

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 JDECO kWh meter from 8/2012 to 8/2013 is equal to 480,572 KWh. The previous data from JDECO are after discount of the losses which are approximately 10.5%, so this data are equal to 531,032 KWh [25].

The amounts of energy generated are shown in Table 6.5.

Table 6.5: Amounts of energy generated by Jericho PV power plant

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)	531,032

The expected amounts of carbon dioxide emissions reduction according to the mentioned data are: 480,572 * 0.7 = 336,400 Kg of carbon dioxide per year.

6.5 Simulink Configuration of Jericho PV Power Plant

Figure (6.5) shows the whole Simulink model, the simulation results for this system for different conditions are in (Appendix B).

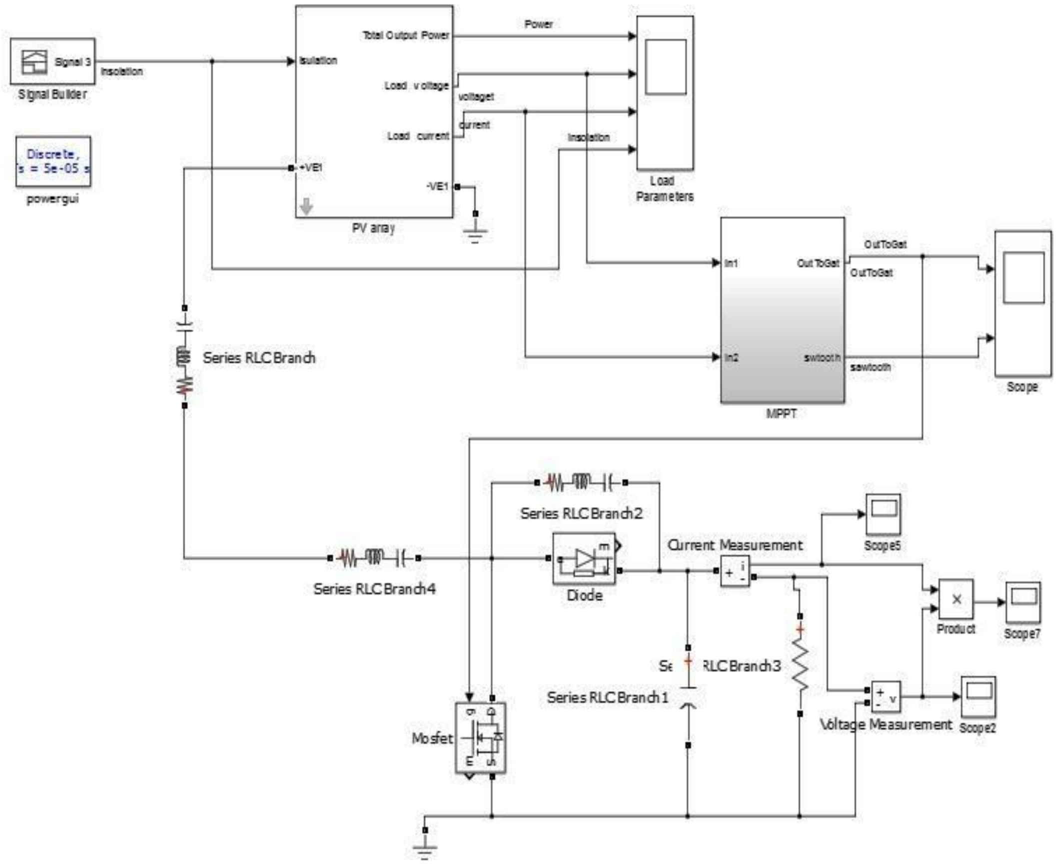

Figure (6.5): Simulink model of Grid tie PV system [26]

6.6 Recommendation

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 15% 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 Seven

Conclusions and Future Scope of Work

7.1 Conclusions

From this research it was shown that it is possible to accurately predict the power output from grid connected photovoltaic arrays by including the effect of temperature and solar radiation. Furthermore, it was shown that it is possible to adapt the size of models and the different PV system configurations which are applicable to a grid connected and modify it in such a way that important information about techno-economic performance of these systems can be obtained.

Using this software Simulink program, and determined the effect of temperature coefficient and non-linear radiation term, the maximum power output from each PV system sizes and configurations can now be predicted with accuracy. This can be done, not only for a single unrealistic value of solar radiation, but under general operating conditions.

Being able to accurately predict the power output is very important for increased growth in the deployment of photovoltaic systems.

7.2 Future Scope of Work

After the completion of the simulation work, the scope is been identified as:

- Build Simulink dynamic smart system with all parts and controller.
- Study effects of switching & fault conditions for grid tied systems.
- Analyze the policy of RE in Palestine regarding the impact of different FIT systems, also the break-even cost of RE in Palestine.
- Analyze the impact of interest (i) or subsidies on the feasibility of RE systems in Palestine.

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[26] MATLAB/Simulink simulation software 2013a.

Appendix A

Specifications of Jericho PV On-Grid System Elements

A1 - PV Module

Kaneka
U-EA115-YJG033/00

Specifications – U- type

1. 1 Module Specifications

Table 1.

PRODUCT:THIN-FILM SILICON PV MODULE			
MODEL: U-EA115			
SPECIFICATION LISTS	**UNIT**	**VALUE**	**REMARK**
Performance at STC (stabilized)			
Nominal Power (Pmax)	**W**	**115 (+10%/-5%)**	
Open Circuit Voltage (Voc)	**V**	**71.0 (±10%)**	
Short Circuit Current (Isc)	**A**	**2.50 (±10%)**	
Voltage at Pmax (Vpm)	**V**	**55.0**	
Current at Pmax (Ipm)	**A**	**2.09**	
Max. System Voltage	**V**	**600**	
Dimension	**mm**	**1210.0 ± 2.5 x 1008.0 ± 2.5**	
Depth	**mm**	**40.0 ± 1.0**	
Weight	**kg**	**18**	
(Reference)			
Performance at STC (initial)			
Power (Pmax)	**W**	**132**	**(typical)**
Open Circuit Voltage (Voc)	**V**	**71**	
Short Circuit Current (Isc)	**A**	**2.5**	
Voltage at Pmax (Vpm)	**V**	**56**	
Current at Pmax (Ipm)	**A**	**2.4**	

(REMARK)

- Even though we don't define the tolerances of Ipm and Vpm, those tolerances are close to ±10% according to the tolerances of Isc and Voc.
- The nominal output value is defined as average value for modules using Kaneka's original evaluate method.
- The performance at STC of the thin film silicon photovoltaic module at the outdoor use has seasonal variations. The amount of solar radiation also fluctuates monthly. The annual average of output could be estimated in consideration of both the variations.
- MODULES are certified by IEC61646 and IEC61730-1/-2 (Application Class A)

1.2 Materials

1.2.1 Photovoltaic cell

Amorphous silicon / micro-crystalline-based

1.2.2 Superstrate (glass substrate)

Float glass (dimensions: 1200 ± 1 mm x 998 ± 1 mm x 5 ± 0.2 mm, squareness: 1/300 or less)

1.2.3 Back cover sheet

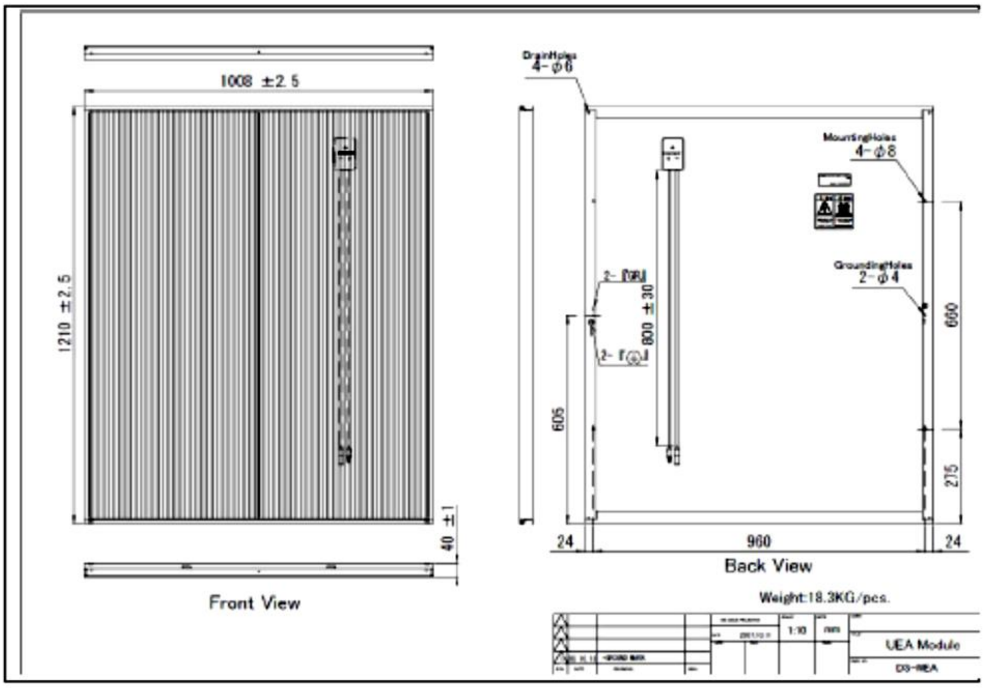
Stacked fluorine-based films (reference thickness: 0.18 mm) are fusion bonded by using EVA resin (reference thickness: 600 μm).

1.2.4 Frame, junction box, output cable, connectors

Frame: aluminum extrusion mold (inner-brim-type frame)
Junction box and cable: Onamba's FNMC80D2S3 (ONAMBA Photovoltaic Cable (TUV), MC3 connectors)

1.3 Dimensions

U-EA115 – Refer to the following diagram.



1.4 Standard operating conditions

The MODULES should be installed at a place where they can receive sufficient sunlight. Places subjected to seawater or snowfall (1 m or more) should be avoided. Ambient temperature should be in the range between -20°C and 50°C and with installation angle more than 5°. The temperature of MODULES should be in the range between -20°C and 80°C.

2. Packing Specifications

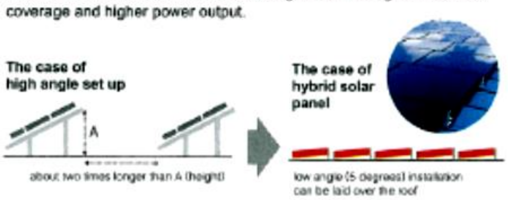
20pcs are packed in a carton, and one carton is placed on a pallet.

3. If the specifications hereof are changed, Kaneka will notify such change in writing to Customer as soon as possible.

U-EA type

HYBRID panels are ideal for low angle installations.

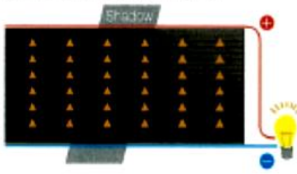
Because of HYBRID's cell structure, low angle (5 degree) roof installations are possible without a significant loss of power generation by shadow. Panels can be installed close together, allowing for more roof coverage and higher power output.



The HYBRID cell structure is shadow tolerant.

The HYBRID panel measures 1,210x1,008mm. Unlike traditional crystalline panels, the HYBRID cells allow it to perform even if part of the panel is shaded*.

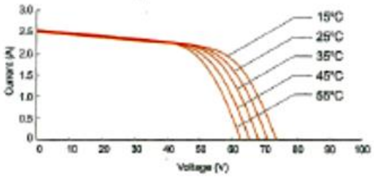
*The cell configuration allows it to prevent power output deterioration under shadow dropped conditions like picture below.



For example, if 20% of one cell becomes shady, remaining 80% of the cell can generate power normally.

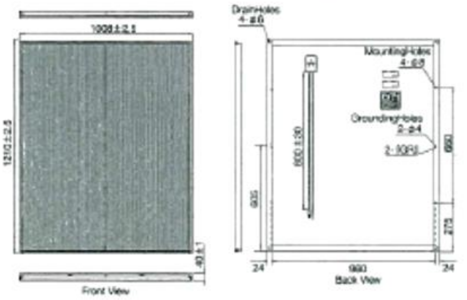
Electrical characteristics
U-EA110 type

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	48.3	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]	0.068				
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 alminum				
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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A2 - Power Conditioner

POWER CONDITIONER

Manufacturing Specifications

Introduction

These specifications apply to the PV (Photovoltaic) inverter (P83B104R).

1. General

This equipment is intended to convert DC power collected from solar cells to AC power which to be synchronized with the voltage and frequency of the connected commercial power supply. It is also equipped with an grid connected protective function.

2. Applicable standards (latest versions)

Japanese Industrial Standards (JIS)
Japan Electric Machine Industry Association (JEM) standards
Guide Book of Electrical Equipment
Technical Guideline of Distributed Resources Connection
Japanese Architectural Standard Specification (Electrical Equipment Work)

3. Service conditions

Installation location … Location should be in indoor, and should satisfy all of the following conditions:
- Location should not be affected from direct sunlight.
- Location should not be affected from heat sources directly, such as heaters.
- Location affected by hot air such as exhaust from air conditioners.
- Location should not be affected from vibration and impact.
- Location should not be near the instrument which emit the sparks.
- Location should be without dust, oil mist, iron powder, corrosive gas, salt and inflammable gas.
- Location should not be affected from noise emission. Noise emission means such as location where person always stays, and where echos the noise.
- Location where should not be a residence. (residence means where people perform daily lives)
- Location should not be exposed to water (splashes).
- There should be more than 100mm clearance in the back, more than 500mm at the top.

Ambient temperature … −10° C to 40° C
Relative humidity: 30 to 90% (non−condensing)
Altitude: 2000 m or less

4. Structure, dimension, circuit

4.1 Structure
(1) This equipment has cubicle structure of isolated closure type.
(2) Operation switches and indicators are located on the front panel; operations can be performed and monitored in this front panel.
(3) External cables shall be connected through the lower part of the front panel.
(4) The protection code is IP20

4.2 Dimension and weight
See Drawing 3/4

4.3 Electrical circuit
See Drawing 4/4

4.4 Painting color
The outer body panel uses Munsell 5Y7/1 (semi−gloss)

5. Electrical requirements

5.1 Common

Item	Rating/Specification	Remarks
Main circuit type	Self commutation voltage type	
Switching method	High frequency PWM	
Electrical insulation method	Commercial frequency insulation transformer method	
Availability of DC side grounding	Without grounding	
Cooling system	Forced air cooling	
Frequency discriminant function	Automatic	Fixed setting is also available.

5.2 Grid connected operation mode

Item	Rating/Specifications	Remarks
Rated output	100kW	
Rated input voltage	DC300V	
Maximum allowable input voltage	DC500V	
Input operating voltage range	DC240V~450V	Rated output range: 270 to 420 V
Maximum power point tracking range	DC240V~420V	
Output electrical system	3−phase 3−wire system	S−phased grounding
Rated output voltage	AC202V	
Rated frequency	50 Hz or 60 Hz	
Grid connected operation range	Voltage: Within rated value ±20 V Frequency: Within rated value ±1%	
Rated output current	285Aac	
AC output current distortion factor	Total current: 5% or less Each number of harmonic: 3% or less	Rated output current ratio
Output power factor	0.95 or more	Grid connected operation range rated output
Efficiency	93%	Note 1
AC overcurrent limiting value	110%	Rated current ratio
Power control method	Maximum output power point tracking	
Output control method	Current control type	
Functions	Automatic start/stop, soft start, automatic voltage adjustment (phase−advancing reactive power control, output control), input current limitation, output current limitation, temperature rise output limitation	

Note 1:It is the rated load efficiency based on efficiency measurement method of JIS C 8961.

P83B Grid connected

B	E0121520	11−06−01	APPROVED BY N.TAZAWA 11−06−03		35735
A	FIRST EDITION: KONDOH	11−05−20	UNIT mm / CHECKED BY NA.TAKIZAWA 11−06−03	TITLE PV INVERTER MANUFACTURING SPECIFICATIONS	
REV.	DESCRIPTION	DATE	SCALE / DESIGNED BY Y.KONDOH 11−06−01		

山洋電気株式会社 SANYO DENKI CO.,LTD. SANYO DENKI CO., LTD. 2011−06−03 ISSUED

DWG NO. 00811456 REV. B 1/4

A3G−F3 00811456.0001

5.5 Grid connected protective function

Item		Detection Level	Detection Time	Remarks
Grid overvoltage (OVR)		225/230/235/240V	0.5/1.0/1.5/2.0s	3−phase detection
Grid undervoltage (UVR)		160/165/170/175/180V	0.5/1.0/1.5/2.0s	3−phase detection
Grid over frequency (OFR)		50.5/51.0/51.5Hz 60.6/61.2/61.8Hz	0.5/1.0/1.5/2.0s	1−phase detection
Grid under frequency (UFR)		48.5/49.0/49.5Hz 58.2/58.8/59.4Hz	0.5/1.0/1.5/2.0s	1−phase detection
Islanding operation detecting functions	Passive−type device Voltage phase jump detection	±3/5/8/10°	0.5s or less	1−phase detection Holding time limit: 5 s
	Active−type device Reactive power variation method	Fluctuation range: Reactive power is 5% of rated output Elements detected: Periodic fluctuations in frequency Detection Level: 0.25Hz (50Hz), 0.3Hz (60Hz) Parallel off time limit: 0.5 to 1.0 s		1−phase detection
Supply prevention time after power recovery		5/150/200/300s		

Note: Underlined datas indicate factory setting values.

6. External Input and Output Signals

Item	Signal Name	Signal Description	Input/Output Specification
External communications	External serial signal	Status information Failure information Measurement information Note 2	RS−485
Synchronization input and output	Reactive power synchronization	Synchronized signal of reactive power change	24 VDC Approx. 10 mA
Measurement input	Solar irradiance	Solar irradiance converter output	4−20mADC
	Temperature	Temperature converter output	4−20mADC
Contact input	External control	Grid connected prohibit command (Factory setting values) Closed: grid connection enabled Open: grid connection disabled	Contacts shall be free from problems with the following voltage and current: 24 VDC Approx. 17 mA
Contact output	Grid connected operation	In grid connected operation	No−voltage, normally open contact output Rated resistance load: 250 VAC 1 A/30 VDC 1 A
	Failure	Failure occurred	
	Grid connected protective device activated	Grid connected protective device activated	

Note 2:Frequency is contained.

7. LCD Display

Display specifications: 2 lines, 16 columns per line, alphanumeric characters

Function	Description
Status information	Operation mode: Grid connected operation mode, Status: OFF, Standby (DC), Standby (grid), Standby (external), Standby (compound), Standby (others), ON
Failure and error information	DC overvoltage, EEPROM error, Unit power error, Temperature rise error, AC overcurrent, Grid connection error, Inverter overcurrent, Circuit breaker opened, Setting error, Fan fuse opened, Arrestor fuse opened, Control power fuse opened, Reactive power synchronization pulse error, Grid overvoltage, Grid undervoltage, Grid frequency rise, Grid frequency lowering, Active system detection, Passive system detection, Grid instantaneous overvoltage, Phase rotation error, Voltage rise suppressive operation, DC ground fault, External communication error, External control, DC overvoltage standby, DC undervoltage, Limiting of output at high−temperature
Measurement information	Total: Total power generation, Total integral power generation, Device: DC voltage, DC electricity, DC power, AC voltage(RS), (ST), (TR), AC electricity (R), (S), (T), AC power, Integral power generation, Insolation intensity, Temperature

8. LED Display

Item	Color	Description
RUN	Green	Lighting signal: PV inverter in operation. Flashing signal: PV inverter in standby mode.
ALARM	Red	Failure occurred.

9. Operation Switches

Name	Description
RUN/STOP	Push the start/stop, and the equipment comes into operation mode. Push the start/stop again, the equipment stops.
RESET	Recovery switch at the time of failure.
MENU, SET, ←, ↑, →	Switch for changing LCD display mode and settings.

10. Breaker list

Solar cell input circuit breaker (MCCB51)

System capacity	100kW
Manufacturer	Hitachi Industrial Equipment Systems Co.,Ltd
Type	P−600F
Rated voltage	DC600V
Rated current	500A

Grid output circuit breaker (MCCB11),

System capacity	100kW
Manufacturer	Hitachi Industrial Equipment Systems Co.,Ltd
Type	S−400B
Rated voltage	AC600V
Rated current	400A

11. Insulation

11.1 Dielectric strength
Between AC circuit and ground, DC circuit and ground, each of them available at AC2000V 1minutes.

11.2 Insulation resistance
Between AC circuit and ground, DC circuit and ground, it is 5MΩ.available for over 5MΩ. Measured voltage is DC500V.

12. Installation procedure

Appropriate adjustment with an existing power supply will be needed for installation of inverter. Thus, it is necessary to have enough discussion with power company in advance.

13. List of attached items

	Item name	Quantity	Remarks
1	Anchor bolt	4	SP−4100(M12)
2	Bolt cap	4	For M16
3	N, P terminal Connection bolt, Nut	6	M10×30L, M10 nut
4	Instruction mannual	1	
5	Inspection report	1	
6	Fuse	set	Spare parts (P413×1, P430×1, P4100H×1)

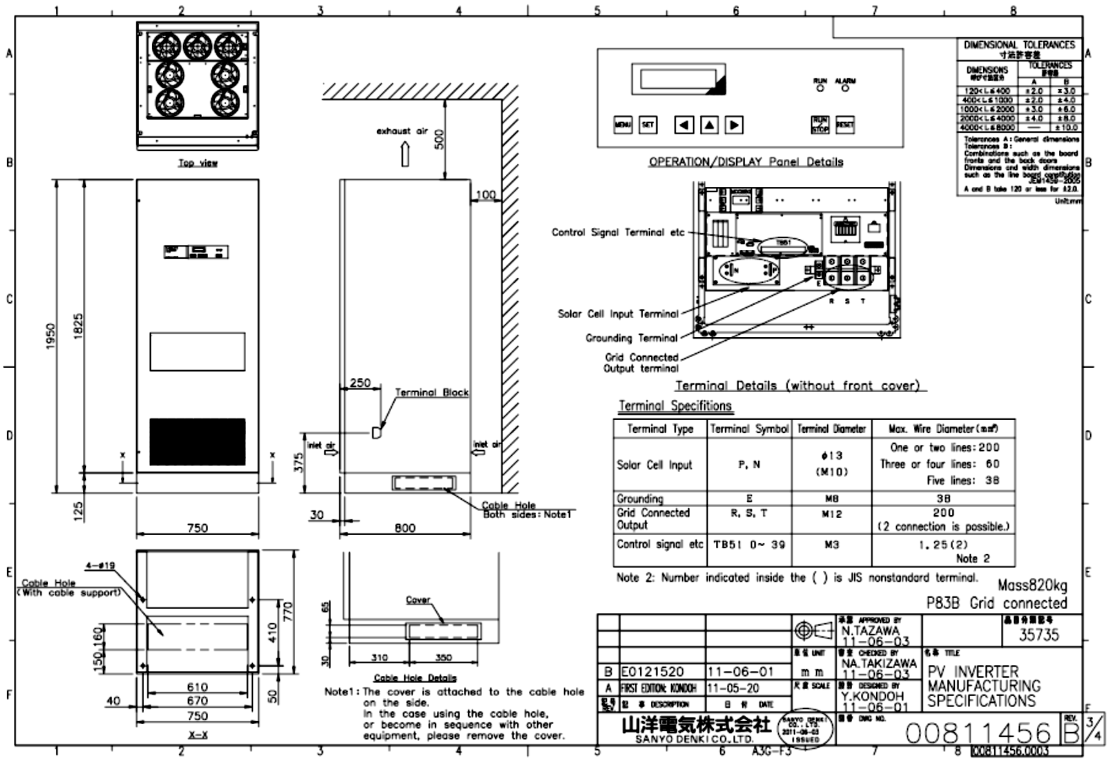
P83B Grid connected

B	E0121520	11−06−01	APPROVED BY N.TAZAWA 11−06−03		35735
A	FIRST EDITION: KONDOH	11−05−20	UNIT mm / CHECKED BY NA.TAKIZAWA 11−06−03	TITLE PV INVERTER MANUFACTURING SPECIFICATIONS	
REV.	DESCRIPTION	DATE	SCALE / DESIGNED BY Y.KONDOH 11−06−01		

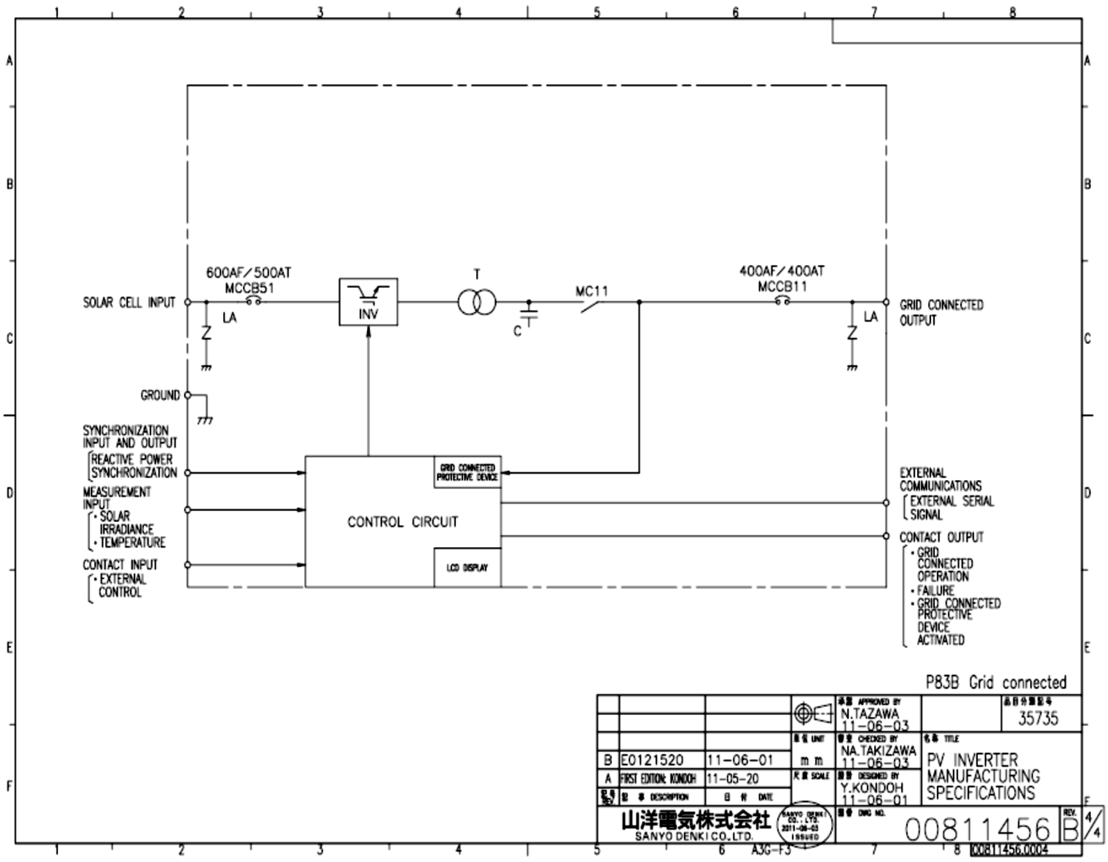
山洋電気株式会社 SANYO DENKI CO.,LTD. SANYO DENKI CO., LTD. 2011−06−03 ISSUED

DWG NO. 00811456 REV. B 2/4

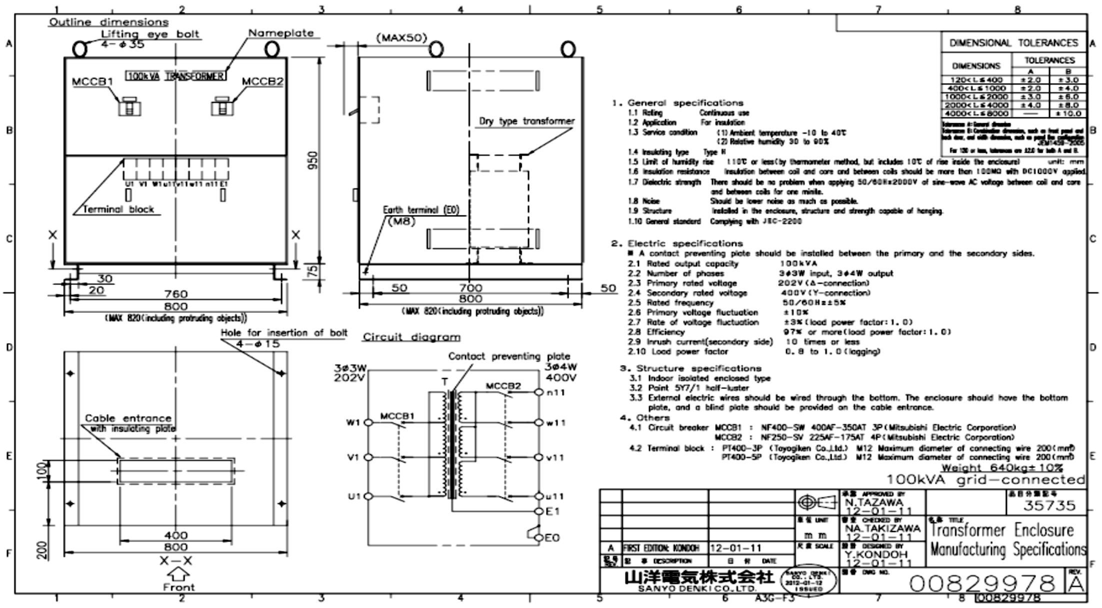
A3G−F3 00811456.0002

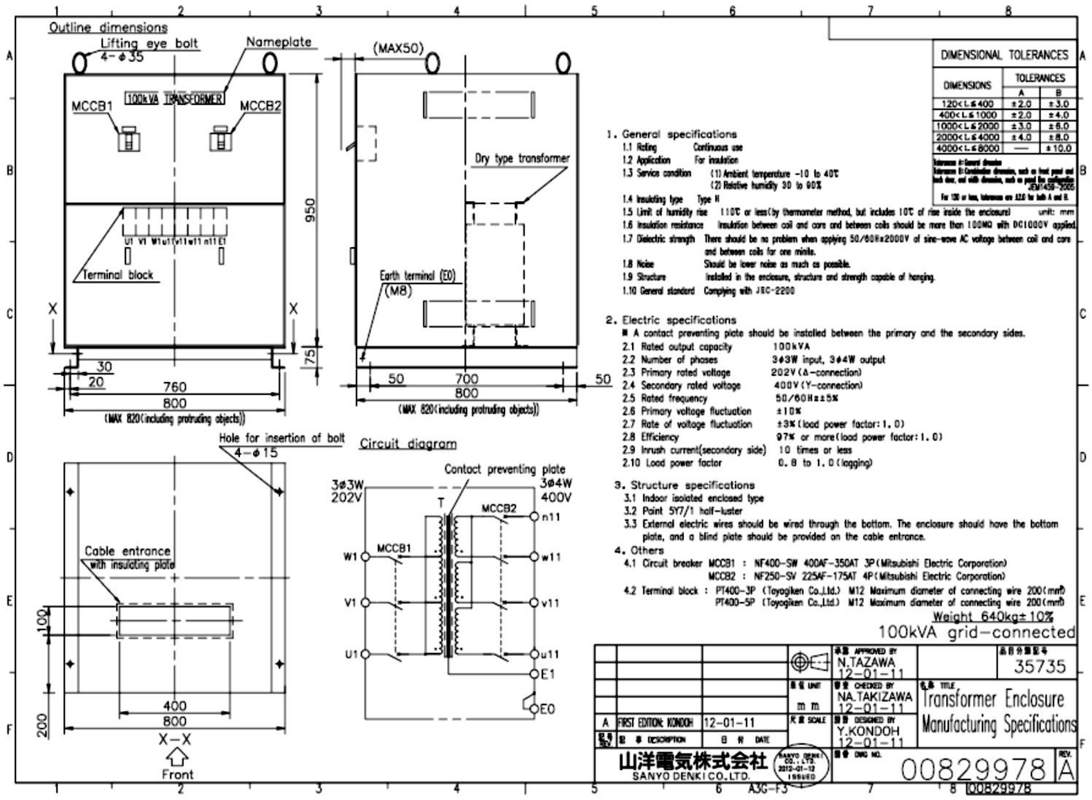


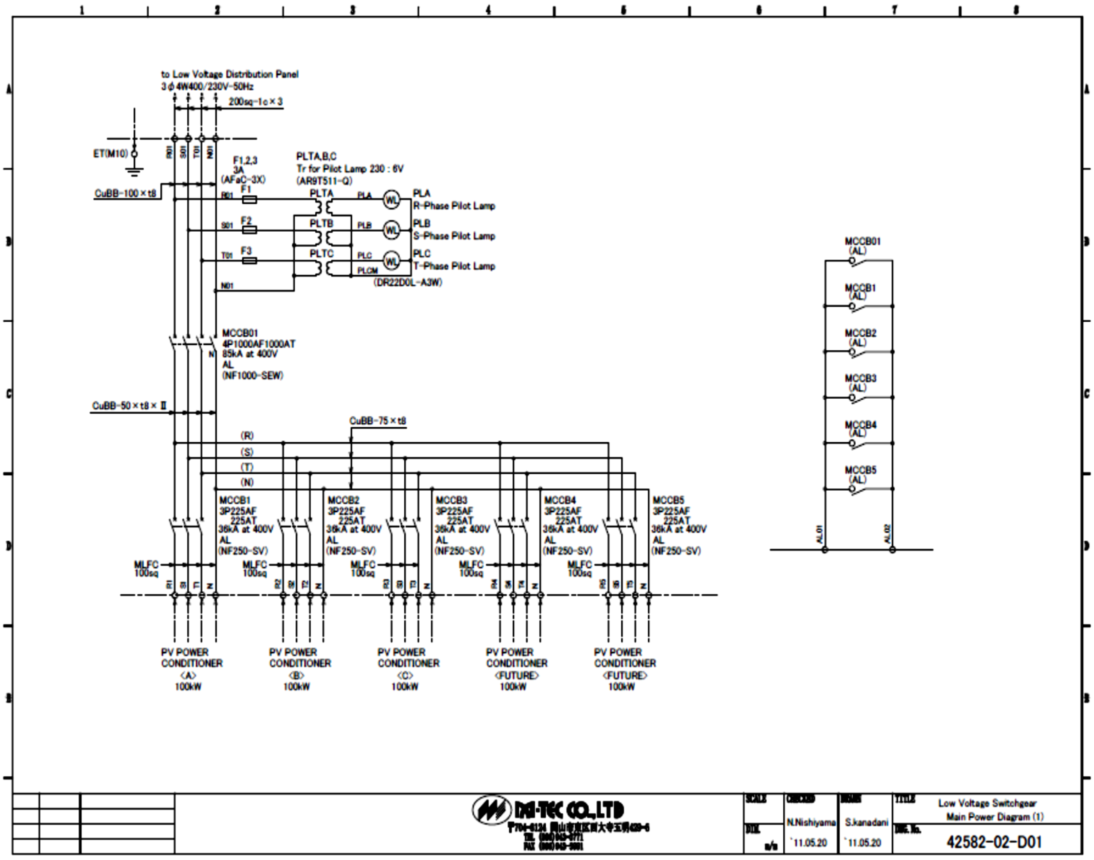
Top view
exhaust air
500
100
1950
1825
125
750
800
250
Terminal Block
inlet air
375
30
Cable Hole
Both sides: Note1
OPERATION/DISPLAY Panel Details
RUN
ALARM
Control Signal Terminal etc
Solar Cell Input Terminal
Grounding Terminal
Grid Connected Output terminal
Terminal Details (without front cover)
Terminal Specifitions
Terminal Type | Terminal Symbol | Terminal Diameter | Max. Wire Diameter
Solar Cell Input | P, N | ϕ13 (M10) | One or two lines: 200 Three or four lines: 60 Five lines: 38
Grounding | E | M8 | 38
Grid Connected Output | R, S, T | M12 | 200 (2 connection is possible.)
Control signal etc | TB51 0~ 39 | M3 | 1.25(2) Note 2
Note 2: Number indicated inside the ( ) is JIS nonstandard terminal.
Mass820kg
P83B Grid connected
DIMENSIONAL TOLERANCES
4-ϕ19
Cable Hole (With cable support)
770
410
150
160
610
670
750
40
50
X-X
Cover
310
350
65
30
Cable Hole Details
Note1: The cover is attached to the cable hole on the side. In the case using the cable hole, or become in sequence with other equipment, please remove the cover.
N.TAZAWA 11-06-03
35735
NA.TAKIZAWA 11-06-03
Y.KONDOH 11-06-01
B E0121520 11-06-01
A FIRST EDITION: KONDOH 11-05-20
PV INVERTER MANUFACTURING SPECIFICATIONS
山洋電気株式会社 SANYO DENKI CO.,LTD.
00811456 B 3/4
A3G-F3



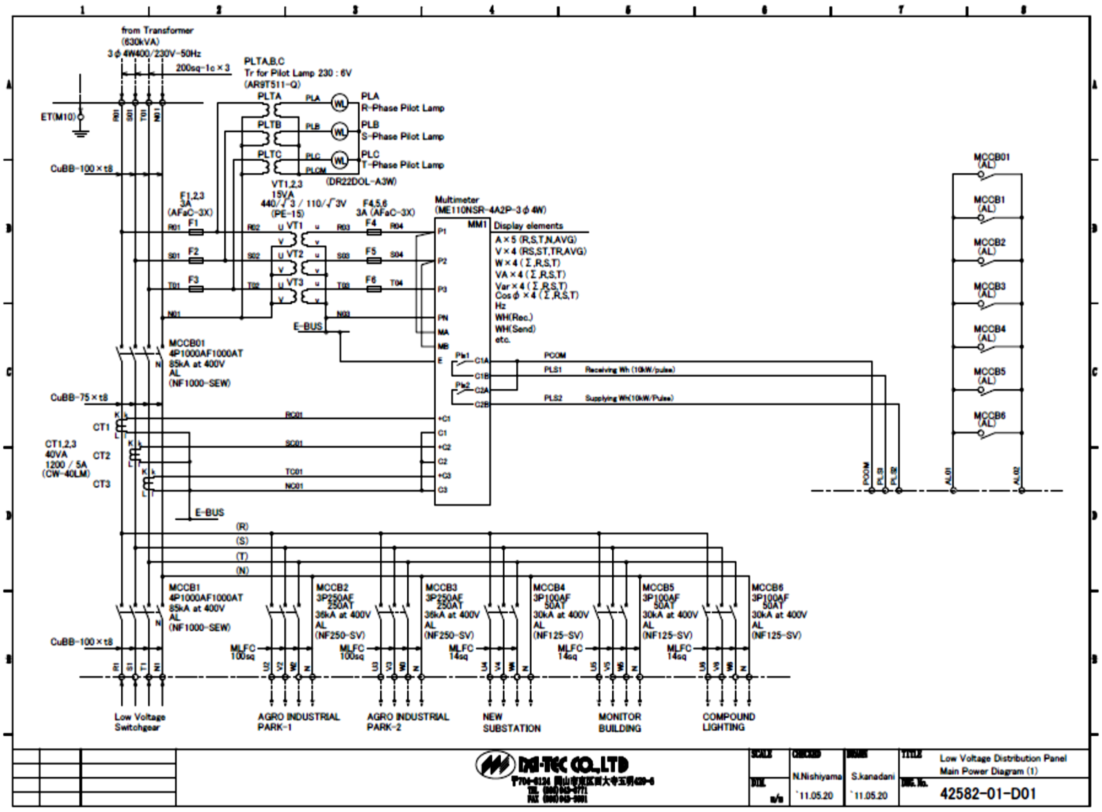
SOLAR CELL INPUT
600AF/500AT
MCCB51
LA
INV
T
C
MC11
400AF/400AT
MCCB11
LA
GRID CONNECTED OUTPUT
GROUND
SYNCHRONIZATION INPUT AND OUTPUT
REACTIVE POWER SYNCHRONIZATION
MEASUREMENT INPUT
• SOLAR IRRADIANCE
• TEMPERATURE
CONTACT INPUT
• EXTERNAL CONTROL
CONTROL CIRCUIT
GRID CONNECTED PROTECTIVE DEVICE
LCD DISPLAY
EXTERNAL COMMUNICATIONS
EXTERNAL SERIAL SIGNAL
CONTACT OUTPUT
• GRID CONNECTED OPERATION
• FAILURE
• GRID CONNECTED PROTECTIVE DEVICE ACTIVATED
P83B Grid connected
N.TAZAWA 11-06-03
35735
NA.TAKIZAWA 11-06-03
Y.KONDOH 11-06-01
B E0121520 11-06-01
A FIRST EDITION: KONDOH 11-05-20
PV INVERTER MANUFACTURING SPECIFICATIONS
山洋電気株式会社 SANYO DENKI CO.,LTD.
00811456 B 4/4
A3G-F3


Outline dimensions
Lifting eye bolt 4-φ35
Nameplate
100kVA TRANSFORMER
MCCB1
MCCB2
Terminal block
U1 V1 W1 u11 v11 w11 n11 E1
(MAX50)
Dry type transformer
Earth terminal (E0) (M8)
950
75
30
20
760
800
(MAX 820 (including protruding objects))
50
700
Hole for insertion of bolt 4-φ15
Cable entrance with insulating plate
100
400
200
X-X
Front
Circuit diagram
Contact preventing plate
3φ3W 202V
3φ4W 400V
T
MCCB1
MCCB2
W1
V1
U1
n11
w11
v11
u11
E1
E0
DIMENSIONAL TOLERANCES
DIMENSIONS | TOLERANCES A | B
120<L≤400 | ±2.0 | ±3.0
400<L≤1000 | ±2.0 | ±4.0
1000<L≤2000 | ±3.0 | ±6.0
2000<L≤4000 | ±4.0 | ±8.0
4000<L≤8000 | — | ±10.0
JEM1459-2005
unit: mm
1. General specifications
1.1 Rating Continuous use
1.2 Application For insulation
1.3 Service condition (1) Ambient temperature -10 to 40℃ (2) Relative humidity 30 to 90%
1.4 Insulating type Type H
1.5 Limit of humidity rise 110℃ or less (by thermometer method, but includes 10℃ of rise inside the enclosure)
1.6 Insulation resistance Insulation between coil and core and between coils should be more than 100MΩ with DC1000V applied.
1.7 Dielectric strength There should be no problem when applying 50/60Hz2000V of sine-wave AC voltage between coil and core and between coils for one minute.
1.8 Noise Should be lower noise as much as possible.
1.9 Structure Installed in the enclosure, structure and strength capable of hanging.
1.10 General standard Complying with JEC-2200
2. Electric specifications
■ A contact preventing plate should be installed between the primary and the secondary sides.
2.1 Rated output capacity 100kVA
2.2 Number of phases 3φ3W input, 3φ4W output
2.3 Primary rated voltage 202V (Δ-connection)
2.4 Secondary rated voltage 400V (Y-connection)
2.5 Rated frequency 50/60Hz±5%
2.6 Primary voltage fluctuation ±10%
2.7 Rate of voltage fluctuation ±3% (load power factor: 1.0)
2.8 Efficiency 97% or more (load power factor: 1.0)
2.9 Inrush current (secondary side) 10 times or less
2.10 Load power factor 0.8 to 1.0 (lagging)
3. Structure specifications
3.1 Indoor isolated enclosed type
3.2 Paint 5Y7/1 half-luster
3.3 External electric wires should be wired through the bottom. The enclosure should have the bottom plate, and a blind plate should be provided on the cable entrance.
4. Others
4.1 Circuit breaker MCCB1 : NF400-SW 400AF-350AT 3P (Mitsubishi Electric Corporation)
MCCB2 : NF250-SV 225AF-175AT 4P (Mitsubishi Electric Corporation)
4.2 Terminal block : PT400-3P (Toyogiken Co.,Ltd.) M12 Maximum diameter of connecting wire 200 (mm²)
PT400-5P (Toyogiken Co.,Ltd.) M12 Maximum diameter of connecting wire 200 (mm²)
Weight 640kg±10%
100kVA grid-connected
APPROVED BY N.TAZAWA 12-01-11
35735
UNIT mm
CHECKED BY NA.TAKIZAWA 12-01-11
TITLE Transformer Enclosure Manufacturing Specifications
A FIRST EDITION: KONDOH 12-01-11
SCALE
DESIGNED BY Y.KONDOH 12-01-11
REV. DESCRIPTION DATE
山洋電気株式会社
SANYO DENKI CO.,LTD.
SANYO DENKI CO., LTD. 2012-01-12 ISSUED
DWG NO. 00829978 REV. A
A3G-F3
00829978


Outline dimensions
Lifting eye bolt 4-φ35
Nameplate
100kVA TRANSFORMER
MCCB1
MCCB2
Terminal block
Dry type transformer
Earth terminal (E0) (M8)
Hole for insertion of bolt 4-φ15
Cable entrance with insulating plate
X-X
Front
Circuit diagram
Contact preventing plate
DIMENSIONAL TOLERANCES
1. General specifications
2. Electric specifications
3. Structure specifications
4. Others
Weight 640kg±10%
100kVA grid-connected
Transformer Enclosure Manufacturing Specifications
山洋電気株式会社
SANYO DENKI CO.,LTD.
DWG NO. 00829978 REV. A


to Low Voltage Distribution Panel
3φ4W400/230V-50Hz
200sq-1c×3
ET(M10)
CuBB-100×t8
F1,2,3
3A
(AFaC-3X)
F1
F2
F3
PLTA,B,C
Tr for Pilot Lamp 230 : 6V
(AR9T511-Q)
PLTA
PLTB
PLTC
PLA
R-Phase Pilot Lamp
PLB
S-Phase Pilot Lamp
PLC
T-Phase Pilot Lamp
(DR22D0L-A3W)
MCCB01
4P1000AF1000AT
85kA at 400V
AL
(NF1000-SEW)
CuBB-50×t8×II
CuBB-75×t8
(R)
(S)
(T)
(N)
MCCB1
MCCB2
MCCB3
MCCB4
MCCB5
3P225AF
225AT
36kA at 400V
AL
(NF250-SV)
MLFC
100sq
PV POWER CONDITIONER
<A>
<B>
<C>
<FUTURE>
100kW
MCCB01 (AL)
MCCB1 (AL)
MCCB2 (AL)
MCCB3 (AL)
MCCB4 (AL)
MCCB5 (AL)
DAI-TEC CO.,LTD
Low Voltage Switchgear
Main Power Diagram (1)
N.Nishiyama
S.kanadani
'11.05.20
42582-02-D01

A3 - Low Voltage Distribution Panel



A4 - Connection Box and Collection Box

CONNECTION BOX AND COLLECTION BOX

3.1 Equipment

1) Connection Box

Generated power by PV module is transferred to connection box. 30 sets of Connection boxes are installed near PV module.

DC power is gathered though diode in the connection box,.

Surge protection device is provided at input and output of circuit.

2) Collection Box

DC power from connection box is sent to 3 sets of collection boxes.

Power is sent from collection box to power conditioner.

Connection Box

Collection Box

3.2 Circuit Diagram

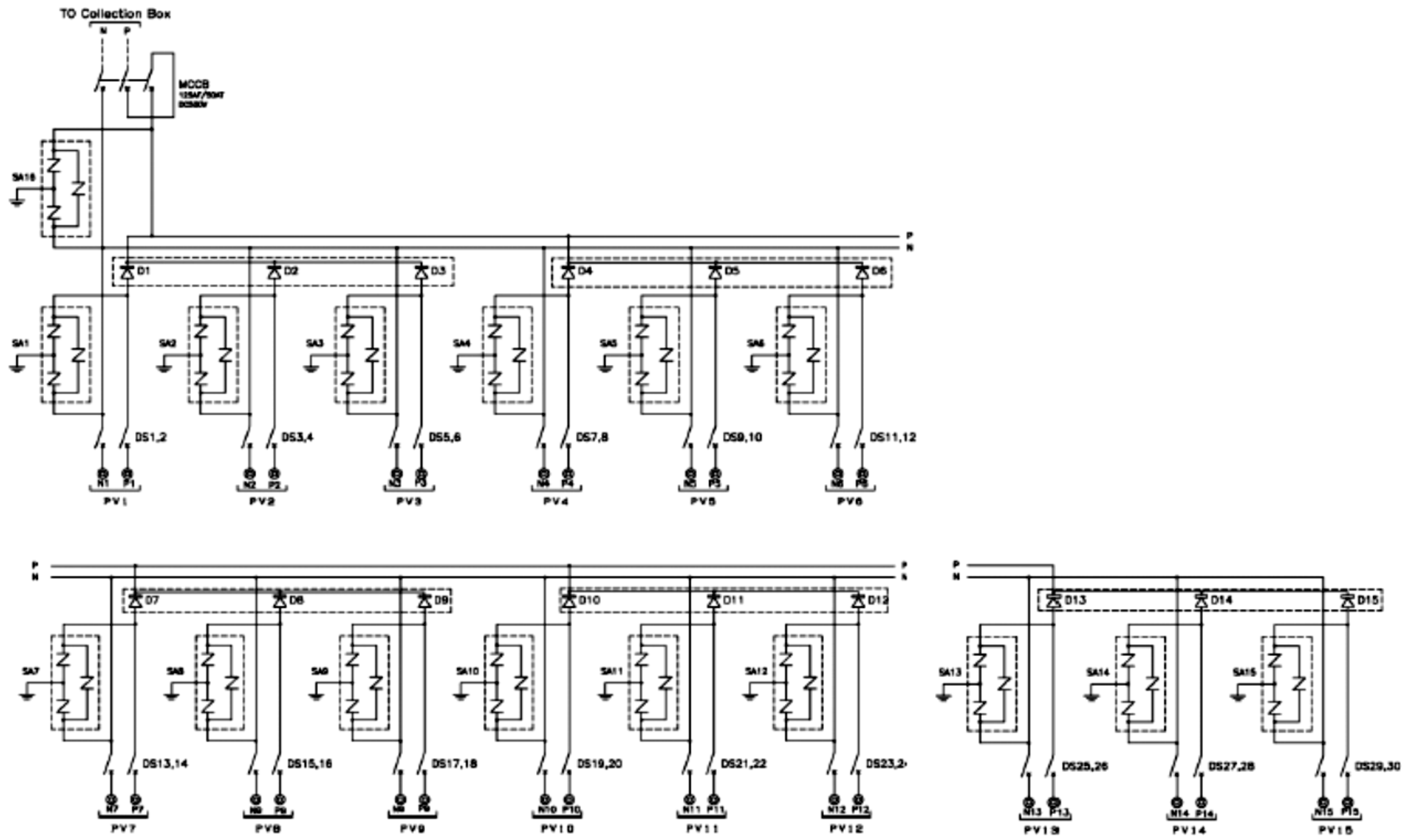


fig.3.2 Connection Box Circuit

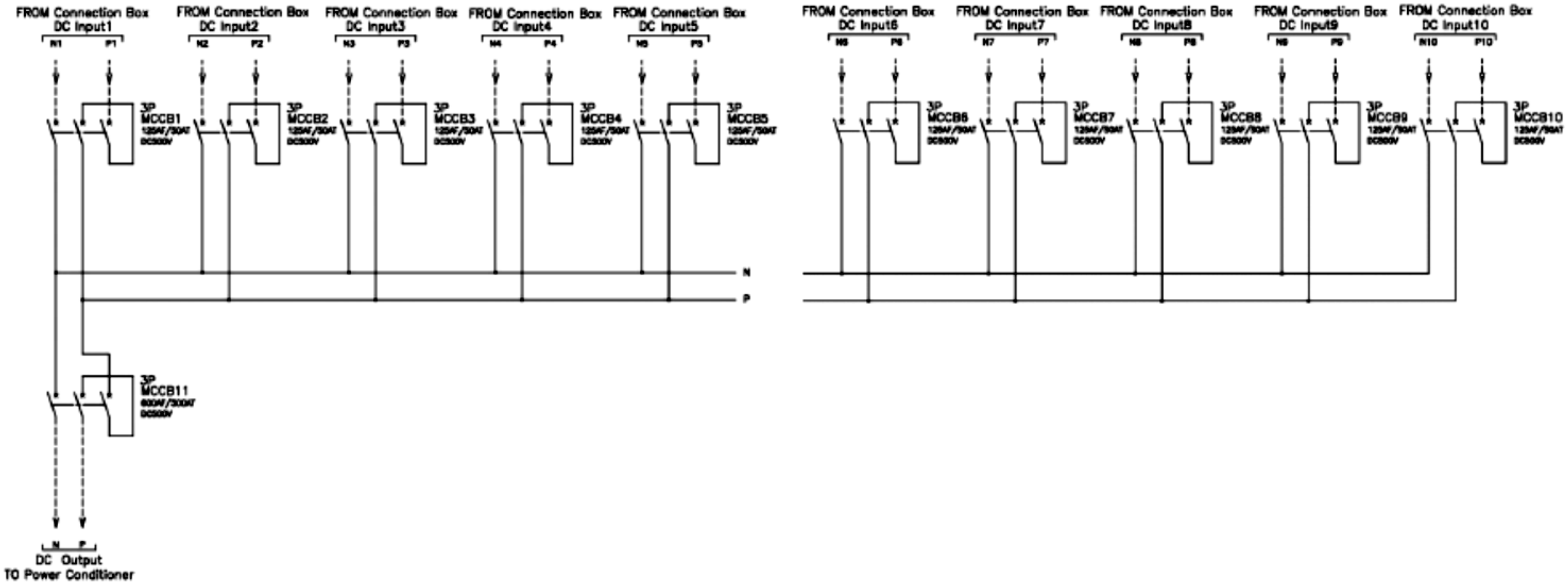
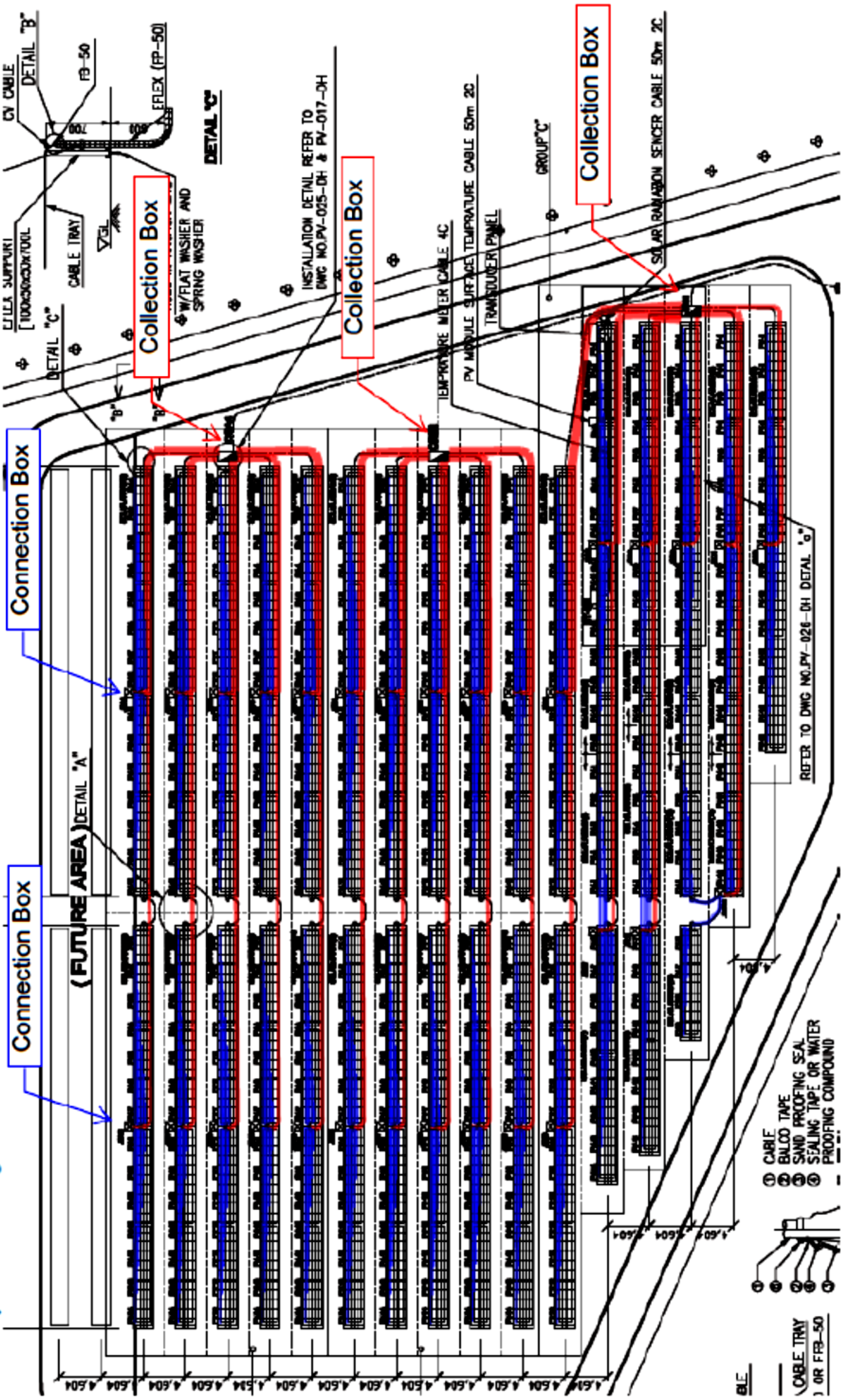


fig.3.3 Collection Box Circuit

3.3 Layout and Cabling



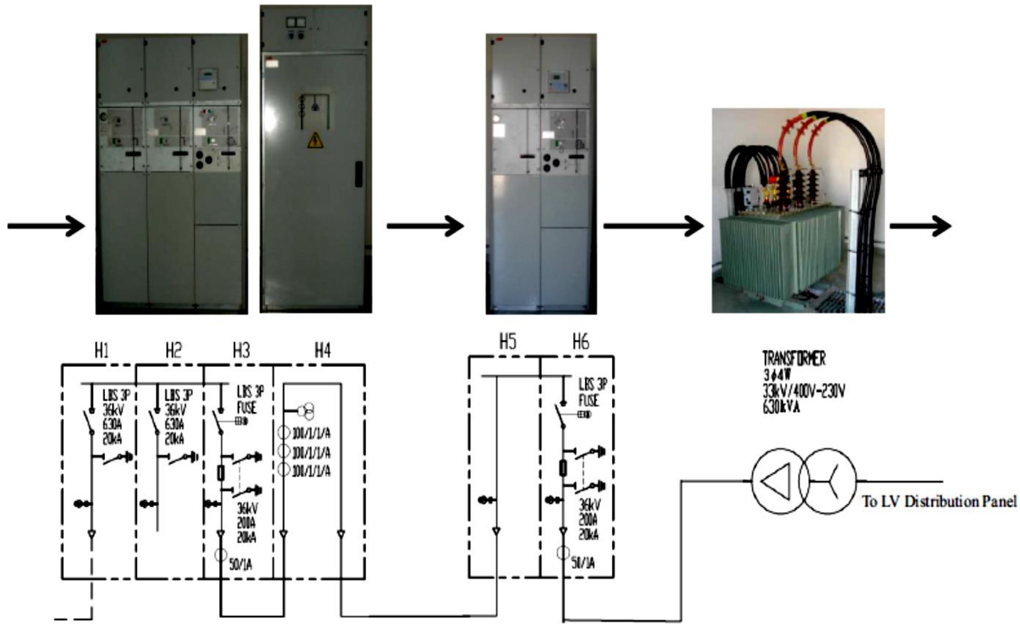
A5 - Substation System

SUBSTATION SYSTEM

6.1 Equipment

The substation consists of 6pce of MV panel and 630kVA transformer.

Power is received in AC 33kV and step down to AC 400-230V.



To Existing Switch Station

fig. 6.1 MV Circuit Diagram

Appendix B

Simulation Models

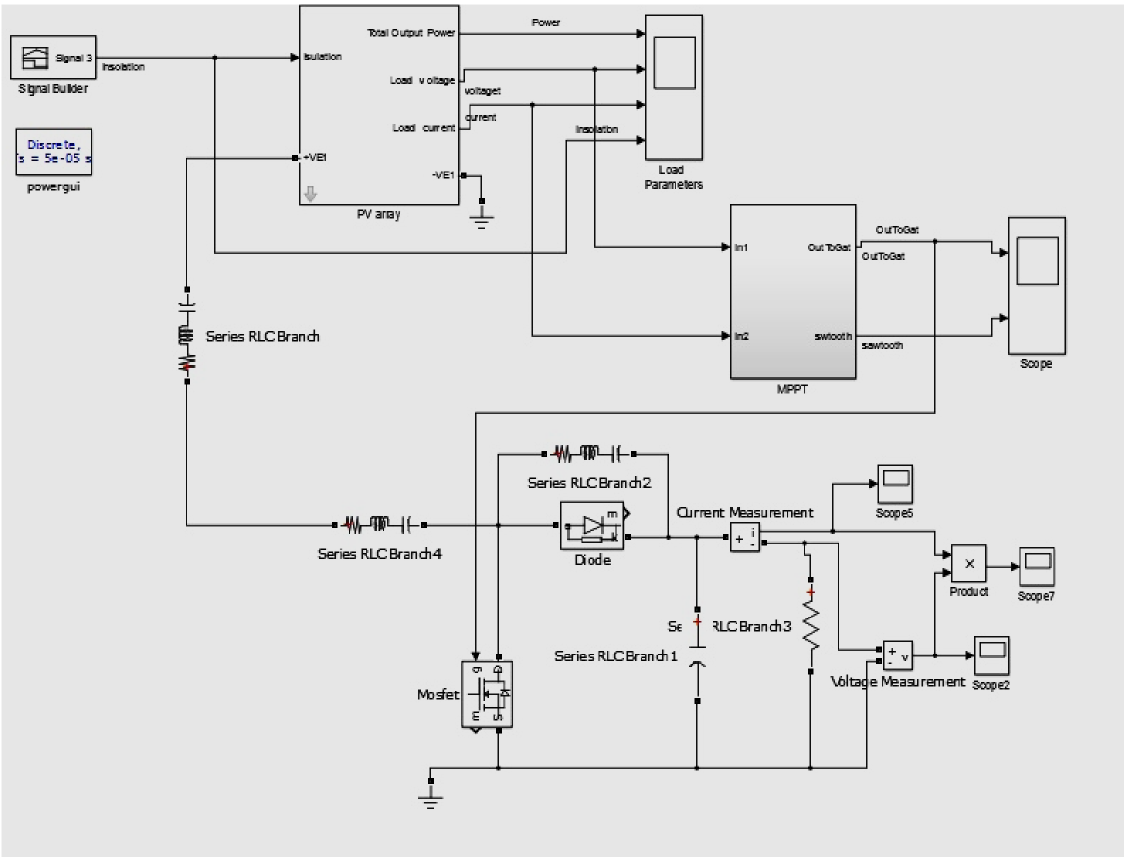


Figure (B.1): Simulink model of Grid tie PV system

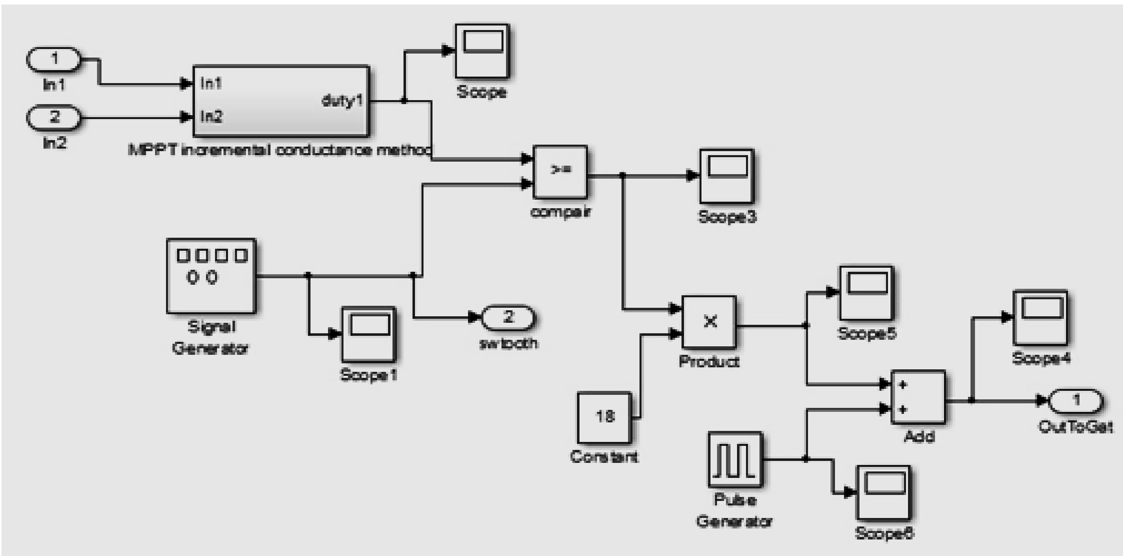


Figure (B.2): Maximum Power Point Tracking MPPT model

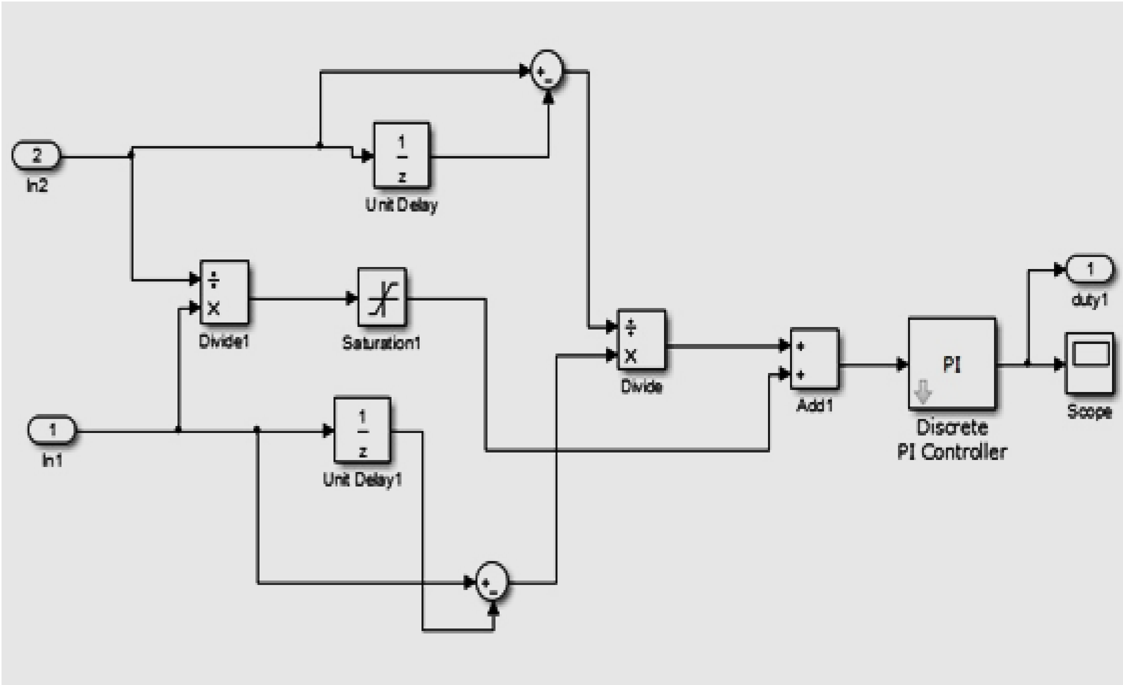


Figure (B.3): MPPT incremental conductance method model

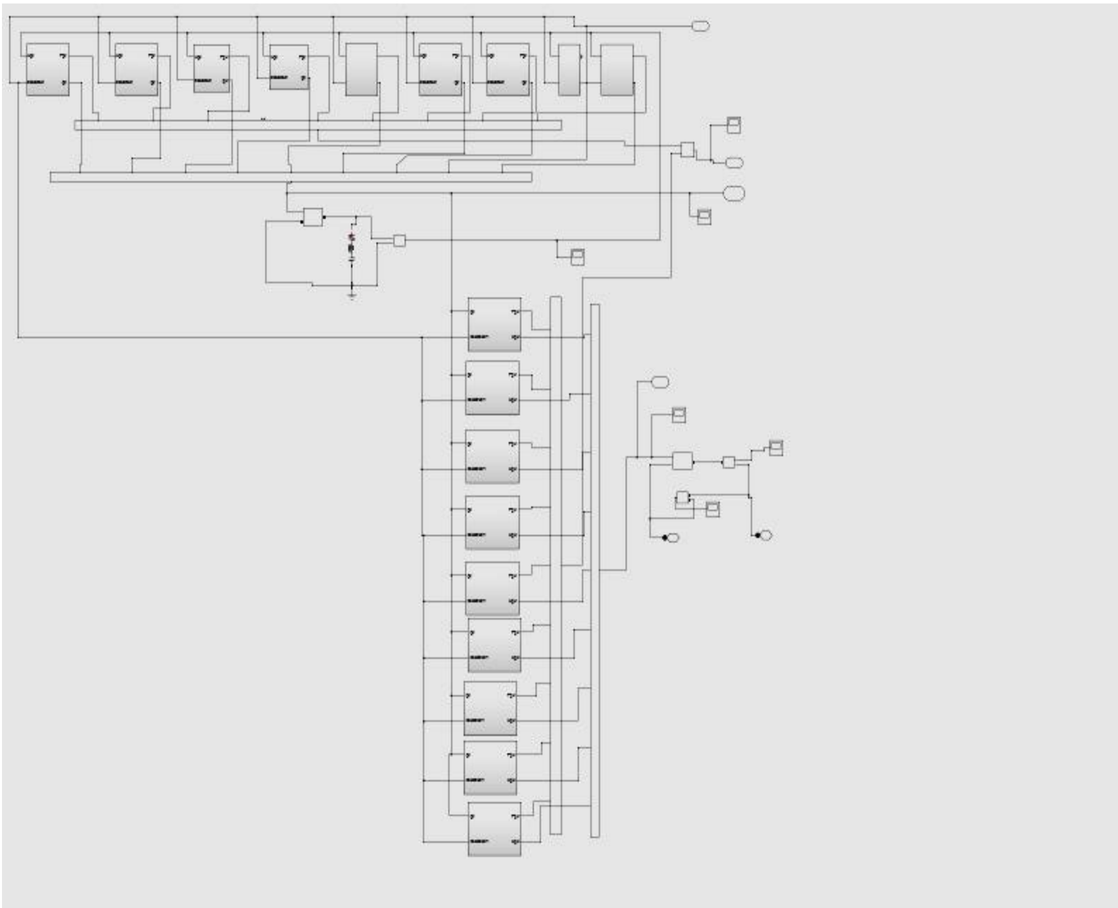


Figure (B.4): PV array modeling

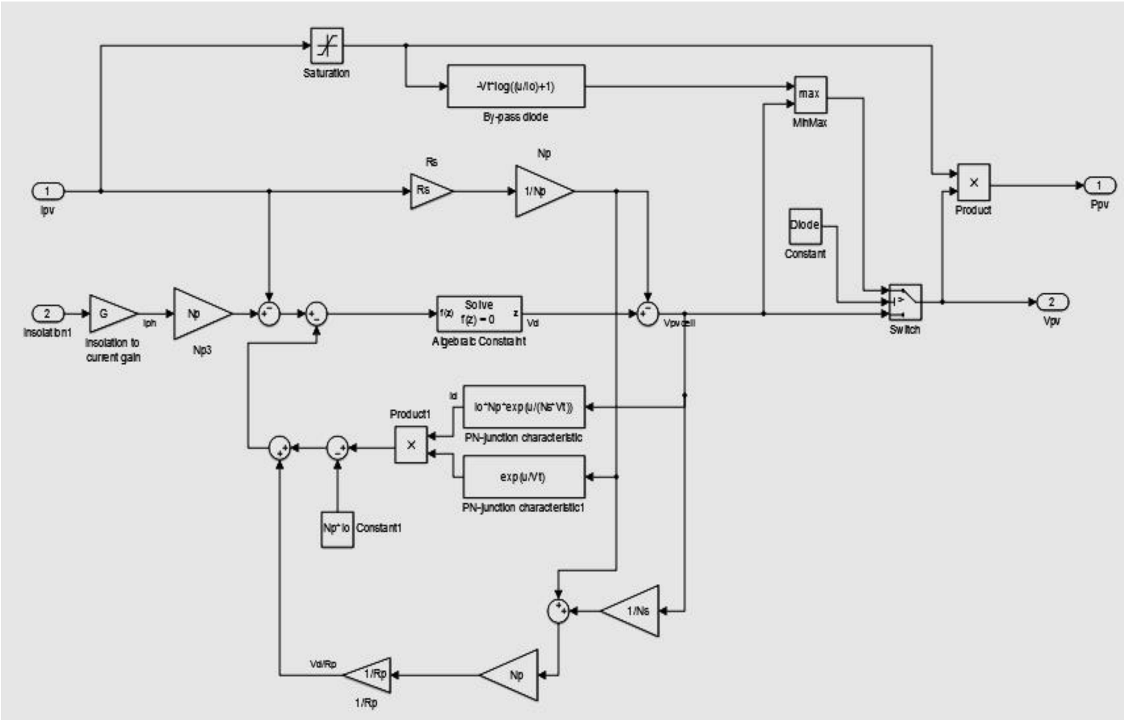


Figure (B.5): PV Module modeling

Appendix C

Performance Results of Jericho PV On-Grid System

Table C1 - Daily report (average for a hour) 11/16/2013

Time	Outdoor Air Temperature [°C]	Solar Radiation [Wh/m2]	PV Module Surface Temperature [°C]	PC1 Output Power [kWh]	PC2 Output Power [kWh]	PC3 Output Power [kWh]	Total Output Power Generated [kWh]
1:00	22.2	0	22.7	0.0	0.0	0.0	0.0
2:00	21.6	0	21.7	0.0	0.0	0.0	0.0
3:00	21.1	0	20.7	0.0	0.0	0.0	0.0
4:00	20.4	0	20.1	0.0	0.0	0.0	0.0
5:00	19.4	0	19.4	0.0	0.0	0.0	0.0
6:00	19.3	0	19.0	0.0	0.0	0.0	0.0
7:00	19.3	33	20.4	1.9	1.9	1.5	5.2
8:00	20.8	235	27.8	16.7	16.8	16.1	49.7
9:00	22.9	495	37.0	38.2	38.3	37.9	114.3
10:00	24.5	703	46.4	53.9	54.0	53.8	161.6
11:00	26.2	826	56.0	62.1	62.3	62.2	186.6
12:00	27.4	859	61.2	64.4	64.5	64.5	193.4
13:00	28.6	808	61.6	60.6	60.7	60.6	182.0
14:00	29.9	651	56.5	48.5	48.5	48.3	145.3
15:00	29.4	436	49.1	31.6	31.6	31.1	94.2
16:00	29.0	183	38.3	12.3	12.3	11.6	36.3
17:00	26.2	11	27.5	0.6	0.6	0.2	1.4
18:00	24.3	0	23.8	0.0	0.0	0.0	0.0
19:00	23.9	0	23.5	0.0	0.0	0.0	0.0
20:00	22.6	0	21.6	0.0	0.0	0.0	0.0
21:00	22.7	0	21.9	0.0	0.0	0.0	0.0
22:00	22.8	0	22.7	0.0	0.0	0.0	0.0
23:00	22.1	0	22.1	0.0	0.0	0.0	0.0
24:00	20.8	0	20.2	0.0	0.0	0.0	0.0
Sum		5,240		390.8	391.5	387.8	1,170.0
Ave	23.6	218	31.7	16.3	16.3	16.2	48.8
Max	29.9	859	61.6	64.4	64.5	64.5	193.4
Min	19.3	0	19.0	0.0	0.0	0.0	0.0

Amount of Generated Energy	1,170.1 kWh

Amount of Reduction of CO2	717.3 kg

Amount of Power Sold of JDECO	1,080.0 kWh

Table C2 - Daily report (maximum) 11/16/2013

Time	Outdoor Air Temperature [°C]	Solar Radiation [W/m2]	PV Module Surface Temperature [°C]	PC1 Output Power [kW]	PC2 Output Power [kW]	PC3 Output Power [kW]	Total Output Power Generated [kW]
1:00	22.6	0	23.2	0.0	0.0	0.0	0.0
2:00	21.9	0	22.2	0.0	0.0	0.0	0.0
3:00	21.4	0	21.0	0.0	0.0	0.0	0.0
4:00	21.3	0	20.8	0.0	0.0	0.0	0.0
5:00	19.7	0	19.8	0.0	0.0	0.0	0.0
6:00	19.7	0	19.6	0.0	0.0	0.0	0.0
7:00	19.6	112	22.6	7.0	7.0	6.2	20.3
8:00	22.2	371	32.9	27.8	27.8	27.3	83.0
9:00	23.5	623	41.5	48.3	48.4	48.2	144.9
10:00	25.3	781	50.4	59.3	59.3	59.2	177.8
11:00	27.3	885	60.4	66.5	66.8	66.9	200.2
12:00	28.4	886	63.2	66.1	66.4	66.5	199.0
13:00	30.2	864	63.9	64.2	64.3	64.3	192.9
14:00	30.8	755	59.7	56.0	56.1	55.9	167.9
15:00	30.1	565	53.3	41.5	41.7	41.2	124.4
16:00	29.8	311	43.7	22.1	22.1	21.6	65.9
17:00	27.9	54	32.3	3.7	3.7	2.6	10.0
18:00	25.1	2	24.5	0.0	0.0	0.0	0.0
19:00	25.0	0	24.1	0.0	0.0	0.0	0.0
20:00	23.3	0	22.3	0.0	0.0	0.0	0.0
21:00	23.3	1	22.9	0.0	0.0	0.0	0.0
22:00	23.4	0	23.0	0.0	0.0	0.0	0.0
23:00	22.4	0	22.4	0.0	0.0	0.0	0.0
24:00	21.4	0	21.3	0.0	0.0	0.0	0.0
Sum							
Ave							
Max	30.8	886	63.9	66.5	66.8	66.9	200.2
Min	18.9	0	18.6	0.0	0.0	0.0	0.0

Amount of Generated Energy	1,170.1 kWh

Max Solar Radiation	886 W/m2	11:25

Amount of Reduction of CO2	717.3 kg

Amount of Power Sold to JDECO	1,080.0 kWh

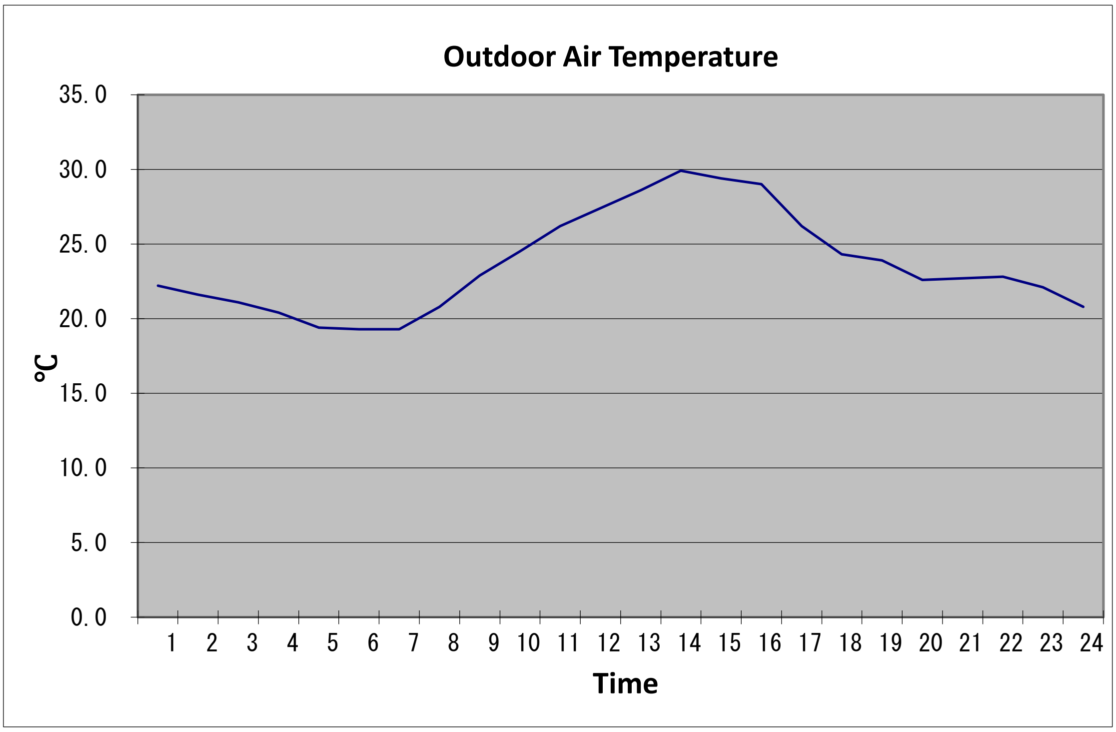


Figure (C1): Daily Outdoor Air Temperature

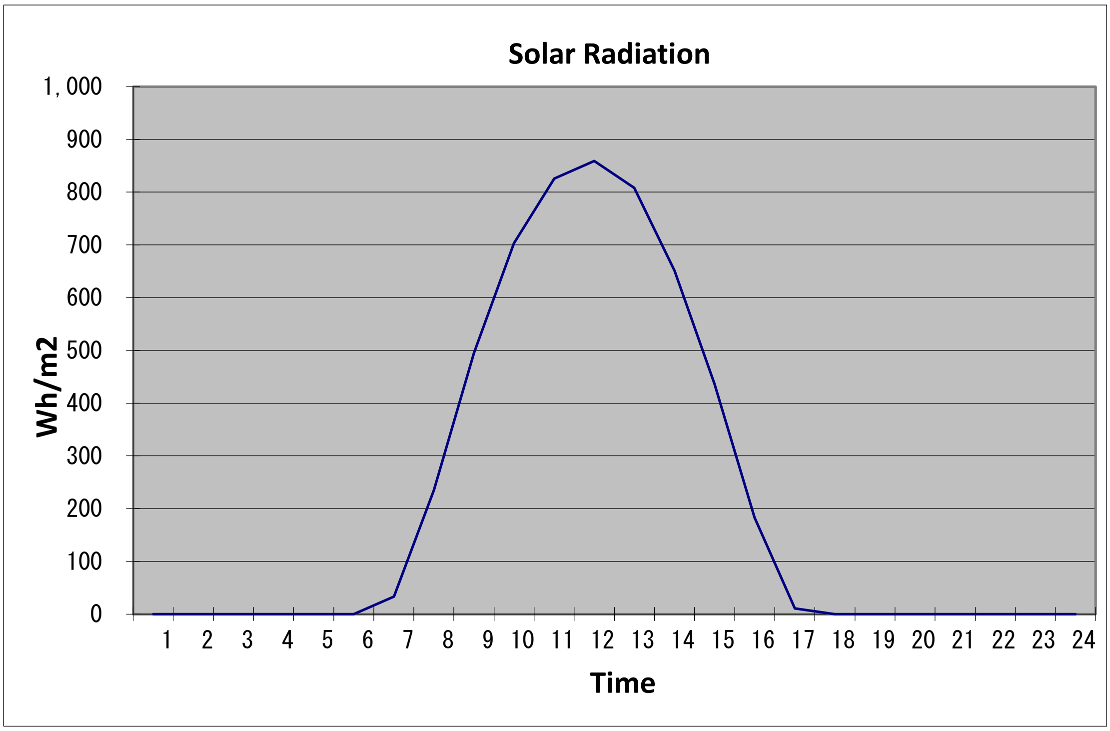


Figure (C2): Daily Solar Radiation

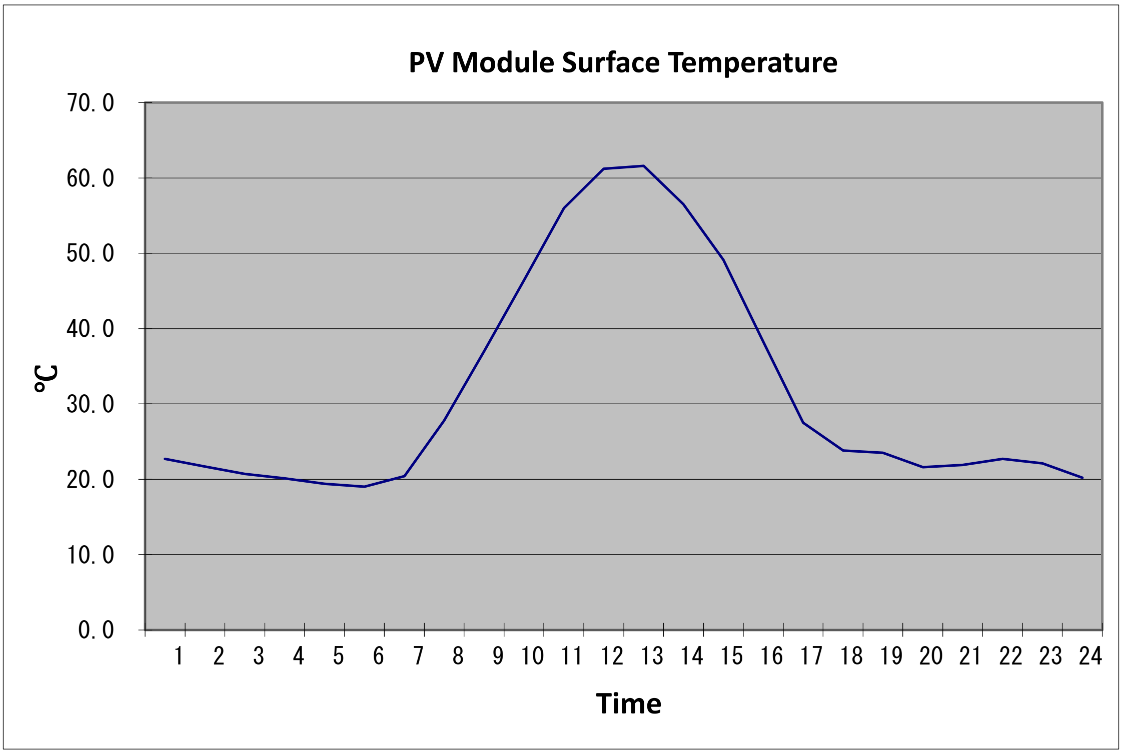


Figure (C3): Daily PV Module Surface Temperature

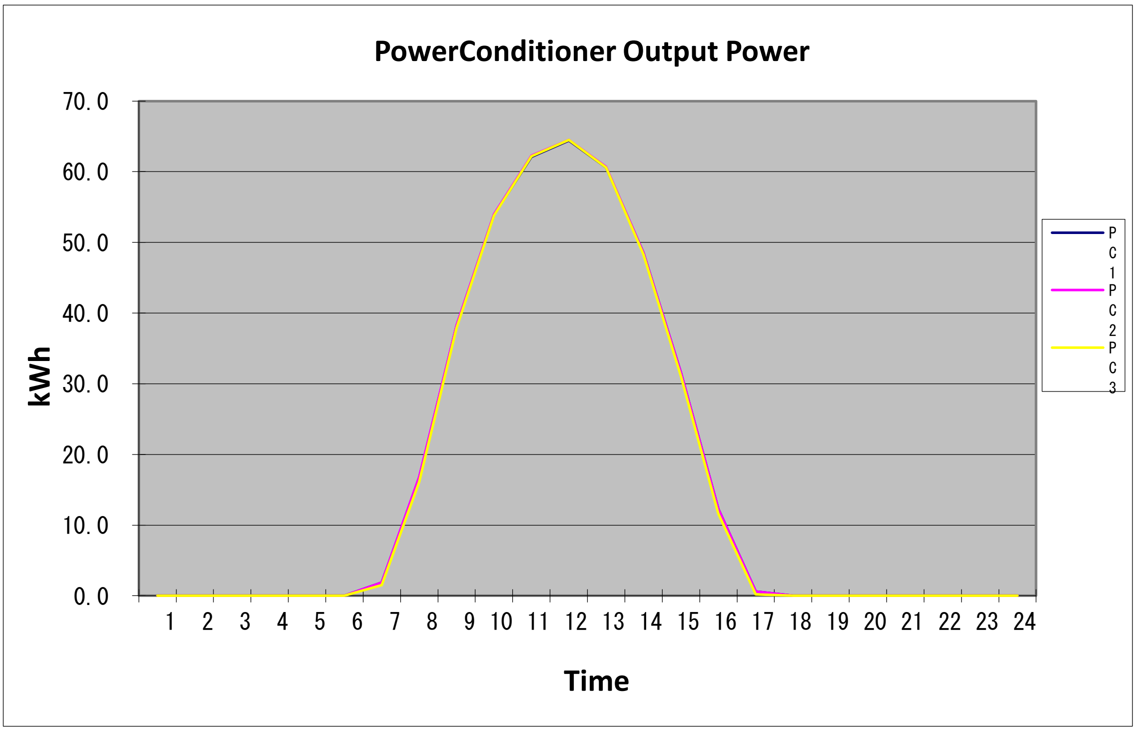


Figure (C4): Daily Power Conditioner Output Power

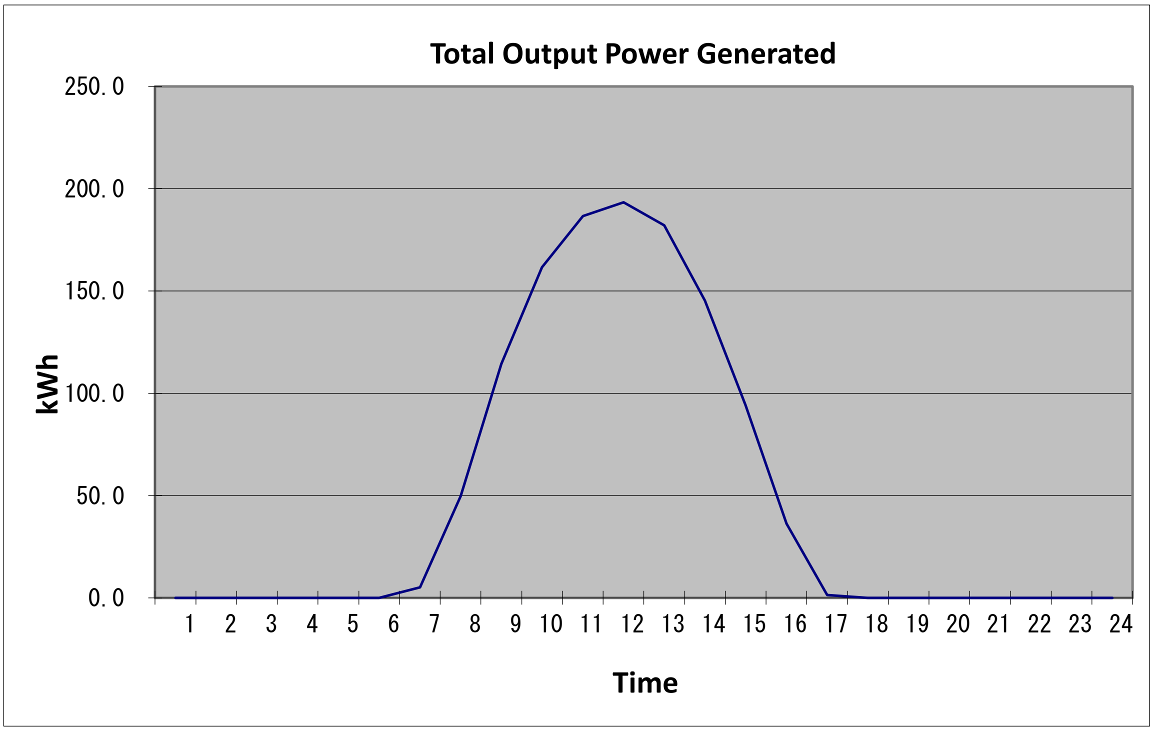


Figure (C5): Daily Total Output Power Generated

Table C3 - Monthly report (Average for a day or sum) 2013/10

Date	Outdoor Air Temperature [°C]	Solar Radiation [Wh/m2]	PV Module Surface Temperature [°C]	PC1 Output Power [kWh]	PC2 Output Power [kWh]	PC3 Output Power [kWh]	Total Output Power Generated [kWh]
1	30.1	6,756	39.4	478.1	481.3	481.7	1,441.1
2	29.9	6,632	39.4	472.8	476.1	476.5	1,425.4
3	30.2	6,354	38.8	447.1	450.4	451.5	1,349.0
4	28.0	6,285	35.7	451.4	454.2	454.0	1,359.6
5	26.8	6,692	35.4	481.0	482.5	482.6	1,446.1
6	25.2	5,920	33.2	425.4	426.4	426.3	1,278.1
7	7.6	1,790	9.5	519.0	522.0	522.3	1,563.3
8	0.0	0	0.0	490.8	494.1	494.4	1,479.3
9	0.0	0	0.0	473.4	477.0	477.7	1,428.1
10	0.0	0	0.0	487.0	491.0	491.7	1,469.7
11	0.0	0	0.0	461.0	464.7	464.9	1,390.6
12	0.0	0	0.0	471.3	475.3	476.2	1,422.8
13	0.0	0	0.0	471.9	475.3	476.0	1,423.2
14	0.0	0	0.0	447.7	451.0	451.6	1,350.3
15	0.0	0	0.0	464.4	468.3	468.4	1,401.1
16	0.0	0	0.0	457.5	461.1	461.7	1,380.3
17	17.5	4,878	24.2	412.9	412.1	419.6	1,244.6
18	26.9	5,757	33.2	408.3	411.2	411.3	1,230.8
19	26.9	5,449	34.5	392.4	394.2	391.3	1,177.9
20	25.4	6,798	33.2	478.2	481.7	482.1	1,442.0
21	26.3	6,176	32.7	424.2	427.8	427.2	1,279.2
22	27.3	6,297	33.2	430.9	435.8	435.9	1,302.6
23	26.8	6,253	34.6	427.9	433.5	433.4	1,294.8
24	24.2	5,440	35.6	380.1	384.9	386.1	1,151.1
25	-	-	-	-	-	-	-
26	25.3	1,595	28.9	102.6	104.2	103.5	310.3
27	24.7	6,136	33.0	414.4	420.6	420.8	1,255.8
28	24.1	6,528	31.7	435.1	441.6	442.7	1,319.4
29	27.7	5,755	32.9	384.0	388.7	387.8	1,160.5
30	26.7	2,726	30.6	209.8	209.2	205.0	624.0
31	26.3	5,086	33.1	383.2	382.6	381.5	1,147.3
Sum		115,303		12,783.8	12,878.8	12,885.7	38,548.3
Ave	17.8	3,843	22.8	426.1	429.3	429.5	1,284.9
Max	30.2	6,798	39.4	519.0	522.0	522.3	1,563.3
Min	0.0	0	0.0	102.6	104.2	103.5	310.3

Amount of Generated Energy	38,547.9 kWh

Amount of Reduction of CO2	23,629.8 kg

Amount of Power Sold of JDECO	21,440.0 kWh

Table C4 - Monthly report (Maximum) 2013/10

Date	Outdoor Air Temperature [℃]	Solar Radiation [W/m2]	PV Module Surface Temperature [℃]	PC1 Output Power [kW]	PC2 Output Power [kW]	PC3 Output Power [kW]	Total Output Power Generated [kW]
1	39.2	996	72.1	71.3	71.6	72.1	215.0
2	38.1	978	70.2	70.0	70.3	70.9	211.2
3	38.3	966	65.2	68.9	69.3	70.2	208.4
4	35.5	1,253	63.0	89.4	89.8	92.5	271.7
5	33.9	1,185	63.4	83.8	85.9	84.4	254.1
6	33.7	1,244	64.8	88.6	89.1	90.3	268.0
7	25.7	890	56.6	76.9	77.2	77.7	231.8
8	0.0	0	0.0	70.5	70.9	71.3	212.8
9	0.0	0	0.0	69.2	69.4	70.2	208.9
10	0.0	0	0.0	72.8	73.3	74.0	220.1
11	0.0	0	0.0	68.8	69.1	69.7	207.6
12	0.0	0	0.0	70.7	71.3	71.9	213.8
13	0.0	0	0.0	70.2	70.5	71.2	211.9
14	0.0	0	0.0	69.1	69.5	70.2	208.8
15	0.0	0	0.0	69.4	69.9	70.4	209.6
16	0.0	0	0.0	71.0	71.5	72.1	214.6
17	35.3	934	69.3	65.7	66.1	66.5	198.3
18	36.3	970	59.0	67.9	68.5	69.3	205.7
19	34.5	1,198	65.6	83.9	85.1	85.9	255.0
20	32.0	1,005	63.3	71.4	71.9	72.5	215.8
21	33.9	913	58.6	63.0	63.4	63.8	190.1
22	35.9	937	60.5	65.9	66.6	67.0	199.5
23	35.4	941	68.5	65.0	65.8	66.1	196.8
24	33.0	958	65.7	67.4	68.1	68.6	204.1
25	-	-	-	-	-	-	-
26	33.6	786	60.7	52.3	53.1	53.4	158.8
27	32.8	964	68.1	65.6	66.3	66.7	198.6
28	31.8	986	61.7	67.9	68.7	69.4	206.0
29	35.0	888	55.8	60.9	61.6	62.0	184.4
30	30.9	754	49.3	57.6	57.5	57.6	172.8
31	33.7	924	61.4	69.8	69.7	70.2	209.7
Sum							
Ave							
Max	39.2	1,253	72.1	89.4	89.8	92.5	271.7
Min	0.0	0	0.0	0.0	0.0	-3.1	-3.1

Amount of Generated Energy	38,547.9 kWh

Max Solar Radiation	1,253 W/m2	10/04 11:41

Amount of Reduction of CO2	23,629.8 kg

Amount of Power Sold to JDECO	21,440.0 kWh

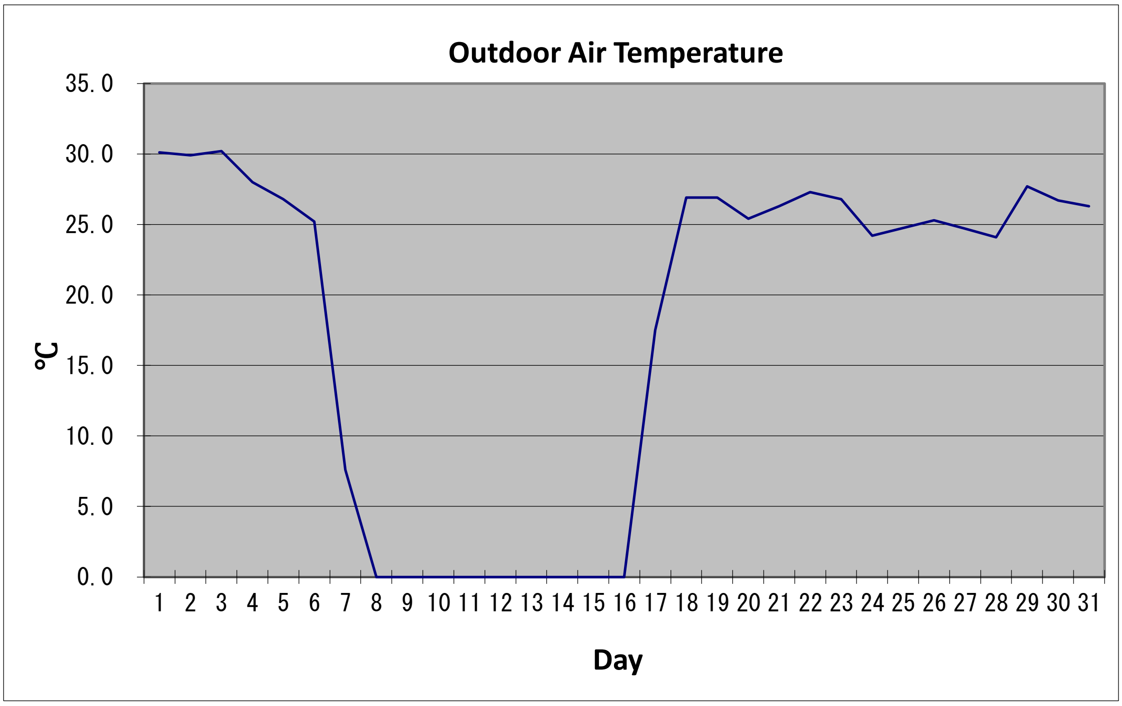


Figure (C6): Monthly Output Air Temperature

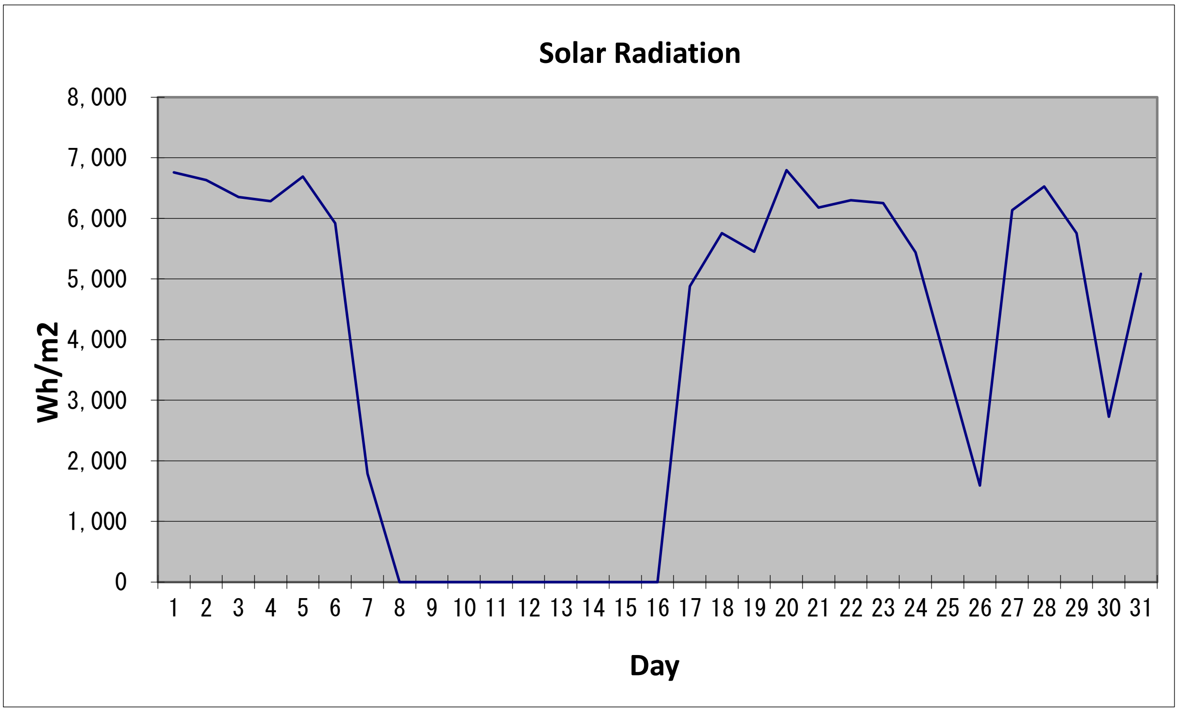


Figure (C7): Monthly Solar Radiation

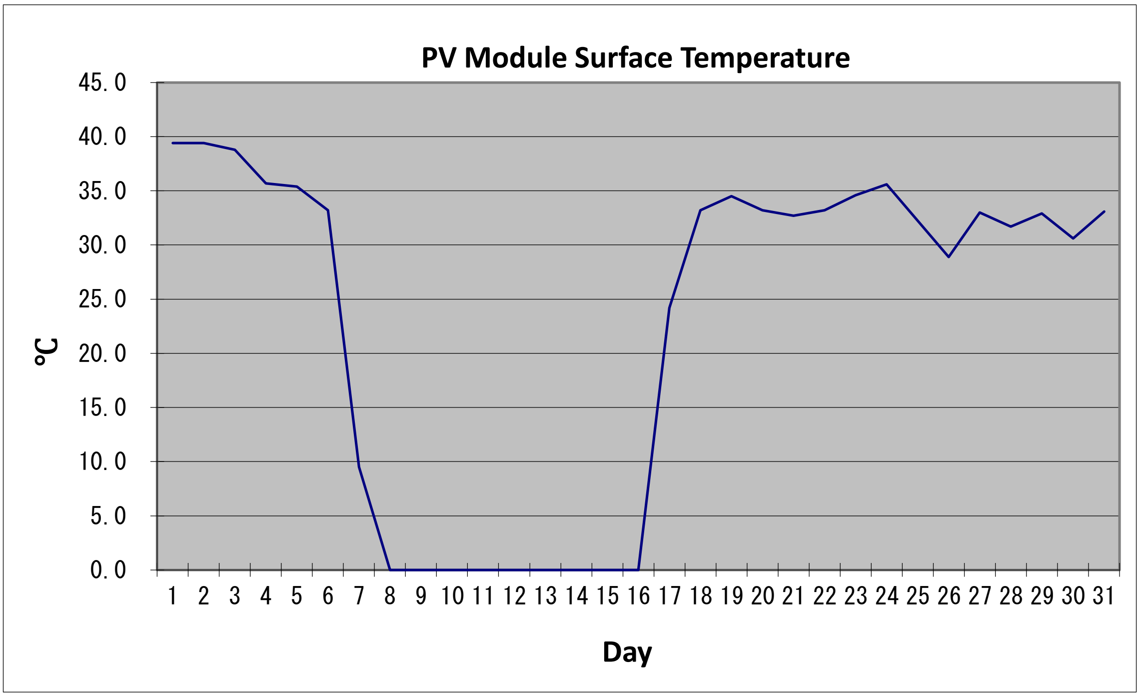


Figure (C7): Monthly PV Module Surface Temperature

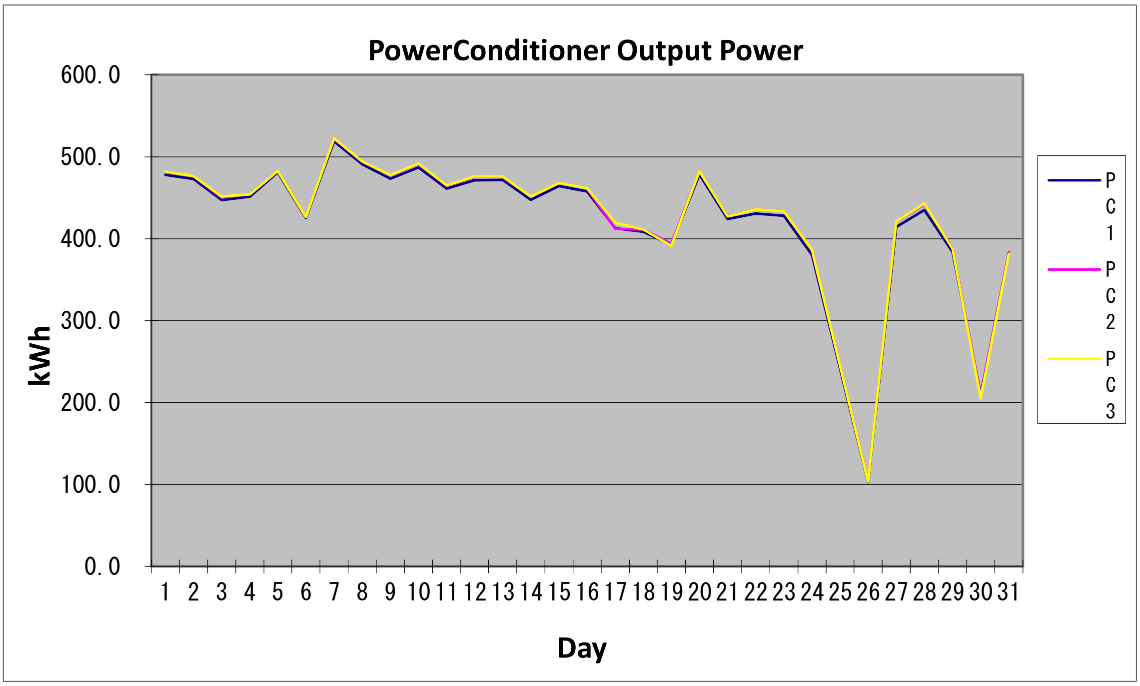


Figure (C8): Monthly Power Conditioner Output Power

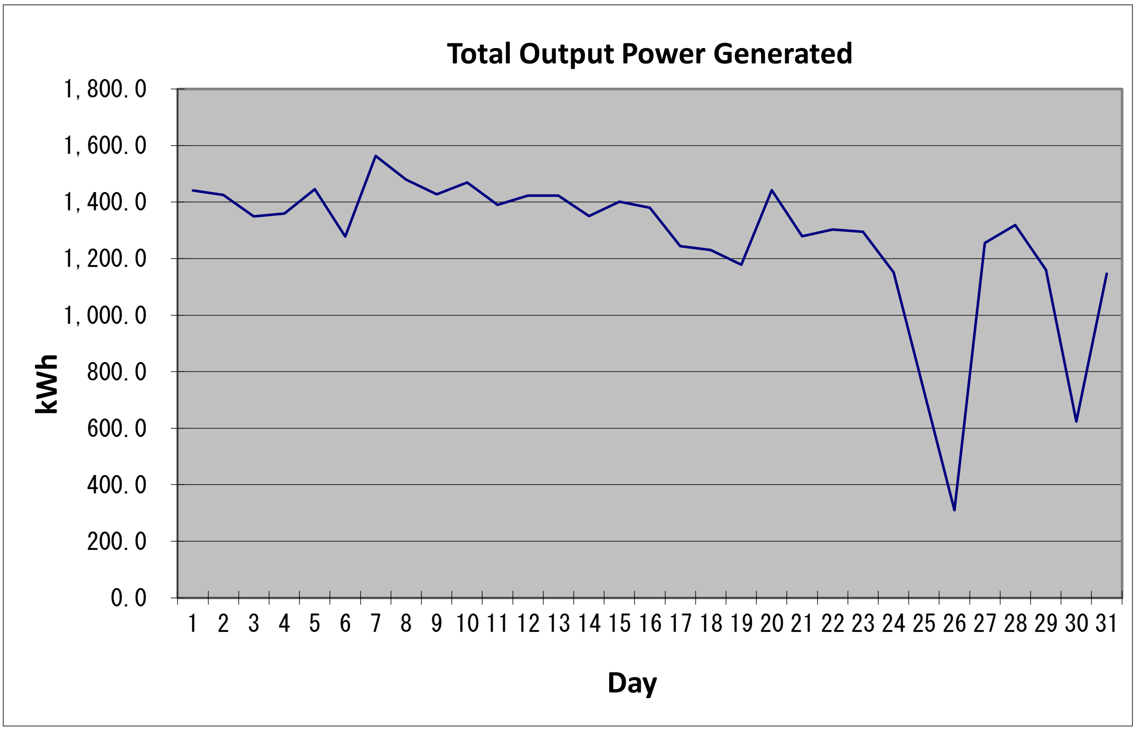


Figure (C9): Monthly Total Output Power Generated

Appendix D

Simulation Results

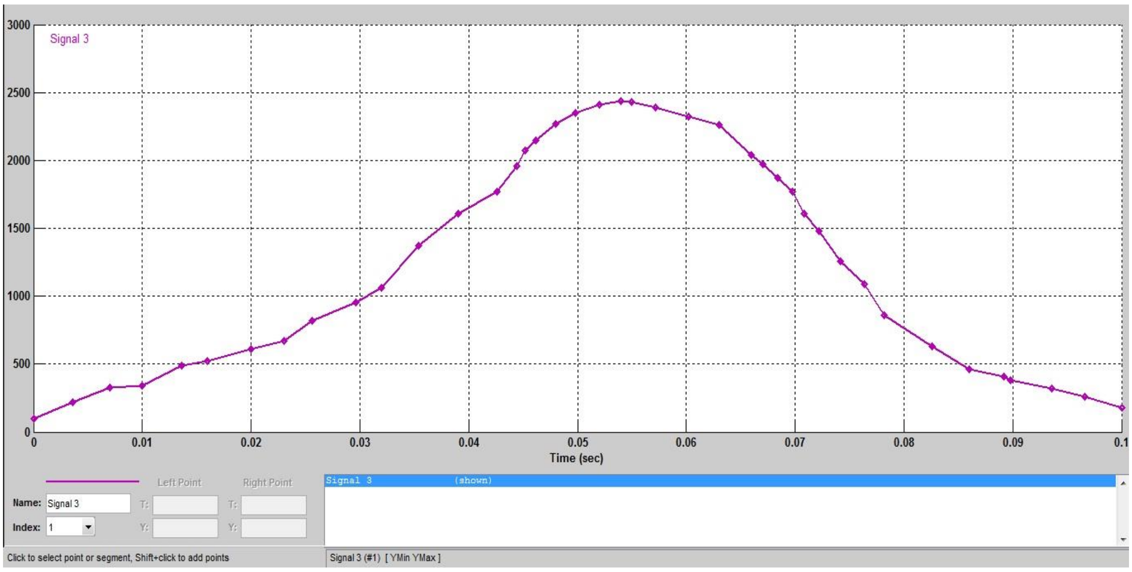


Figure (D.1): Solar radiation versus time [Y - axis: solar radiation (kW/m^2), X - axis: time (sec)]

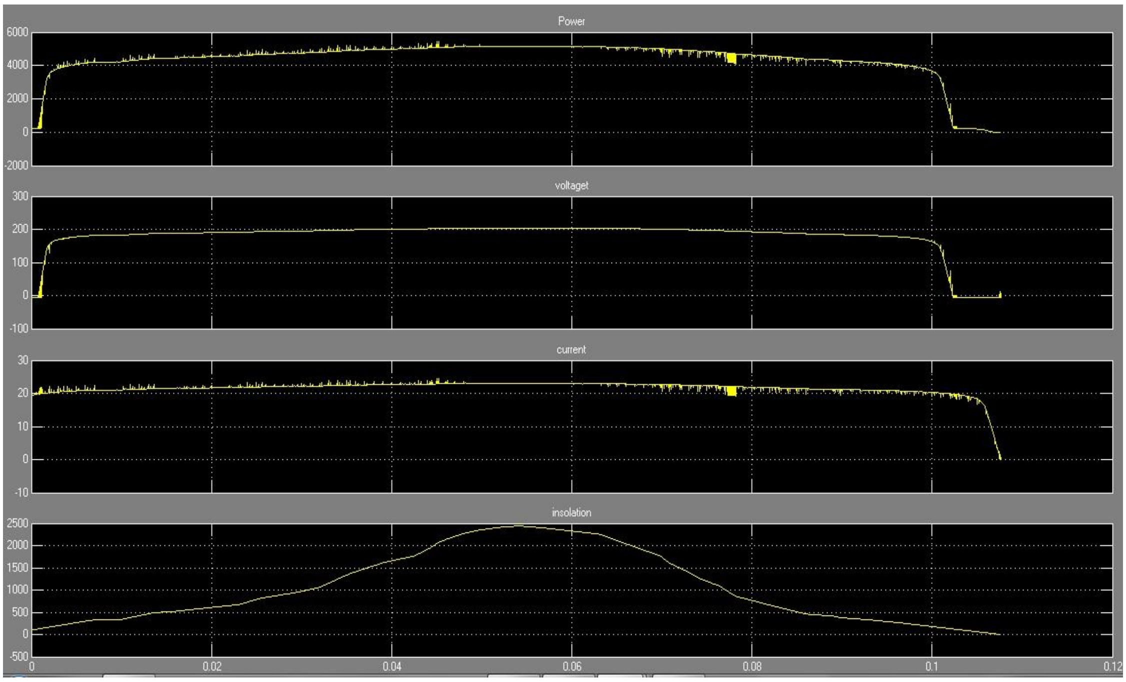


Figure (D.2): Output power (kW), output voltage (volt) and output current from PV array and MPPT duty cycle with changing a radiation (kW/m^2), [X - axis: time (sec)].

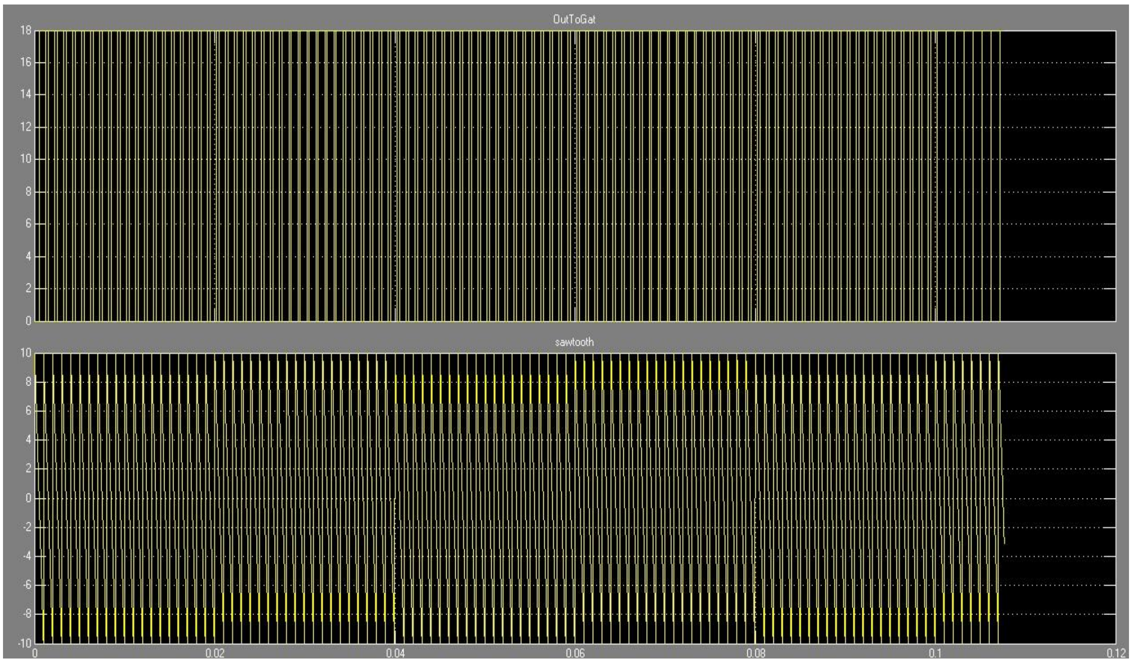


Figure (D.3): Output voltage v-AC PV array by using constant voltage MPPT controller [Y - axis: voltage (volt), X - axis: time (sec)] and current i-AC [Y - axis: current (A), X - axis: time (sec)] from grid tie inverter with deference radiation.

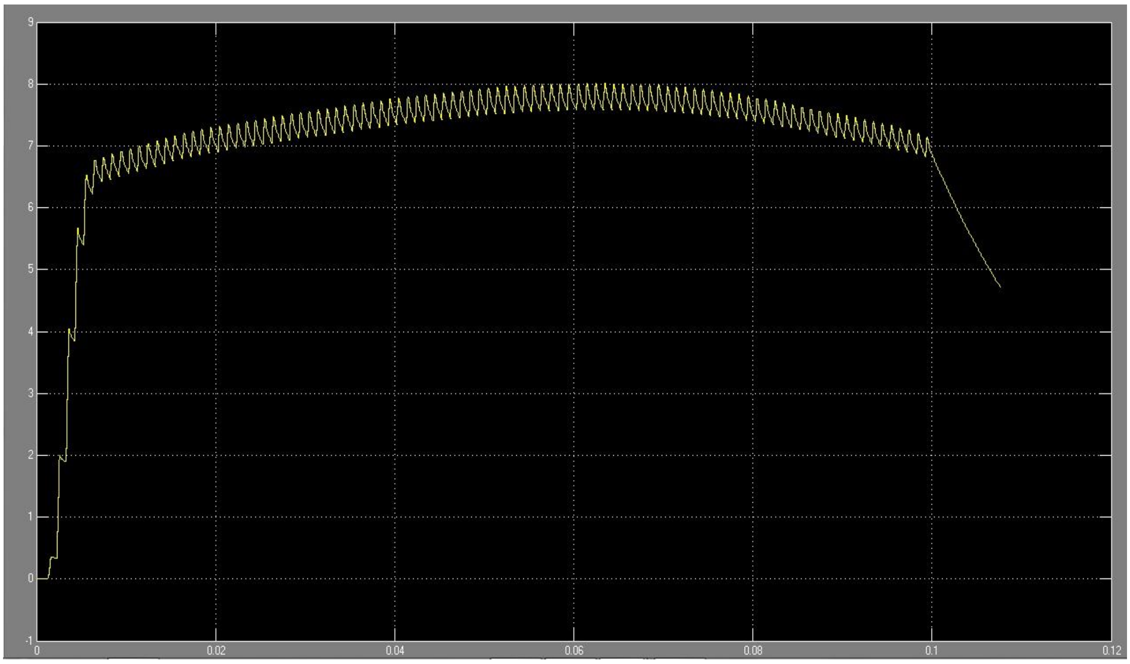


Figure (D.4): Current of PV array by using constant voltage MPPT controller [Y-axis: current (A), X - axis: time (sec)].

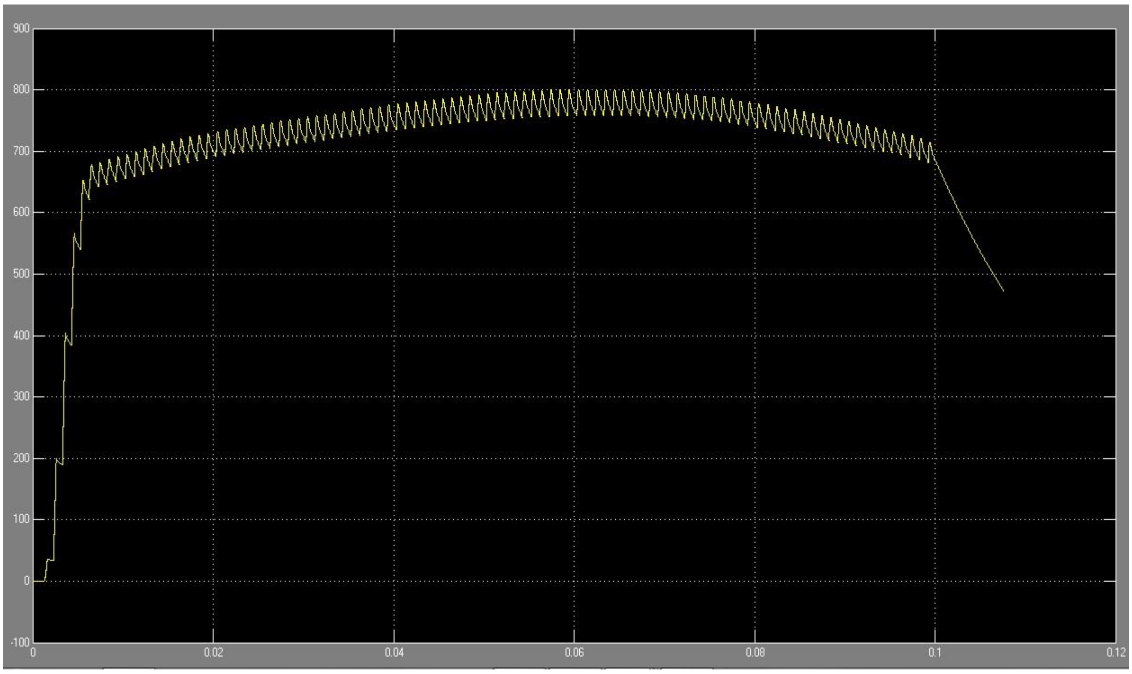


Figure (D.5): MPP voltage regulation of PV array by constant voltage MPPT controller [Y - axis: voltage (volt), X - axis: time (sec)].

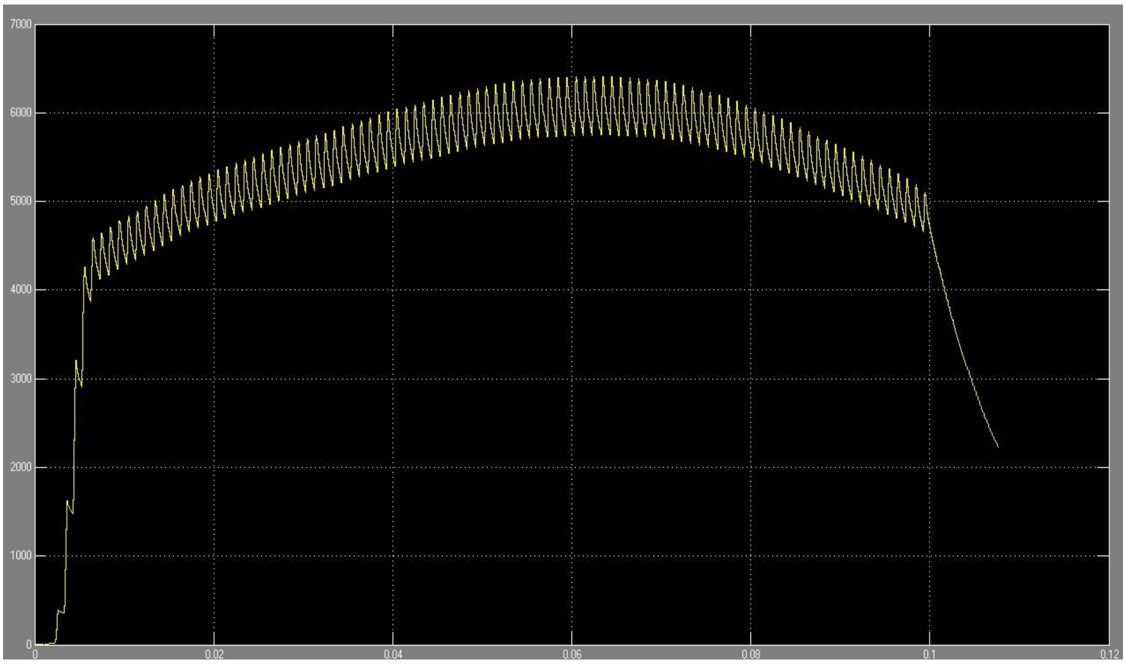


Figure (D.6): The power output from PV array with constant voltage MPPT controller [Y - axis: power (watt), X - axis: time (sec)].

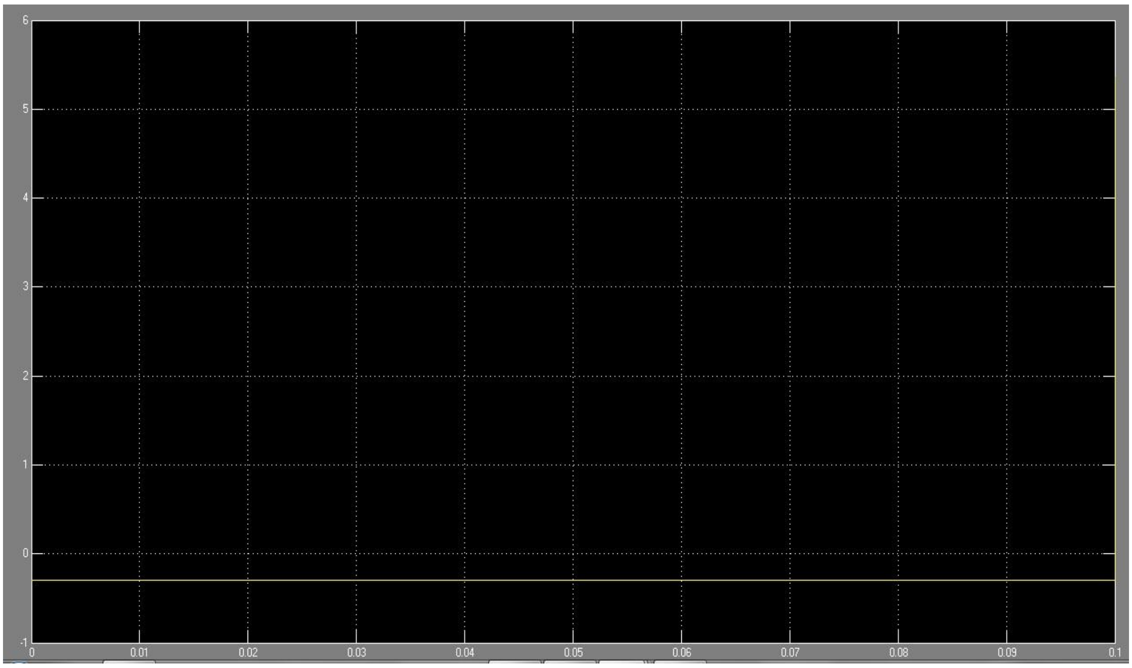


Figure (D.7): MPP voltage regulation of PV array by constant voltage MPPT controller with incremental conductance method [Y - axis: voltage (volt), X - axis: time (sec)].

Appendix E

Table of interest at i = 10%

	Single Payments		Uniform-Series Payments				Uniform Gradient	
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Annual Series A/G
1	1.1000	0.9091	1.00000	1.0000	1.10000	0.9091		
2	1.2100	0.8264	0.47619	2.1000	0.57619	1.7355	0.8264	0.4762
3	1.3310	0.7513	0.30211	3.3100	0.40211	2.4869	2.3291	0.9366
4	1.4641	0.6830	0.21547	4.6410	0.31547	3.1699	4.3781	1.3812
5	1.6105	0.6209	0.16380	6.1051	0.26380	3.7908	6.8618	1.8101
6	1.7716	0.5645	0.12961	7.7156	0.22961	4.3553	9.6842	2.2236
7	1.9487	0.5132	0.10541	9.4872	0.20541	4.8684	12.7631	2.6216
8	2.1436	0.4665	0.08744	11.4359	0.18744	5.3349	16.0287	3.0045
9	2.3579	0.4241	0.07364	13.5795	0.17364	5.7590	19.4215	3.3724
10	2.5937	0.3855	0.06275	15.9374	0.16275	6.1446	22.8913	3.7255
11	2.8531	0.3505	0.05396	18.5312	0.15396	6.4951	26.3963	4.0641
12	3.1384	0.3186	0.04676	21.3843	0.14676	6.8137	29.9012	4.3884
13	3.4523	0.2897	0.04078	24.5227	0.14078	7.1034	33.3772	4.6988
14	3.7975	0.2633	0.03575	27.9750	0.13575	7.3667	36.8005	4.9955
15	4.1772	0.2394	0.03147	31.7725	0.13147	7.6061	40.1520	5.2789
16	4.5950	0.2176	0.02782	35.9497	0.12782	7.8237	43.4164	5.5493
17	5.0545	0.1978	0.02466	40.5447	0.12466	8.0216	46.5819	5.8071
18	5.5599	0.1799	0.02193	45.5992	0.12193	8.2014	49.6395	6.0526
19	6.1159	0.1635	0.01955	51.1591	0.11955	8.3649	52.5827	6.2861
20	6.7275	0.1486	0.01746	57.2750	0.11746	8.5136	55.4069	6.5081
21	7.4002	0.1351	0.01562	64.0025	0.11562	8.6487	58.1095	6.7189
22	8.1403	0.1228	0.01401	71.4027	0.11401	8.7715	60.6893	6.9189
23	8.9543	0.1117	0.01257	79.5430	0.11257	8.8832	63.1462	7.1085
24	9.8497	0.1015	0.01130	88.4973	0.11130	8.9847	65.4813	7.2881
25	10.8347	0.0923	0.01017	98.3471	0.11017	9.0770	67.6964	7.4580
26	11.9182	0.0839	0.00916	109.1818	0.10916	9.1609	69.7940	7.6186
27	13.1100	0.0763	0.00826	121.0999	0.10826	9.2372	71.7773	7.7704
28	14.4210	0.0693	0.00745	134.2099	0.10745	9.3066	73.6495	7.9137
29	15.8631	0.0630	0.00673	148.6309	0.10673	9.3696	75.4146	8.0489
30	17.4494	0.0573	0.00608	164.4940	0.10608	9.4269	77.0766	8.1762
31	19.1943	0.0521	0.00550	181.9434	0.10550	9.4790	78.6395	8.2962
32	21.1138	0.0474	0.00497	201.1378	0.10497	9.5264	80.1078	8.4091
33	23.2252	0.0431	0.00450	222.2515	0.10450	9.5694	81.4856	8.5152
34	25.5477	0.0391	0.00407	245.4767	0.10407	9.6086	82.7773	8.6149
35	28.1024	0.0356	0.00369	271.0244	0.10369	9.6442	83.9872	8.7086
40	45.2593	0.0221	0.00226	442.5926	0.10226	9.7791	88.9525	9.0962
45	72.8905	0.0137	0.00139	718.9048	0.10139	9.8628	92.4544	9.3740
50	117.3909	0.0085	0.00086	1163.91	0.10086	9.9148	94.8889	9.5704
55	189.0591	0.0053	0.00053	1880.59	0.10053	9.9471	96.5619	9.7075
60	304.4816	0.0033	0.00033	3034.82	0.10033	9.9672	97.7010	9.8023
65	490.3707	0.0020	0.00020	4893.71	0.10020	9.9796	98.4705	9.8672
70	789.7470	0.0013	0.00013	7887.47	0.10013	9.9873	98.9870	9.9113
75	1271.90	0.0008	0.00008	12709	0.10008	9.9921	99.3317	9.9410
80	2048.40	0.0005	0.00005	20474	0.10005	9.9951	99.5606	9.9609
85	3298.97	0.0003	0.00003	32980	0.10003	9.9970	99.7120	9.9742
90	5313.02	0.0002	0.00002	53120	0.10002	9.9981	99.8118	9.9831
95	8556.68	0.0001	0.00001	85557	0.10001	9.9988	99.8773	9.9889
96	9412.34	0.0001	0.00001	94113	0.10001	9.9989	99.8874	9.9898
98	11389	0.0001	0.00001		0.10001	9.9991	99.9052	9.9914
100	13781	0.0001	0.00001		0.10001	9.9993	99.9202	9.9927

جامعة النجاح الوطنية
كلية الدراسات العليا

التأثير الفني والاقتصادي لأنظمة الخلايا الشمسية الموصولة مع شبكات الكهرباء على أمن الطاقة في فلسطين /النظام الشمسي في أريحا: دراسة حالة

إعداد
عبد اللطيف واصف عبد اللطيف خاروف

إشراف
د .عماد بريك

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة النظيفة وإستراتيجية الترشيد بكلية الدراسات العليا في جامعة النجاح الوطنية نابلس فلسطين.

2014

التأثير الفني والاقتصادي لأنظمة الخلايا الشمسية الموصولة مع شبكات الكهرباء على أمن الطاقة في فلسطين /النظام الشمسي في أريحا: دراسة حالة

إعداد

عبد اللطيف واصف عبد اللطيف خاروف

إشراف

د .عماد بريك

الملخص

هذا البحث قائم على بناء نموذج رياضي محوسب لنظام شمسي موصول مع الشبكة الكهربائية وذلك باستخدام برنامج الماتلاب سيميولينك من اجل دراسة وتحليل الأداء الفني والاقتصادي لبناء هذه الأنظمة بالاعتماد على تغير الظروف البيئية والبيانات المناخية المتوفرة مثل درجة الحرارة، كمية الإشعاع الشمسي وسرعة الرياح.

الهدف الرئيسي من البحث يتمثل في تصميم نظام شمسي موصول مع الشبكة الكهربائية باستخدام برنامج الماتلاب سيميولينك وتطبيقه على النظام الشمسي في أريحا كدراسة حالة.

لإنجاز هذا الهدف تم دراسة النماذج الرياضية المحوسبة والتي تميز كل جزء في النظام الشمسي مثل اللوح الشمسي، منظم تتبع نقطة القدرة القصوى، المحول، ومن ثم تحويل هذه النماذج الرياضية إلى نماذج سيميولينك.

إضافة إلى ذلك يجب التحقق من الخصائص الهندسية لتصميم التوصيلات المختلفة لكل أجزاء النظام الشمسي الموصول مع الشبكة الكهربائية بهدف دراسة تشغيل النظام في ظروف مناخية مختلفة.

نماذج التنبؤ الحالية مفيدة جدا في حالة الأنظمة الموصولة مع الشبكة الكهربائية والتي تعمل عند نقطة القدرة القصوى حيث أن هذا النموذج المصمم يتم من خلاله عمل محاكاة لمعرفة نتائج تشغيل عناصر النظام لكل فترة زمنية محددة ويتنبأ أيضا بدقة عن كمية إنتاج الطاقة خلال هذه الفترات وبالاعتماد على البيانات ألمقاسه.

كذلك يتم من خلال البرنامج المحوسب الذي تم تصميمه معرفة كمية إنتاج الطاقة بتغيير ظروف التشغيل، زيادة درجة الحرارة أو كمية الإشعاع الشمسي، وقد تم تحليل البيانات المقاسة من النظام الشمسي في أريحا كدراسة حالة.

في حالة البحث على الضغط المتوسط لشبكة كهرباء أريحا والنظام الشمسي في أريحا فأن الآثار الفنية لنسبة المشاركة الحالية وهي قدرة محطة الطاقة الشمسية الحالية وتساوي 300 ك.و، كانت غير ملحوظة ومهملة.

في حالة الدراسة للضغط المنخفض، فأن التوصيات لتقليل الآثار الفنية السلبية لمولدات الخلايا الشمسية الموصولة والموزعة على الشبكة التقليدية هي استخدام أنظمة الشبكات الذكية لمراقبة أداء الشبكة الساعي والتحكم في أوقات تبادل الطاقة، بالإضافة إلى تحديد نسب مشاركة أنظمة الخلايا الشمسية على الشبكة الكهربائية بنسبة 15% بواسطة منظم الشبكة لزيادة الأمان، أو تحديد نسبة المشاركة لأنظمة الخلايا الشمسية بقيمة الحد الأدنى لقيمة حمل المغذي.

في حالة التحليل والتقييم الاقتصادي للنظام الشمسي في أريحا تبين أن سعر الطاقة الكهربائية المولدة من محطة أريحا الشمسية هو(US$/kWh) 0.18 مقارنة مع (US$/kWh) 0.19 للطاقة المولدة من مصادر تقليدية.