An-Najah National University

Faculty of Graduate Studies

Techno-Economic Analysis and Energy Management of Installation onGrid PV Systems “An-Najah National Hospital as Case Study’’

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Dedication

To Palestine …

To my parents Yousef &Lamia…

To my sisters Shatha, Rasha & Shahd…

To my brother and my soulmate Mohammad…

To my grandmothers and grandfathers…

To my teachers…

To my friends…

To all of them,

I dedicate this work

Acknowledgments

First of all, thank god.

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

I would like to express my special thanks and appreciation to my advisor Dr. Imad Ibrik for his continuous support, guidance and encouragement throughout the duration of this work.

Thanks go also to the Energy Research Center and to the staff of Clean Energy and Conservation Strategy Engineering Master Program in An-Najah National University.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان

Techno-Economic Analysis and Energy Management of Installation onGrid PV Systems "An-Najah National Hospital as Case Study''

أقر بأن ما شملت عليه الرسالة هو نتاج جهدي الخاص, باستثناء ما تمت الإشارة إليه حيثما ورد, وأن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة علمية أو بحثية

Declaration

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

Student's Name: أحمد يوسف خالد خلوف **:اسم الطالب**

Signature **:التوقيع**

Date 2016 - 8 - 14 **:التاريخ**

Abbreviations

GHG	Greenhouse Gases
PV	Photovoltaic
DSM	Demand Side Management
NEDCO	North Electricity Distribution Company
IEC	Israel Electric Corporation
JEDCO	Jerusalem Electricity Distribution Company
SELCO	South Electricity Distribution Company
HEPCO	Hebron Electricity Distribution Company
PEA	Palestinian Energy Authority
GPP	Gaza Power Plant
GEDCO	Gaza Electricity Distribution Company
WB	West Bank
DC	Direct Current
AC	Alternating Current
SOC	State of Charge
EES	Electrical Energy Storage
BSS	Battery Storage System
UPS	Uninterrupted Power Supply
VRLA	Valve Regulated Lead Acid
LF	Load Factor
CFL	Compact Fluorescent Lights
DG	Distributed Generation
ADSM	Active Demand Side Management
EE	Energy Efficiency
DR	Demand Response
TOU	Time of Use
CPP	Critical Peak Pricing
DSC	Demand Side Control
ROR	Rate of Return
SPBP	Simple Payback Period

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Techno-Economic Analysis and Energy Management of Installation on Grid PV Systems "An-Najah National Hospital as Case Study''

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Abstract

This thesis analyzes the performance of implementation of on-grid PV systems and energy management system in Palestine, from thetechnical and financial point of view. Also the design and simulation of a 104kWp grid connected PV system and a Demand Side Management (DSM) system for An-Najah National Hospital and summarizes its performance results using PVsyst computer software. The simulation results were positive as the peak demand was reduced from 240kW to 160kW for building

This PV system and DSM system is comprised of the following components. An array consist of PV modules produced from apolycrystalline solar cell of 330W, making up a total peak power of 104 kW. In addition, there are five dual mode inverters of 20kW and an energy storage system of 68 kWh which used in energy management and shortages cases.

The system will produce about 187000kWh per year. From economical viewpoint PV systems and DSM systems have high initial cost which was about 187000$, but the economic evaluation of the system shows that unit cost of the system was about 0.19$/kWh and 0.15$/kWh for PV system with DSM and for PV system without DSM which was less than from energy cost from NEDCO which selling energy to consumer by 0.21$/kWh

this means the unit cost is acceptable in both cases and makes annual saving about 40000$ in electrical energy bills. In the economic evaluation the Rate of Return (ROR) method and Simple Payback Period SPBP was considered and the ROR was about 23% and the SPBP was 7 years including battery replacement cost and these results show that the system has high revenues and profit for the lifetime, in other words, the project is highly feasible.

Introduction

Energy sector is considered the backbone of the economy in all countries where the provision of energy services, especially electricity well contribute in achieving the development objectives of countries in industry, commerce, agriculture, and countries dependency[1,2]. Sustainability in the energy sector is very important to guarantee a dignified life for other generations while traditional energy sources are limited, decreasing, expensive, and having negative impacts on the environment; mainly fossil fuel is used in energy generation which emitting greenhouse gasses (GHG) and other pollutants to the atmosphere during burning process [3,4,5].

After fossil fuel crisis in the 1970s, international environments agreements and regulations as Clean Air Act 1956 and penalties that governments decided to make on power plants when emitted pollutants exceed allowable values clean and renewable energy became valuable and its studies increased sharply. In Palestine various renewable energy sources are available but the photovoltaic (PV) technology is considered a suitable technology. 5400watt/m^2/day solar irradiance that available in Palestine makes investments in solar energy economically feasible [5, 6]. Generally, it is difficult to have free fault electrical power supply systems and these failures in some utilities like hospitals, banks, schools and telecoms utilities are not acceptable for any reason. So emergency backup systems were innovated there are many common types of power supply backup systems that depend on served facilities, load types, and rating. The most used one is diesel generator for many reasons such as availability in market, reliability, portability and maintainability. Other backup systems can use renewable energy sources especially photovoltaic systems which possible to use in critical facilities such as hospitals, telecom sites, and traffic lights. Photovoltaic systems have many advantages: solar energy is free since it's supplied by nature, maintenance and operations costs are very low, and operate without any noise. On the other hand, photovoltaic systems have high initial costs [3, 7].

Objectives

The main objective of this thesis is to analyze the performance of implementation of on-grid PV systems and Demand Side Management(DSM), from thetechnical and financial point of view.

The specific objective:

- Determine the technical evaluation of installation PV grid systems on the electrical network.
- Determine the negative impacts if installation solar PV systems on the grid.
- Simulate the management of PV systems.
- Analyze the feasibility of using on-grid PV systems in Palestine.

Outcomes of the Work:

- Evaluation the impacts of DSM on solving the lack of supply on NEDCO network.
- Evaluation the technical and economic impacts of using DSM on

daily load curve of facilities (An-Najah National Hospitalcase study)

- Economic Analysis of using energy management opportunity through different tariff structure.
- Evaluation of pollution reduction through using clean energy sources (PV).

Thesis Structure

The thesis work has been summarized in seven chapters.

Chapter One: Electricity Situation in Palestine

This chapter illustrates the general statutes of electricity in Palestine. And it shows the solar energy potential in Palestine also renewable energy projects that install in Palestine.

Chapter Two: Solar Photovoltaic Installation

This chapter describes PV systems types, elements, and specifications of different types of PV systems

Chapter Three: Energy Management and Demand Side Management and Load Factor Analysis

This chapter illustrates the energy management benefits and techniques using PV systems.

Chapter Four: Selection of Optimum System for An-Najah National University Hospital

This chapter describes the sizing and selection of PV system and configuration.

Chapter Five: Demand Side Management for An-Najah National University Hospital

This chapter describes the design of energy management system for the Hospital.

Chapter Six: Economic Analysis of Installation on Grid PV Systems in An-Najah National Hospital

This chapter studies the evaluation of economic impacts of the usage of PV systems and energy management systems.

Chapter Seven: Conclusion and Future Scope of Work

This chapter describes the research conclusion and future scope of work.

Chapter One

Electricity Situation in Palestine

1.1 Overview of Electric Status in Palestine

The energy sector in Palestine is facing many challenges due to the political situations and the Israeli occupation. First,one is the dependency on Israel as around 86% of electricity consumed is imported from the Israel Electric Corporation (IEC). Second, that is, the costs of imported energy are exorbitant as the yearly bill is estimated at about 500 million dollars. Finally, many environmental risks arise from the use of traditional sources of energy. These facts are important challenges encourage the Palestinian decision-maker to make plans and actions.[1]

In 2009, the power consumption in Palestine was around 4.413 GW / hour. These power needs are imported from three sources: around86% from IEC, around 5% from Egypt and Jordan, and around 10% from Palestine Electric Company- Gaza. The bill of imported electricity ranges from 400 to 500 million dollars annually. [1]

Electricity services including distribution and maintenance are carried out by Palestinian providers these main providers are JEDCO, NEDCO, SELCO and HEPCO or municipalities such as Tulkarem, Qalqlya and many other cities that do not follow private electric companies.[2]

It should be noted that there are no purchase agreements between the Palestinian Energy Authority (PEA) and IEC and thus, the purchase is done through bilateral contracts between the IEC and Palestinian providers.

The most prominent characteristics of the power sector in Palestine that are around 75% of consumption are consumed by household and services while 25 %are consumed by economic and productivity activities. The expected consumption in 2020 is to reach 8.400 GW / hour- assuming an annual growth rate of 6%. [2]

In Palestine, the wastage of electricity is about 26% of imported energy which considered a high value that may affect cost so the electricity prices are relatively high as a result of importing most of the needs from Israel also due to high losses. [2]

The average consumption of electricity is around 830 kW / hour per year per capita, which considered too low compared with neighboring countries as it around 2093 in Jordan, 1549 in Egypt and 6600 In Israel.[2]

Amounts of imported energy from IEC, Jordan, Egypt and the generated energy from GPP are illustrated in tables 1.1 and 1.2 respectively for the West Bank and Gaza in 2009. [2]

Table (1.1): Electrical supply sources in West Bank in 2009. [1]

Supply Source	Rating in MVA
IEC	600
Jordan	20
Total	620
Maximum Demand in the West Bank	550

Table (1.2): Electrical supply sources in Gaza in 2009. [1]

Supply Source	Rating in MVA
IEC	110
Egypt	17
GPP	0-60
Total	137-197
Maximum Demand in Gaza	210

1.1.1 Electricity Distribution in Palestine

IEC is the main supplier of electricity to Palestinian, IEC supplies electricity in many connection points using overhead lines. In the West Bank, there are three main supply substations at 161/33kV that supplied from the IEC which are in Hebron, A tarot and Ariel. [2]

The electrical networks in the West Bank are considered as medium voltage networks below 33kV. Also, some loads, especially in the northern area of the West Bank, are supplied by distribution feeders from substations inside Israel from which distribution feeders cross the border to supply Palestinian loads, such as the case of 22 kV feeders supplying Qalqilya and Tulkarm areas. Also, 33 kV feeders from Beisan substation are supply Jenin area. [2]

Figure 1.1 shows the location of the 161kV substations and the number of distribution feeders that supply Palestinian loads. In 2006, the contracted capacity from IEC was about 550MVA, which was divided into 125MVA for the north, 95MVA for the south and 330MVA for the central area under JDECO. The situation in early-2007 has not changed much as compared to 2006, except that in the case of JDECO, another 50MVA will probably have been added. In principle, the electricity is supplied to the Palestinian loads at 33kV or 22kV through IEC owned MV lines. [2]

Palestinian electricity providers companies and municipalities do not have control of the supply through the transmission or the distribution lines that extend from the 161kV substations. Palestinian control begins in most cases after the connection point with these feeders, which are metered for billing purposes by IEC to the electricity provider and municipalities. [2]

Large number of connection points is exist in the Northern of the West Bank which exceeds 120 with a total contracted capacity of 125MVA, while in the Southern of the West Bank more than 45 point sexist with a contracted capacity of 95MVA and in the middle of the West Bank area they are 25 points with a capacity of 380MVA. [2]

The connection points in the West Bank are mixed between LV and MV. The difference is that if the connection point is on the MV side, then the Palestinian providers can extend the MV network and install transformers and LV lines, whereas if the connection point is on the LV side, the Palestinian providers cannot expand the LV network. The inability to extend the MV and LV networks has contributed to network deficiencies, such as very low voltage and high technical losses. In addition, the lack of financing due to the deteriorating situation in the collection of the electricity bills for utilities, municipalities, and villages has affected the maintenance of the networks, which in turn has increased losses, outages, and overloading of feeders. [2]

The electric situation in the West Bank and Gaza need to re-evaluate there is a monopoly in the supply in the West Bank for lack of generation and there is no competition especially since the price of electricity in Palestine of the highest prices in the region also different prices from one company to another and from one municipality to another and from one village the other, the weak electrical distribution system where the loss ratio of up to about 26%, which is one of the largest percentages in the distribution systems in the region. [1-3]

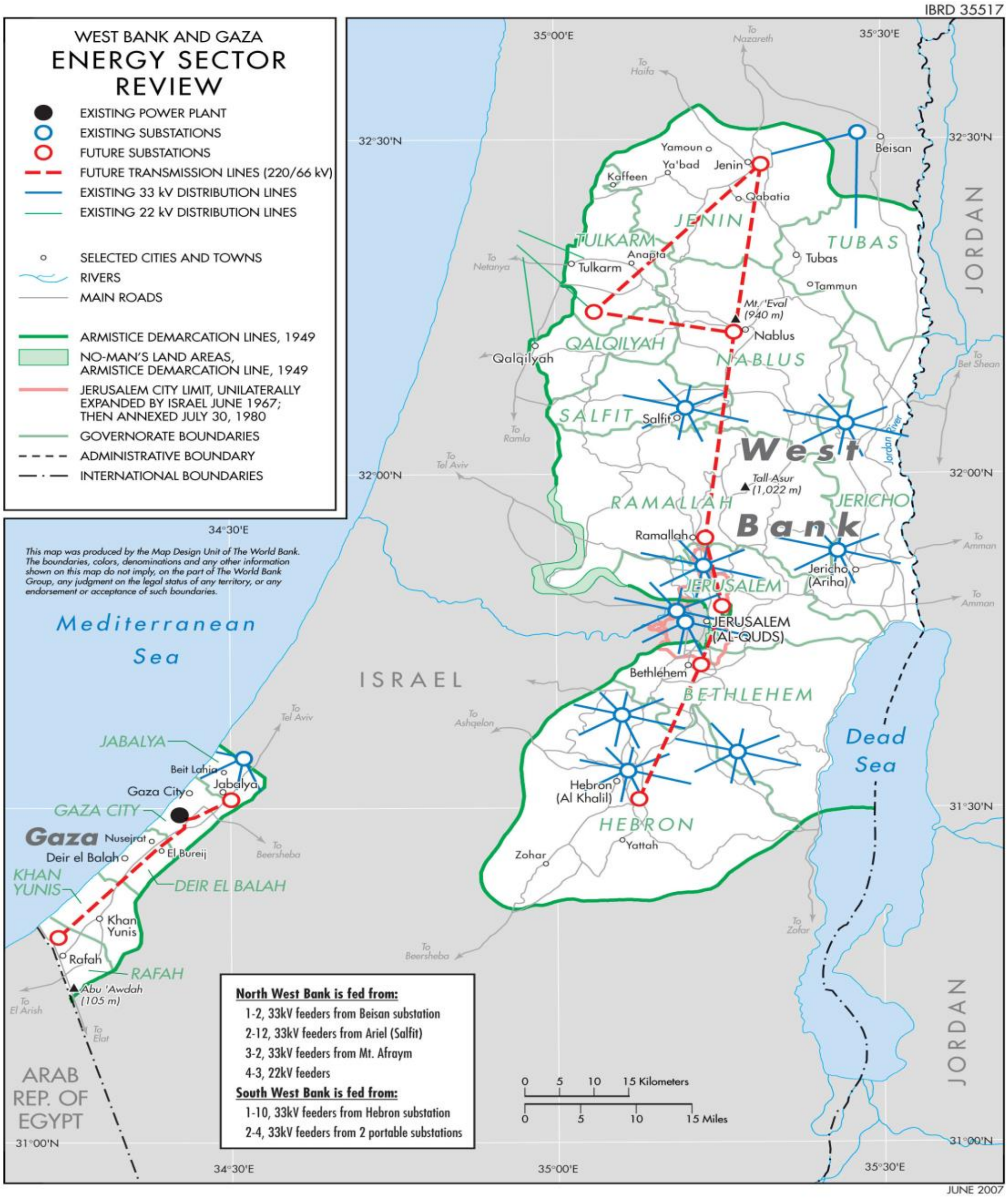

Figure (1.1): Electricity Supply System in West Bank and Gaza [2]

Palestine has two electricity distribution scenarios the first one is private sector responsibility that covers around 70% of total energy consumption in the west bank while 30% of the consumption managed by municipalities. Private sector consists of four main distributions companies which are JDECO, NEDCO, SELCO, and HEBCO. These companies control the electricity distribution in West Bank. Figure (1.2) which illustrates areas of each electric company. [3]

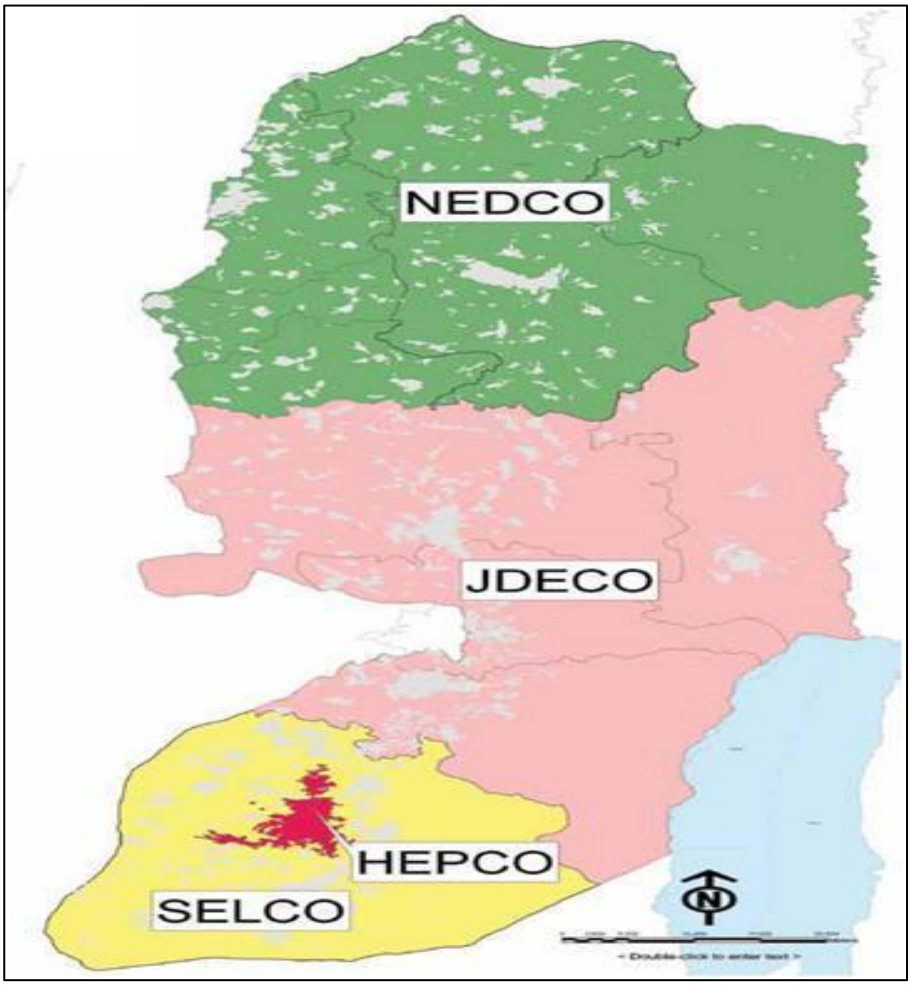

Figure (1.2): Areas of Each Electric Company [3]

The situation in Gaza strip is different little bit as it has an electricity generation plant, Gaza power plant GPP has 140MVA electricity generating capacity, but it does not operate normally due to political issues and which about diesel lacks as Israel controls its the dependency on GPP is not possible and it does not satisfy the whole demand so the rest demand is imported from IEC and Egypt by GEDCO which has the whole responsibility on electricity distribution in Gaza strip.[3]

1.2 Problems of Energy Sector in Palestine

As mentioned before that the main problem in Palestine is the occupation and the energy sector suffered from it, these problems lies in that the sole source of electricity in the WB and GS is from the IEC, and these problems are can be summarized by following :

1.2.1 Lack of Electricity Supply in Palestine

Due to the monopoly of electricity production in Palestine by the IEC and as electricity is considered as the main source of energy. The IEC and the Israeli government are neglecting the growing needs of energy in the Palestinian areas which affect the quality of supply and cause shortages in the electric network especially at peak demand periods this encourage Palestinian to think about solutions to enhance the quality of electric supply despite the lack of sources .Also, the IEC neglect many rural areas and did not serve them due to political issues despite about 99% of households were connected to the public electricity in 2006.[4]

1.2.2 Distribution Losses in Palestine

One of the main challenges for the electric rehabilitation plan is the distribution losses, which are considered as the highest in the region. Although the electricity supply is assured by the IEC, which uses the electric transmission and distribution network, no efforts were made to rehabilitate this network .While the electricity distribution loss in the Palestinian Territories about 10% to 20% of the total energy injected. [4]

1.2.3 High Energy Cost

As mentioned before that the electricity production in WB is monopolized by the IEC gives it the power to impose high prices. The IEC is thus able to discourage private manufacturing companies from competing with it by using small independent power stations at their factories. Municipalities in the WB collect the electricity bill from the final consumers. They determine the final price based on the IEC price plus a margin of 10% to cover salaries, maintenance and allow a profit margin. The electricity price reached a very high level in WB (0.13-0.5)$/kWh; this is 3 times higher than the average price in Israel0.07$/kWh.[4, 5]

1.3 Potential of Solar Energy in Palestine

For many reasons also problems that mentioned before, renewable energy sources in Palestine become very important also energy security reason and the economic conditions improvement. Palestine is located between 34° 20′ - 35° 30′ E and 31° 10′ - 32° 30′ N, and its elevation is from 350 m below sea level in the Jordan valley and exceeding 1000 m , above sea level in some locations in the West Bank. It has about 3000 sunshine hours per year .also it has high annual solar radiation amounting to 5.4 kWh / m^2 – day on a horizontal surface. This radiation varies from 2.63 kWh/m^2 – day in December to 8.4 kWh / m^2 – day in June. So Palestine has a high potential of solar energy. These high values of solar radiation encourage the use of solar energy for different applications such as water heating, electricity generation, water desalination and water pumping. [3, 4]

Figure (1.3) which illustrates the annual solar radiation in the West Bank areas that were Nablus, Jenin and Tulkarem it is noted that the highest values were in June and July however, the lowest values were in January and December.[3]

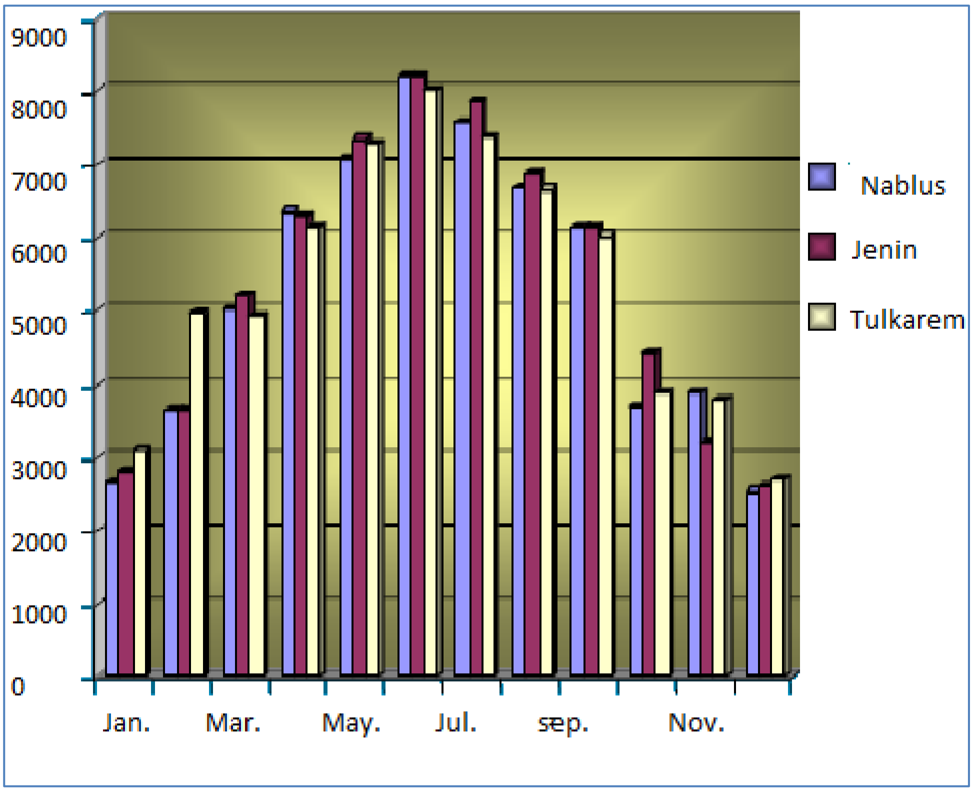

Figure (1.3): Annual solar radiation in Nablus, Jenin and Tulkarem. [3]

In Nablus area, the Energy Research Center made many measurements of solar radiation in Palestine using Pyranometer and the result was great and shows that we have a very good potential of solar energy in this area. Figure (1.4) shows the solar radiation in Nablus in 2013. [4]

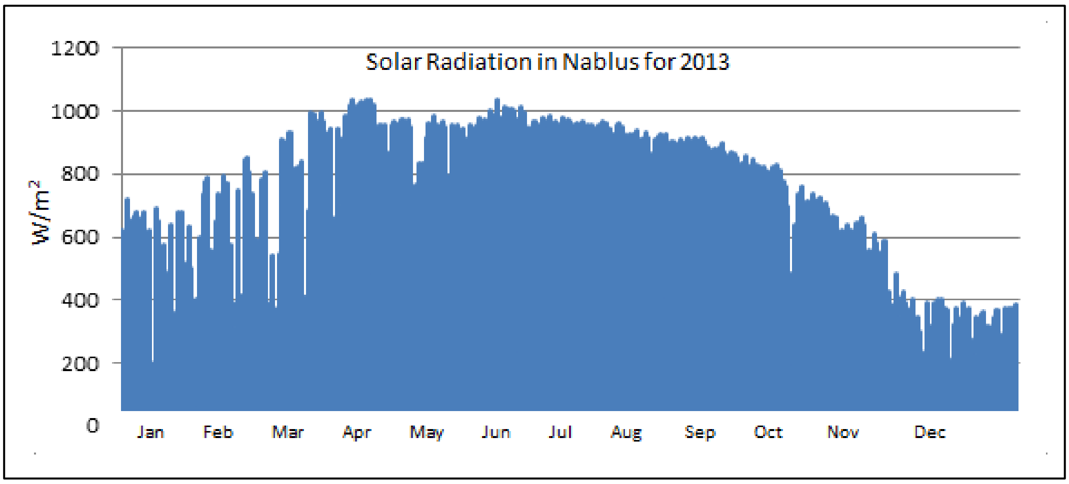

Figure (1.4): Solar Radiation Density in Nablus Area in 2013. [4]

These results which show the high solar energy potential encourage Palestinians to increase the usage of solar energy in effective ways such as water heating, water desalination, and electricity generation. On other hand, Palestinians are using the solar energy in water heating for many years as almost all houses have a Solar Water Heater (SWH) on their floors. [4]

1.4 Photovoltaic Projects in Palestine [4, 5]

Photovoltaic systems are not used as much as possible in Palestine due to financial and political situations, but there are some projects available in some location in WB, and these projects are:

1. Electrification of isolated villages through photovoltaic Systems Wadi Alrakheem, Atouf and Al-Kaabneh Village, WB, Palestine.

2. PV powered water pumping units: Decentralized PV generators with a total peak power of 65 kWp in remote villages as Ammoriah, Qariout.

3. Using solar energy for public lighting in Palestine as Wadi Al-nar and Wadi Gaza Bridge.

Chapter Two

Solar Photovoltaic Systems

2.1 Introduction to Solar PV Systems [6-8]

In this chapter,a literature review about PV system will be introduced including all system element, types, and standards starting from the smallest elements in the system which are the PV cell going throw system configuration until system connection in grid interactive one also advantages and disadvantages of PV system will be discussed. The following figure(2.1) illustrate a block diagram of general PV system include all components that may be used which depends on the PV system type. A breakdown of all component and system will be discussed in this chapter. [6]

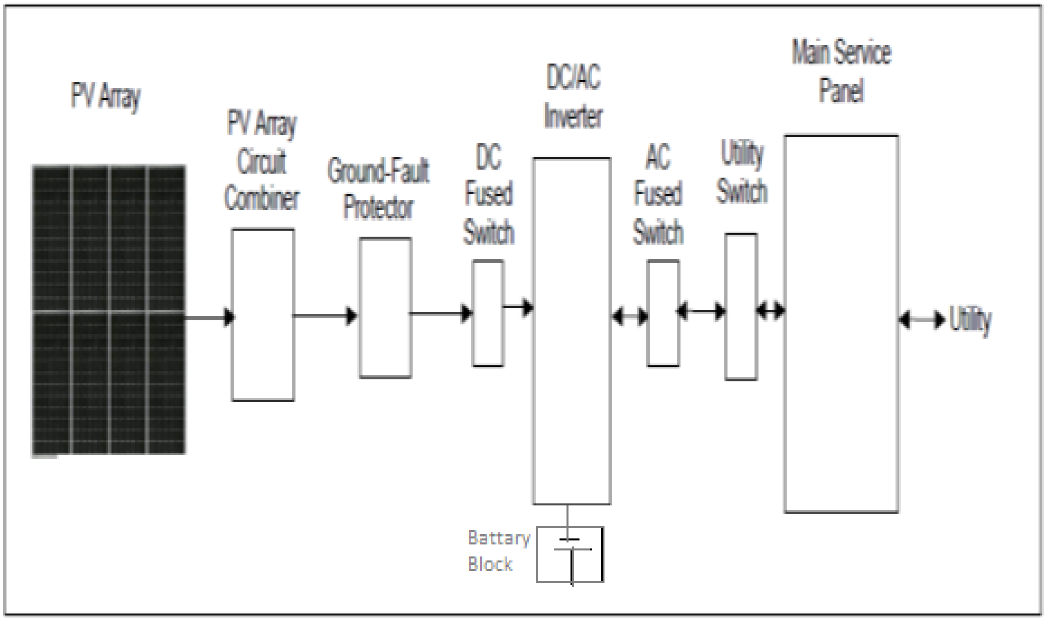

Figure (2.1): General Block Diagram of PV System. [7]

2.1.1 The Discovery of PV Effect:

The photovoltaic effect was discovered in 1839 by French physicist Becquerel; it remained in the laboratory with no development or application. In 1954, bell laboratories produced the first silicon solar cell of the discovered effect, and soon it began to find an application for this cell for its power capacity. In the present, the PV effect has wide uses and applications in producing electrical power and it has huge applications in the power systems around the world. [6]

Solar cells

A solar cell main and basic unit of a photovoltaic system. It is a simple and elegant device that converts light directly into electrical energy. Solar cells are made from semiconductors such as silicon and have much in common with other solid-state electronic devices, such as diodes, transistors, and integrated circuits. The electrical output of a single solar cell is usually small, on the order of 1W or less so that many cells are connected together to achieve greater power output.[6]

Depending on the manufacturing process, most of the modules can be of three types [7]:

1. Mono-crystalline Silicon.
2. Polycrystalline Silicon.
3. Amorphous Silicon.

2.1.2 PV Cells Structure:

The PV cell looks like the p-n junction diode, the top of the cell is the n-Type semiconductor that has electrons, the next level is the separation region, it may be a liquid electrolyte, or it may be a solid semiconducting material. The next level is the p-Type Semiconductor that contains the holes. This is explained graphically in figure (2.2). [6]

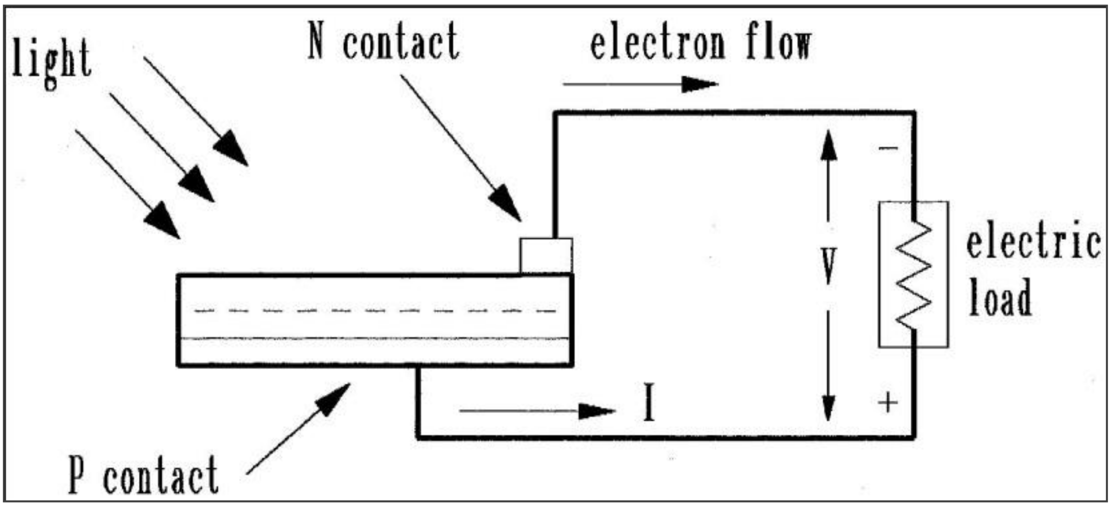

Figure 2.2: Photovoltaic effect converts the photon energy into voltage across the p-n junction. [6]

When light falls on the PV cell, the photons in the light are transferred by electrons at the top level, this creates charge carriers in the separation region electron-ion pairs if the separation region is a liquid electrolyte or electron-hole pairs if the separation is a solid semiconducting material, these carriers create a voltage gradient that gets circulated as a current through the external circuit. The electrical power that is the conversion of the sun power is the current squared multiplied by the external resistance, this ideal case. [6]

Mechanical developments were added to the cell structure to obtain limited properties and for protection; this is shown in figure 2.3

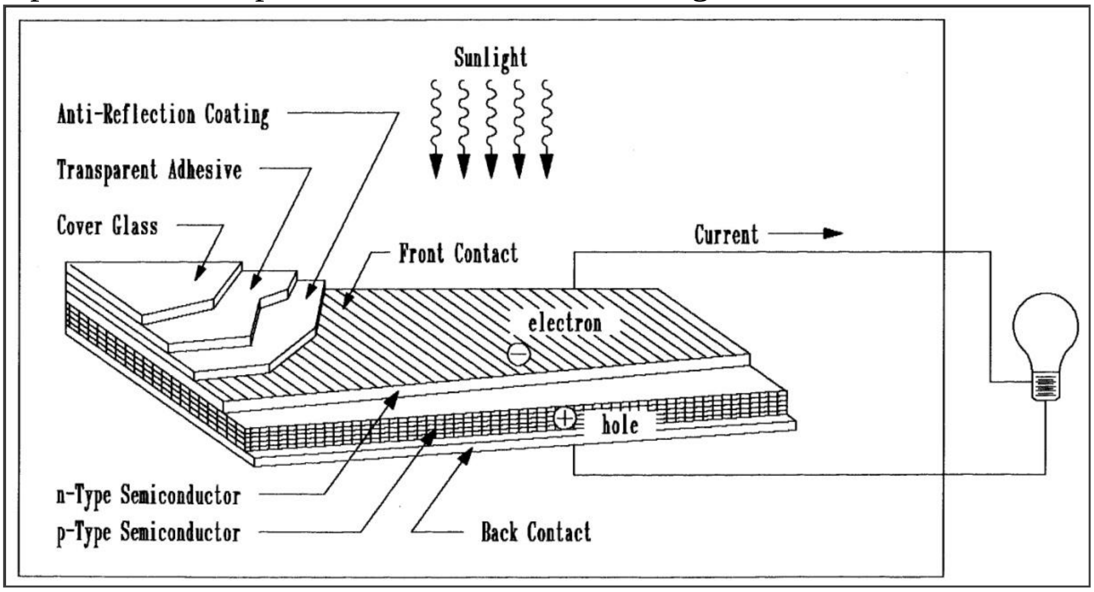

Figure 2.3: The PV construction with the addition of the mechanical developments. [6]

2.1.3 PV Modules and Arrays:

The basic block of the PV power system is the solar cell that is shown in figure 2.4, the group of these cells connected in series and in parallel is called the module, and agroup of the modules connected in series and in parallel to obtain the needed voltage and current is called the array. [6]

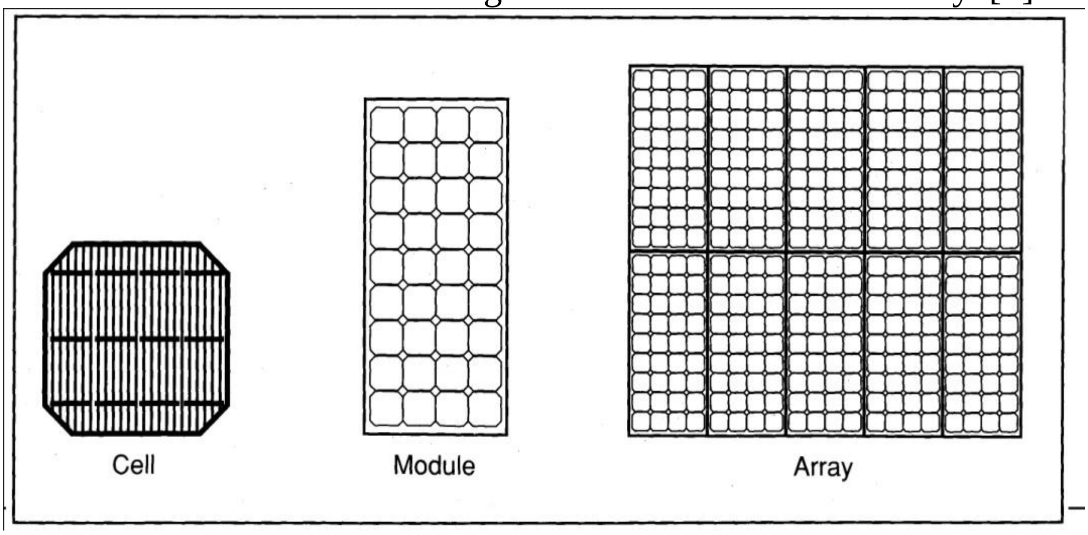

Figure 2.4: Cell, module, and array that form the solar system. [6]

Other additions can be added to module for protection, and to be practical in operating, these additions are shown in figure 2.5, these are the holding frame which contains all module and additions, a protection box from the changeable weather of high and low temperature, snow, rain, and water since there are electrical connections, Transient material to protect from weathers and accidents, high transmissivity glass, buses transfer current to module terminals and a clearance between the frame and others . [6]

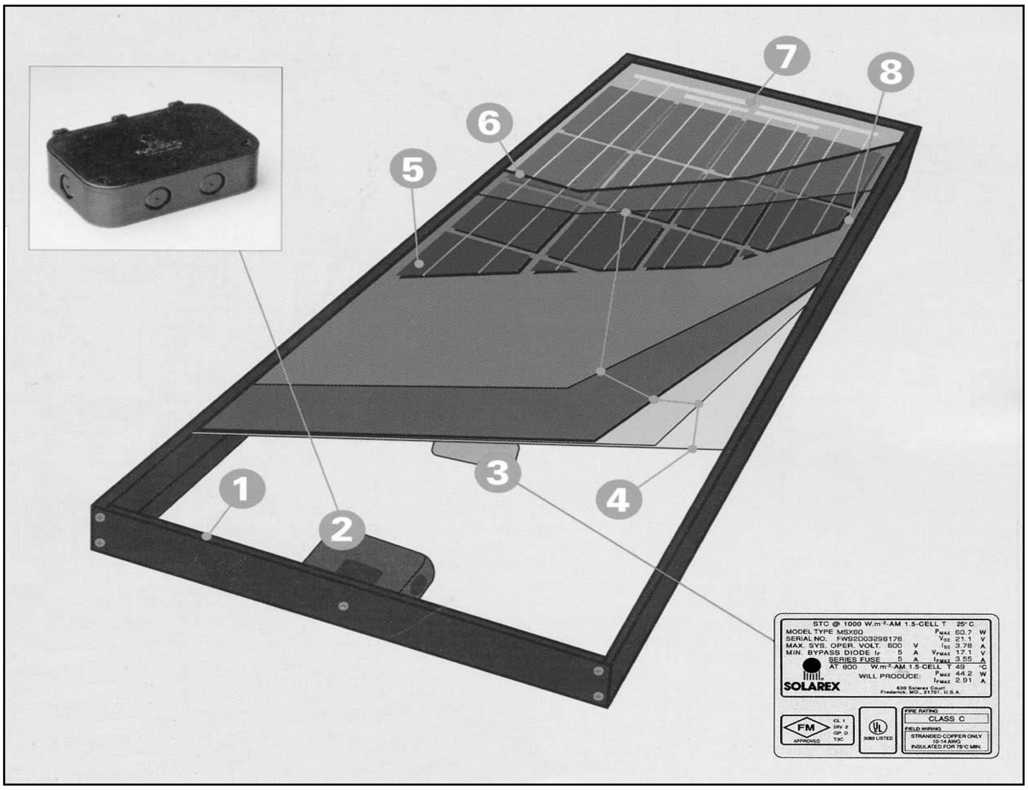

Figure 2.5: The module construction, consists of: (1) holding frame, (2)Weatherproof junction box, (3)The rating paper, (4)Transient material to protect from weathers and accident, (5)The PV cell, (6)High transmissivity glass, (7)Busses, (8) clearance.[6]

2.2 Charge Controller

The charge controller is the component that usually used in off-grid PV systems to charge the batteries and to prevent batteries from being overcharged by the array and from being over discharged by the D.C loads there are many different types of PV controllers in the market the main of types of them are the following: [8]

1- **Shunt controllers**: that designed for small PV systems to prevent overcharging simply by shunting the batteries from the array when they are fully charged.

2- **Single stage controllers**: this kind of charge controller prevent battery overcharging by switching the current off when the battery voltage reaches a value called the charge termination set point. The array and battery are automatically reconnected when the battery reaches a lower value called the charge resumption set point.

3- **Multi-stage controllers**: this is the most complicated charge controller which establish different charging currents automatically depending on the State of Charge SOC .The full array current is allowed to flow when the battery is at a low state of charge. As the battery bank approaches, full charge the controller dissipates some of the array power so that less current flows into the batteries. [8]

2.2 Inverters [8]

Inverters are devices that used in both on- grid and off grid PV systems its converts DC power into standard AC power to be used in AC loads or synchronizing it with utility power in grid interactive case there are three main categories of inverters:

• The first category is line-tied inverters which are used with utility connected PV systems.

• The second category is stand alone or static inverters which are designed for independent utility free power systems and are appropriate for remote PV installation.

• The third category is the dual mode inverter also known as backup battery inverter in this type, the direct current generated by the solar panels is first sent directly to a battery and the internal controller check if the battery block need charging or not if not then it convert the DC current to AC that suitable to loads or utility. This type of solar energy inverter is more expensive than the other two types because it contains all of the benefits of the others. It allows the system to produce, store, and consume any electricity that your solar system produces, while also maximizing system energy production by sending any extra energy into the local electrical grid which has the ability to generate profit. [9]

2.2 Electrical Energy Storage (EES) [10]

In high penetration of PV system in some projects ,a surplus free energy sometimes is available. This surplus energy can be stored in EES and used on other time in leakage or shortages times. EES can lower electricity costs since it can store electricity bought at low prices and they can use it during peak periods in the place of expensive power. Consumers who charge batteries during low prices hours may also sell the electricity to utilities or to other consumers during peak hours. [10]

2.2.1 Electrical Energy Storage Categories

EES technologies have categories classifications depends on the application, such as, in terms of their functions, response times, and suitable storage durations. One of the most widely used methods is based on the form of energy stored in the system as, which can be categorized into mechanical, electrochemical, thermo chemical, chemical and thermal energy storage. But the most used EES in renewable energy and PV system is the electrochemical one (Batteries).

2.2.2 Electrochemical Storage Systems [11]

Here various types of batteries will be described. Most of them are mature for practical use, the most known battery types are lead acid, NiCd/NiMH, and Li-ion.

Lead Acid Batteries [11]

Lead-acid batteries are the most used batteries in the world and have been commercially deployed since about 1890. Lead-acid batteries are used in many applications both mobile and stationary. The main typical applications that use lead acid batteries are emergency power supply system’s such as uninterrupted power supply (UPS),PV systems and energy management systems, the service life of lead-acid batteries varied from 6 to 15 years with a cycle life of1500 cycles at 80 % depth of discharge, and they achieve cycle efficiency levels of around 80 %to 90 %. The most common types of lead acid batteries called valve regulatedlead acid batteries (VRLA) and the absorbed glass mat batteries (AGM). [11]

Nickel Cadmium and Nickel Metal Hydride Batteries [11]

Nickel Cadmium (NiCd) batteries are a very successful battery product. Compared to lead acid batteries, nickel-based batteries have a higher power density, a slightly greater energy density and the number of cycles is higher also it is the only battery capable of performing well even at low temperatures in the range from -20 °C to -40 °C. Large battery systems using vented NiCd batteries operate on a scale similar to lead acid batteries. But, due to the toxicity of cadmium, these batteries are presently used only for stationary applications.

NiMH batteries were developed initially to replace NiCd toxic batteries. Indeed, NiMH batteries have all the positive properties of NiCd batteries, with the exception of the maximal nominal capacity which is still ten times less when compared to NiCd and lead acid. Furthermore, NiMH batteries have much higher energy densities. In portable and mobile applications sealed NiMH batteries have been extensively replaced by lithium ion batteries. On the other hand, hybrid vehicles available on today's market operate almost exclusively with sealed NiMH batteries, as these are robust and far safer than lithium ion batteries. [11]

Lithium Ion Batteries (Li-ion)[11]

Lithium-ion batteries are the most important storage technology in portable and mobile applications such as laptop, cell phone, and electric bicycle since around 2000. High cell voltage levels of up to 3.7 nominal Volts mean that the number of cells in series with the associated connections and electronics can be reduced to obtain the target voltage. [11]

Lithium ion batteries have high efficiency, that in the range of 95 % - 98 %. Nearly any discharge time from seconds to weeks can be realized, which makes them a very flexible and universal storage technology. Since lithium-ion batteries are currently still expensive, they can only compete with lead-acid batteries in those applications which require short discharge times. [11]

2.5 Types of PV Systems

There are twomain types of PV systems the first one is which known as OFF-grid systems while the other which known as ON-grid or grid tied systems. PV modules are common in both OFF-grid and ON-grid systems while batteries are the main difference between them. Figures 2.6 and figure 2.7illustrates both systems. [6-9]

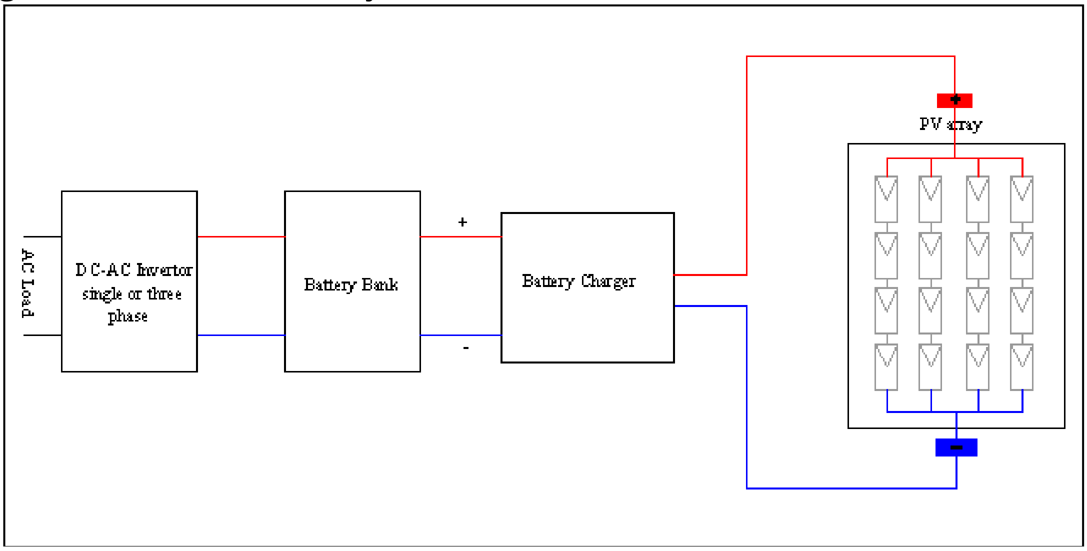

Figure 2.6: OFF-grid PV system block diagram.

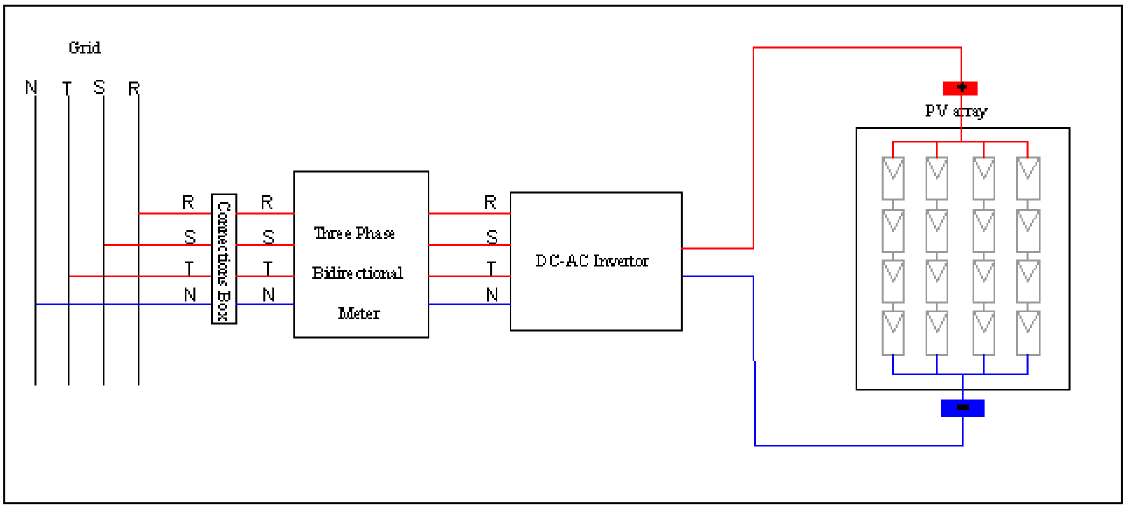

Figure 2.7: ON-grid PV system block diagram.

2.5.1 Stand-Alone Systems (OFF-Grid) [7]

Specifications:

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

2.5.2 Simple Utility-Interactive (ON-Grid) [7]

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

Specifications [7]:

- PV system supplements on-site energy usage, electrical loads are supplied by either the PV system or utility or a combination of both, depending on the amount of PV generation and magnitude of the load. [7]
- PV array is directly connected to the inverter input, and inverter AC output is connected to the utility grid.
- PV system operates in parallel and synchronously with the utility grid.

2.5.3 Utility Interactive with Battery Storage [7]

Specifications:

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

2.6 Policies of Grid-Connected PV Systems [7]

In this section the main metering policies of grid-connected PV system will be discussed briefly also the main advantages and disadvantages will be shown.

2.6.1 Feed in Tariff (FIT)

As the generation costs of energy depend on the source technologies, so it will be great to have special metering policies for the RE sources such as PV , the wind and other RE sources due to this FIT system was created.

FIT provide technology-specific tariff levels. The tariff levels depend on many factors such as Plant capital cost, Operation and maintenance cost, According to the expected amount of electricity generated and the estimated lifetime of the power plant. [7]

2.6.2 Net Metering [7]

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 consumer who generates electricity from a RE source (wind, solar, water or biomass).

One of the key aspects of 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 inspecting and approve net metering equipment.
- Determine the size of the 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 bi-directional 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 the United Statesrequires an upfront subsidy which, at the end of the day, resultat least the price rate established for that technology. This type of net metering is considered simplest that the proposed approach [7].

Chapter Three

Energy Management and Demand Side Management and Load Factor Analysis

3.1 Introduction

Energy management is one of the most important issues in the energy sector, especially for energy generation, transmission and distribution companies. It aims to optimize one of the most complex technical creations that we know. An important indicator that used in the evaluation of electric network and energy management opportunity is the Load Factor (LF), the load factor can be defined as the ratio of the average demand to the maximum demand in a specified time period this period can be a day month or a year, if the load factor was estimated for a certain day then it can named as the daily load factor, and in the same way for week, month and year. The value of LF can be estimated using equation (3.1). [12]

$$LF=\frac{Average\ Demand}{Maximum\ Demand} \tag{3.1}$$

Generally, LF ranges between 0.54 and 0.70 and the average demand for all customers should be about 60% of the peak demand. For offices building shows a different pattern. The load factor ranges between 0.35 and 0.52. This reflects the fact that the office building is really used less than half the time. Generally, working hours span from 8 a.m. to 6 p.m. While in 24 hours operations loads which may be in some manufacturing processes such as steel mills and refineries, the load factor will be close to 1, this means that the loads are turned on and left running continuously. [12]

While there are wide and large experiences in optimizing energy generation and distribution, the Demand Side Management (DSM) that receives increasing attention by research and industry. Demand side management is a portfolio of measures to improve the energy system on the side of consumption. It ranges from improving energy efficiency by using better materials, over smart energy tariffs with incentives for certain consumption patterns, up to sophisticated real-time control of distributed energy resources, also, the DSM can be defined as actions that taken to influence the way in which consumers are using electricity to achieve energy savings and higher efficiency in energy use.[12]

Primary reasons for implementing DSM [12]

- Shortages of Power Supply.
- Distribution network overloads during peak loads.
- For the utility companies, it is mainly due to uncertainty in future demands, fuel prices, and availability. Also to maintain market position against competitors.

Demand side management includes any action on the power system that may reduce the demand starting from simple energy conservation which is replacing old incandescent light to compact fluorescent lights (CFLs) up to installing a sophisticated dynamic load management system.

In Palestine case due to the lack of electricity supply, high distribution losses and high energy cost DSM is very important to enhance the quality of power supply despite the lack in supply situation and this may reduce the shortage cases in peak period as happened in some areas as Jenin city which has a very high demand compared with the available supply from the IEC.

3.2 Demand Side Management

Utilities are trying to encourage their customers to alter their demand profile, and this is generally accomplished through positive tariff incentives allowing customers to schedule demand activities to reduce their energy costs in other words to save money. This will give a positive impact to utilities as they reduce consumer's demands from the peak period. Also, the utilities may impose some penalties that charged in special cases as the continued operation of inefficient equipment with unnecessarily high loads: this is intended to encourage customers to upgrade equipment and thereby reduce electrical demand. A straightforward reduction in energy consumption will normally reduce costs, and a shift of demand to a different time might reduce costs if an appropriate tariff is available.

Another key point of DSM importance is increasing of using grid-tied PV systems in electrical network with high penetration level, it should guarantee that these systems are effectively integrated and not just connected to the networks. Grid-tied PV systems are currently the most important Distributed Generation (DG) technology that uses inverters to convert the primary DC current into AC. This fact, together with its rapid penetration in distribution networks within the framework of successful regulatory state and marketing programs makes PV worthwhile to be considered in the planning and operation of present and future electricity networks also the great benefits of PV systems to the electricity systems, as reductions of losses, peakloads and environmental impacts but due to the inherent uncontrollable characteristics of the solar resource, network operators have hesitated to rely on PV as a firm capacity component. However, recent technological developments in power conditioning systems enable a true dynamic interaction between PV systems and the networks. Also, due to the progressive decrease of incentives for PV electricity in grid-connected markets, new operation modes for PV systems should be explored beyond the traditional maximization of PV electricity feed-in thus the Active Demand Side Management (ADSM) was created to displace the consumer's load curve in response to local PV system and external conditions (external grid). In this way, the consumer becomes an "active consumer" that can also cooperate with others and the grid, increasing even more the PV value for the electrical system also increasing the revenues of active consumers. [12]

3.3 Demand Side Management Categories [13]

The main types of DSM activities may be classified into two main categories:

A) Energy Efficiency (EE).

B) Demand Response (DR).

These two main categories will be illustrated in this section, figure 3.1 illustrate the demand side programs that focuses on demand response.

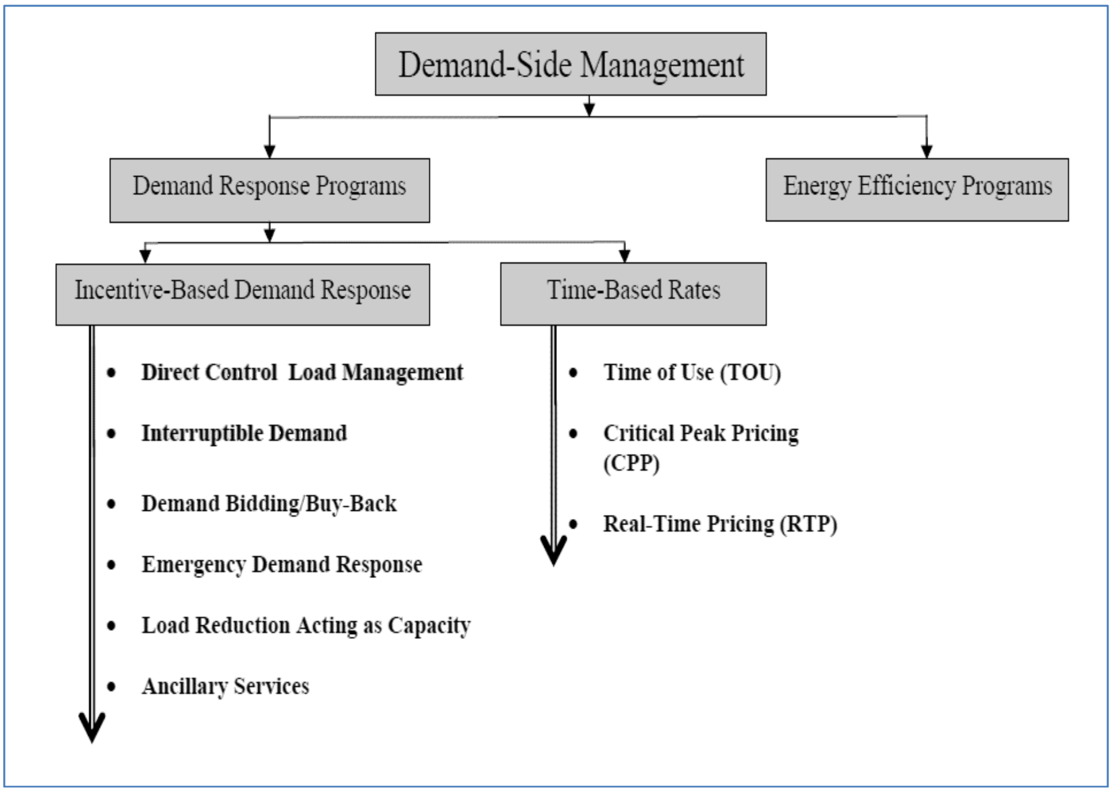

Figure (3.1): DSM Programs: Focused on Demand Response.[15]

DSM manipulates residential electricity usage to reduce cost by altering the system load shape Common techniques used for load shaping are peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape as shown in Figure 3.2 [14]

3.3.1 Incentive-Based Demand Response Programs [12-15]

These programs include an incentive for customer participation and they provide an active tool for load-serving entities, electric utilities or grid operators to manage their costs and maintain reliability. Some of the incentive-based programs that exist are:

- Interruptible Demand
- Demand Bidding/Buyback
- Emergency Demand Response

All these DR programs are work to increase the reliability of the power system by reducing energy cost for their customers who interact positively and reduce their demand which helps in peak demand reduction and load shifting.

3.3.2 Time-Based Rate Program [12-14]

In Time-Based Rate Program, the consumer has the decision to reduce their demand due to extra cost that added. This technique used for managing the peak demand, user defined pattern modification of electricity usage is the most popular technique utilized. There are three main Time-Based Rate Programs:

- Time of Use Rates (TOU):the energy prices is changed respect to time of use usually the energy price increased in peak demand periods.
- Critical Peak Pricing (CPP): it looks like TOU but it relies on very high prices during critical peaks rather than average TOU rates, also identifying spikes in peak demand and communicating price changes with end users to provoke shifts in energy consumption
- Real-Time Pricing (RTP):the changes in energy prices not based on fluctuations only but also to notify consumers to integrate demand-side applications to participate in load-shifting decisions. [13]

3.3.3 Load Shaping Techniques

DSM works to reduce electricity consumption in residential and industrial loads using deferent programs as mention before. DSM manipulates residential and industrial electricity usage to reduce cost by altering the system load shape, the common techniques that used in load shaping are peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape as shown in Figure (3.2).

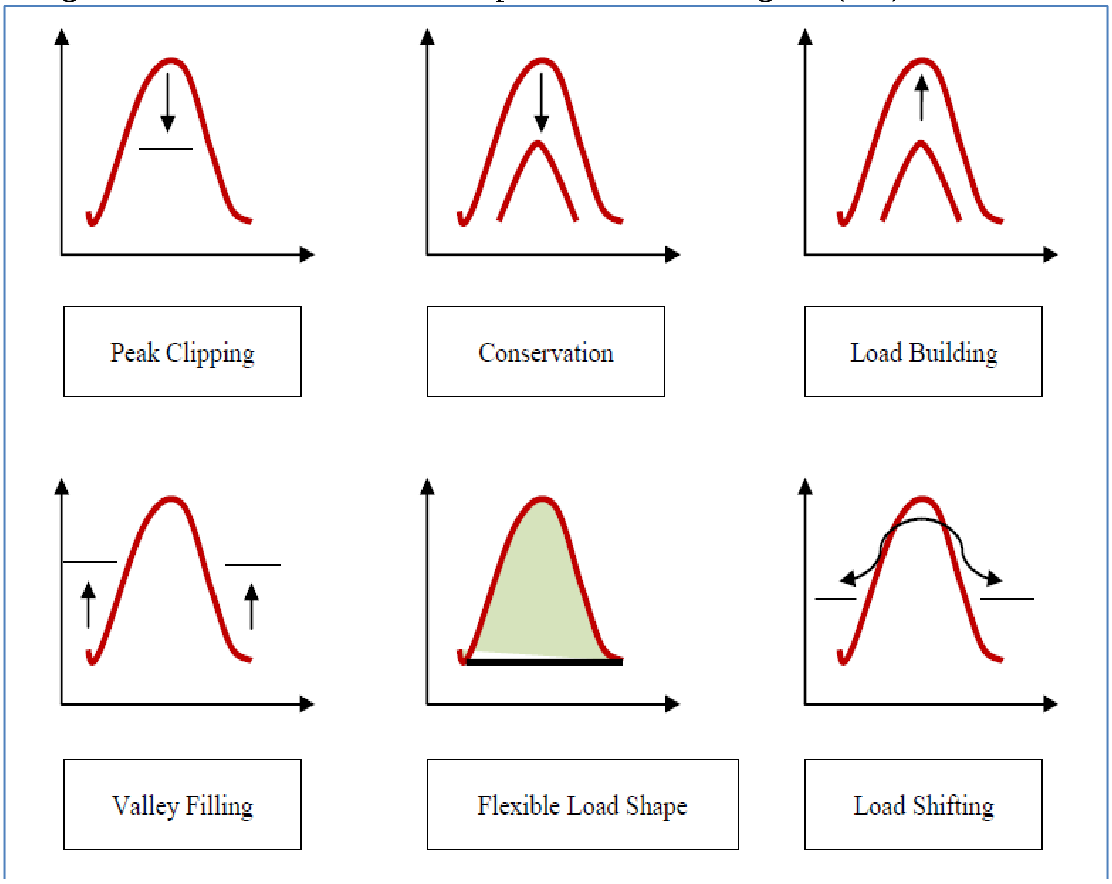

Figure (3.2): Load Shaping Techniques. [14]

Load leveling help to optimize the current generating base-load without the need for reserve capacity to meet the periods of high demand, many technologies can be used such as the following techniques: [14]

- Peak clipping; here demand peaks are clipped and the load is reduced at peak times. This form of load management focuses on reducing peak demand.
- Valley filling; here low demand periods are filled by building off-peak capacities.

- Conservation; using high efficient loads instead of old traditional one and reducing overall consumption.
- Load building; due to normal growth day by day will increase the load and overall consumption
- Flexible load shape; specific contracts and tariffs with the possibility of flexibly controlling consumers load time and periods.
- Load shifting; here loads are shifted from peak to valley times achieving clipping and filling

3.4 Demand Side Control (DSC) [21]

DSC is one of the most important DSM techniques for manipulating the energy demand profile from appliances through different combinations of switching strategies, either on/off or proportional control. The key point of using DSC is to find the best switching strategies for loads with minimum impact on services, in order to achieve the minimum difference between demand and supply. It can improve the energy match between demand and supply from intermittent sources and reshape the demand profile towards more favorable one.

In DSC, many parameters have to be taken into account the first one is the load demand priorities which will be classified from high to low due to its importance and the control method, either on/off or proportional, will be specified for each individual load depends on each priority. The second one is the control method which essentially to decides how the demands are controlled. There are two main control methods are available: on/off control and proportional control, the on/off control is mean that a certain load can be turned off or not while the proportional control means a percent of the defined load may turn off or not. The third parameter which is the solar energy and storage availability the last one which is the time, as it plays a mainrole on the peak demand and load curve. Figure (3.3) illustrate the DSC parameters and constraints. [13]

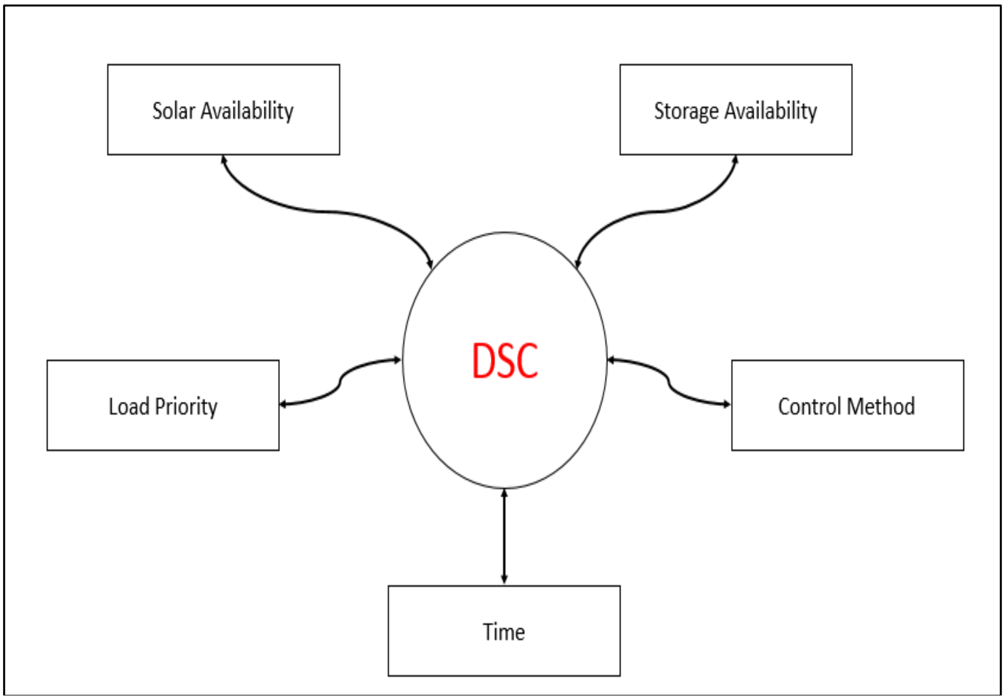

Figure (3.3): DSC Parameters and Constrains

3.5 Demand Side Management Impacts [13-15]

3.5.1 Demand Side Management Advantages [13-15]

DSM has proved to be advantageous to both consumers and the utilities. Some studies in DSM have listed the following points.

- DSM will reduce the peak demand then it will reduce construction costs for new energy facilities.
- Reduced power cuts/shortages and increased system reliability.

- Consumer's electricity bills will be reduced through the use of energy efficient appliances and through monitoring the time of consumption of electricity.
- Improving energy system efficiency by improving generation efficiency and load factor.
- Reducing Green House Gases (GHG) emissions through efficient generation and minimizing thermal generation

3.5.2 Demand Side Management Disadvantages [13-15]

Besides all advantages of DSM implementation, there are many disadvantages to be concerned before the implementation of DSM system some of these disadvantages:

- Large investments for installing DSM equipment and controls may diminish the chance of expanding the fixed assets of the utility itself and slow or no repayment for their investments.
- DSM may reduce marketing power income because of carrying out DSM so as to affect their profits.

Chapter Four

Selection of Optimum System for An-Najah National University Hospital

4.1 Introduction [4]

An-Najah National Hospital is the first university hospital in Palestine, and will combine to provide the best medical services to the Palestinian citizen, and between medical educations, because the region needs to have a medical hospital and various specialized sections meet the needs of the different health of citizens. The establishment of this hospital, which will provide productive for specialists, will contribute increasing of medical specialists and skilled, so the presence of this university hospital will contribute to supplement of health sector expertise and capabilities important to the development in health sector, which is an important investment in the presence of capacity and medical competencies in Palestine, reduce the brain drain, and polarization as well.

In 2008, the university signed a joint cooperation agreement with the Palestinian Ministry of Health, regarding the establishment of the university hospital and run it. The signing took place at an official ceremony in the office of President of the University Prof. Rami Hamdallah, who represented the university at the signing ceremony, and Dr. Fathi Abu Maghly who was the Palestinian Minister of Health.

It is noteworthy here that the Palestinian National Authority is the most important partner that have funded follow-up rehabilitation of existing buildings, and the creation of buildings complementary to qualify, to be almost the first stage of an area of 17,000 square meters of integrated hospital, which plans a second phase to be an area of 65,000 square meters.

4.2 Energy Analysis of An-Najah National University Hospital [4]

Building (A) which is the northern and outpatient building, this building has average demand about 377.7 kVA. Figure (4.1) illustrate the daily load curve of building (A) which has a minimum value about 198 kVA and maximum value about 588kVA.

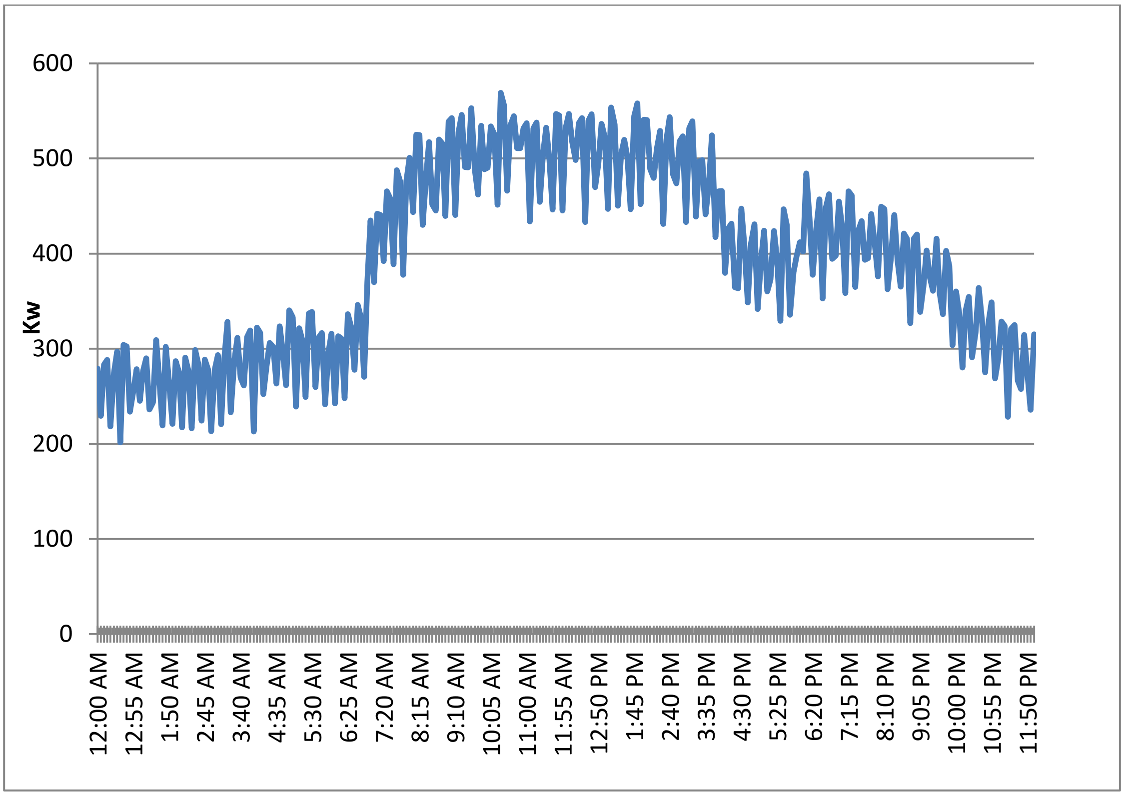

Figure (4.1): Daily Load Curve of Building (A).

From daily load curve it clear that the maximum demand of building (A) was between 8:00 AM and 4:00 PM which is normal as the hospital staff starts their duties at 8:00 AM also patients visits and staff duties end at 4:00 so many air conditioning units and lighting units depend on the staff duties and this unithas a big value of energy demand.

All these data from energy analyzer that was installed by the Energy Research Center in the main distribution board of buildings A, B and C in different periods of the year. The whole data have negligible differences on other days as it was small values.

For Building (B) which is the Emergency and Bedrooms (Southern Building) the energy analyzer told us that this building has average demand about 116 kVA. Figure (4.2) illustrate the daily load curve of Building (B) which has a minimum demand value about 64 kVA and maximum demand value about 244kVA. In building (B), it seems that it has smaller demand values compared with building (A). this because it is smaller building compared with A and it contains bedrooms which did not have large loads.

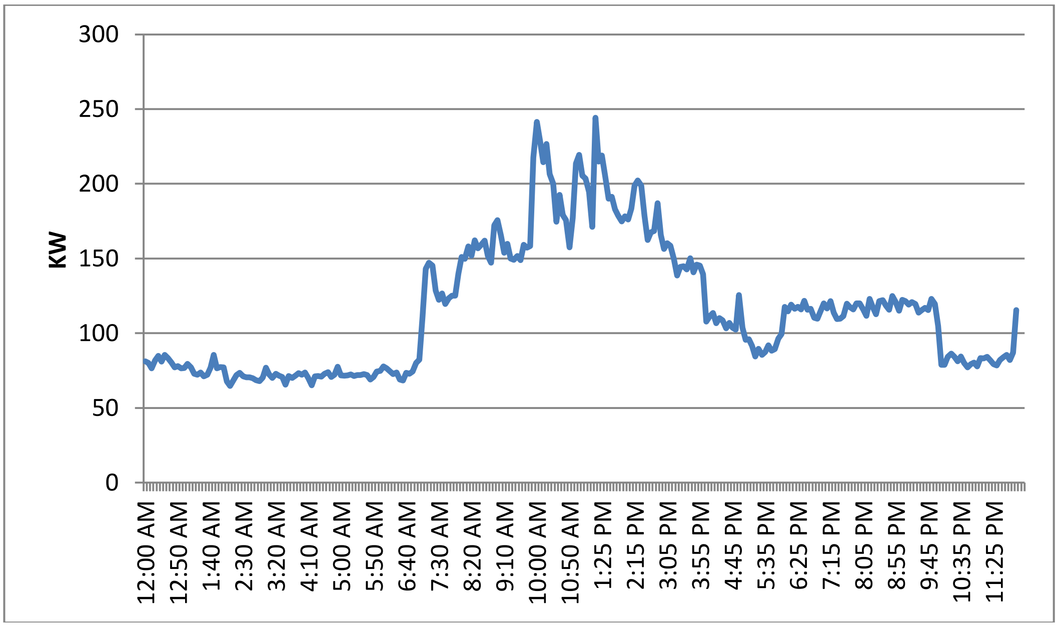

Figure (4.2): Daily Load Curve of Building (B).

Building (C) which is the middle building between buildings A and B and connects between them, from energy analyzer data and the daily load curve of it. Figure (4.3) illustrate the daily load curve of Building (C) with average demand about 357 kVA, 190 kVA minimum demand, and 547kVA maximum demand.

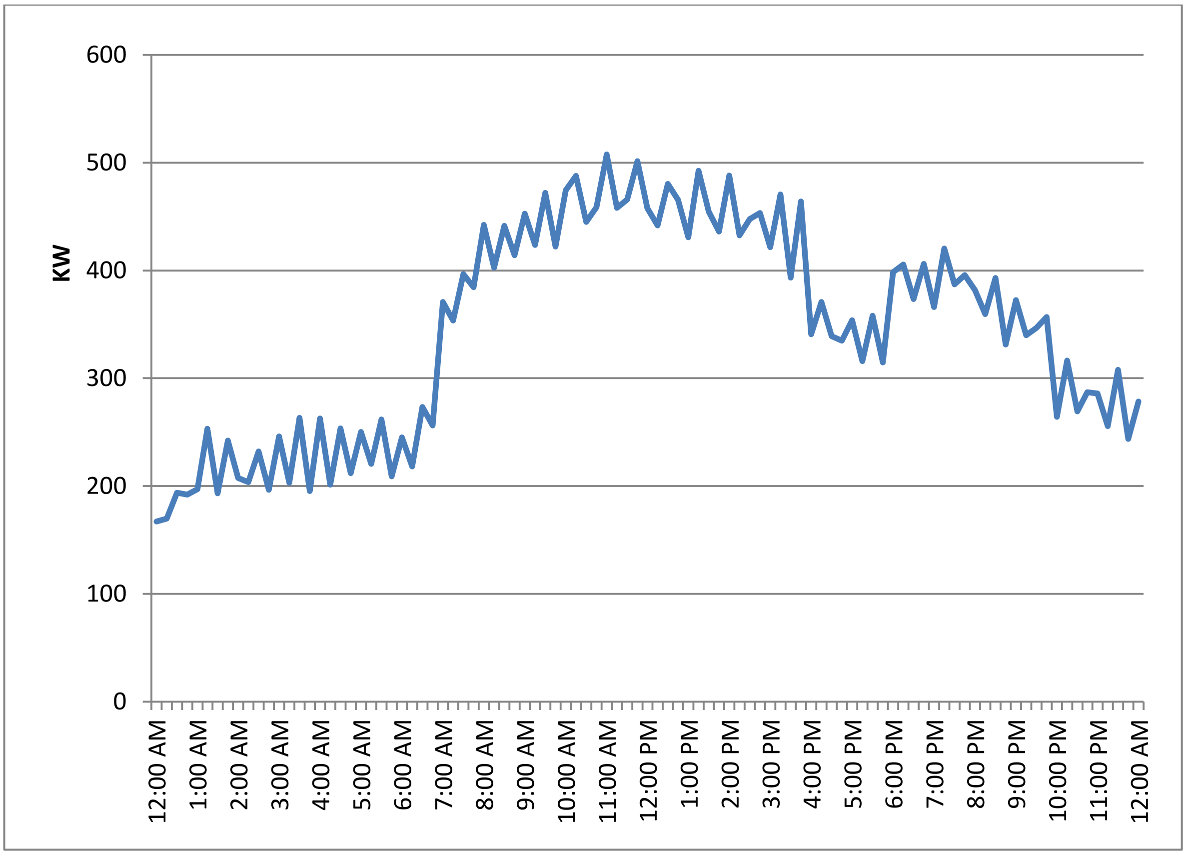

Figure (4.3): Daily Load Curve of Building (C).

4.3 Energy Consumptions Bills of An-Najah National University Hospital [4]

In An-Najah National University Hospital three individual feeders from NEDCO and each one feeds only one building with its special energy meters that connected at the end of NEDCO feeders the subscribes number of the hospital buildings are 59872, 59873 and 59874 respectively for buildings A, B and C.NEDCO is using flat metering system with rate around 0.73 NIS per kWh. Tables (4.1), (4.2) and (4.3) will illustrate the real consumed energy for buildings A, B and C in the period between June-2015 and September-2015.

Table (4.1): Consumed Energy of Building (A).

Month	Consumed Energy (kWh)	Consumed Energy Cost(NIS)
June	137358	109782.01
July	139454	111457.22
August	175087	139936.53
September	175101	139947.72

Table (4.2): Consumed Energy of Building (B).

Month	Consumed Energy (kWh)	Consumed Energy Cost(NIS)
June	46645	37280
July	69581	55611
August	96258	76933
September	59450	47514

Table (4.3): Consumed Energy of Building (C).

Month	Consumed Energy (kWh)	Consumed Energy Cost(NIS)
June	83707	66901
July	92854	74212
August	102738	82112
September	102225	81702

From monthly bills, it noticed that the hospital has a large bill and it has to pay more than 200 thousand of NIS every month, so the hospital has to pay attention about energy consumption and has to reduce its bills using grid-connected PV system.

4.4 Photovoltaic System Design for An-Najah Hospital

Any PV system is composed by the total photovoltaic panels responsible of generating electricity by transforming solar energy. On grid-tied PV installations, it supposed to produce energy as much as possible, as the main goal of grid-tied PV system to sell energy to the grid and make aprofit with it. Actually, the main limiting factors of plant size are money, area, and social acceptance. Large PV plants have a wide range of kWp of power, starting from few kWp such up to MWp.

In grid-tied PV systems design, the loads should be taken into account, in An-Najah hospital system the daily load curves of buildings A, B and C are the main sources of important data in the design of the system. The daily demands will be considered for each building individually as each one has a different feeder that connected on the grid. Then the penetration level will be considered as 30% of demand. PV penetration is defined as the ratio of the produced PV Energy to the consumed energy of the load. [7]

Practically many factors will affect the system outputs so in PV system design the de-rating should be considered due to losses that issued by temperature, dust, wiring, shading, tilting, azimuth tracking, invertersefficiencies, and aging. The whole de-rating value could be considered between 75% - 90%. Performance ratio (PR) that refers to the relationship between the actual and theoretical energy outputs of the PV plant. The ideal PR value is 100% but due to different types of losses practically high-performance PV plants can, however, reach a performance ratio of up to 80%. The following equations describe PV penetration level, PV system capacity, and the performance ratio respectively. [8]

$$\text{PV Penetration level} = \frac{\text{PV Produced Energy}}{\text{Load Consumed Energy}} \text{ x } 100\% \quad (4.1)$$

$$\text{PV System Capacity} = \frac{\text{Desired Demand}}{\text{Average Solar Radiation}} \quad (4.2)$$

$$\text{Performance Ratio (PR)} = \frac{\text{Actual Reading of Plant output}}{\text{Nominal Plant output}} \text{ x } 100\% \quad (4.3)$$

4.4.1 Photovoltaic Design for Building (A)

In large PV systems, its configuration can vary significantly in size. Then different configuration strategies maybe used in system design and implementation. Practically PV modules sizes are varied from 5Wp up to 300Wp also current and voltages are varied and have wide range depends on the manufacturers and used technologies so that the connection of PV modules arrays and string should take the MPPT rating into account. Then the number of arrays, panels and inverters should confirm the PV Plant rating. In large PV systems to have the better reliability of the system, it's recommended to divide the panels into different arrays and different inverter thus if there is a problem with one inverter the other ones can still continue generating energy. However, the system reliability is recommended, but it makes the project more expensive because more equipment is needed.

Annajah hospital PV system is considered a large system which is clear from daily load curves of each building. Referring to figure (4.2) the area under the daily load curve represents the demand of the building which was 9048 kWh. Then using penetration level equation, the daily produced energy of PV system will be 2714kWh taking into account average solar radiation in Palestine which is equal to 5.4kWh/day then using equation (4.2) the PV system capacity will equal to 502 kWp. Considering 90% de-rating factor in the system design then Building (A) PV system capacity will be about 550kWp to ensure the desired penetration value.

The first step in the design is to determine the number of PV modules that are needed for Building (A) PV system to determine that then the rating of used PV module should be considered, in this system design a mono-crystalline PV module was selected due to many advantages compared to other types of PV modules especially the high efficiency, long life span which about twenty-five years with small degradation in output and the more wattage per square meter. In An-Najah Hospital PV system CS6X - 305M design by Canadian Solar is used. This module rating is 305Wp at STC conditions and other characteristics are shown in table 4.4.

Table (4.4) Canadian Solar Inc. CS6X - 305M characteristic.

Watts (STC)	305 W
Max Power Voltage (VMPP)	36.6 V
Max Power Current (IMPP)	8.33 A
Open Circuit Voltage (VOC)	45.2 V
Short Circuit Current (ISC)	8.84 A

The number of needed modules can be obtained from the following equation formula.

$$\mathbf{Npv} = \frac{\text{Desired Power of PV Plant}}{\text{Nominal Power of PV Module}} \qquad \mathbf{(4.4)}$$

$$\mathbf{Npv} = \frac{550\ \text{KWp}}{0.305\text{Kwp}} = \mathbf{1803\ modules}$$

The other important element in grid-tied PV systems is inverter as it has the responsibility of transforming the PV generators outputs which are DC to AC. This is important as the electric distributions networks are operate in AC electricity also the inverter is responsible on the synchronization of its AC outputs as voltages, phases, and frequency with the grid also it has the responsibility of monitoring the grid for anti-islanding protection, which in such case the inverter should disconnect the PV system from the grid. [9]

As mentioned before the system capacity of Building (A) is 550kWp so the grid tied inverter ratings should be compatible with PV strings and arrays ratings. Theoretically, the systems could have only one inverter of 550kWp or above rating but due to the reliability issues, it’s recommended to use many smaller inverters with an accumulating rating of 550kWp at least. In the system design, Sunny Central 100 of SMA was selected. At least 5 units are needed to cover the PV plant capacity and one is recommended as standby.

The SMA Sunny Central 100 have internal maximum power point tracker that operates on voltages between 450-820V this should be taken into account in arrays configurations so that each array voltage should be in the MPPT range also taking into account the voltages variation due to temperature changes in winter and summer.

If an array of 15 modules were connected in series the VMPP will be around 550V which is in the MPPT range. As 15 modules array will be used then the system will has 120 strings in parallel these strings will be distributed to 5 SMA Sunny Central 100 inverters. The output of each inverter will be connected the main distribution board of Building (A) using special MCCB with the proper rating. Figure (4.4) will illustrate the system schematic including PV modules, arrays, strings and inverter.

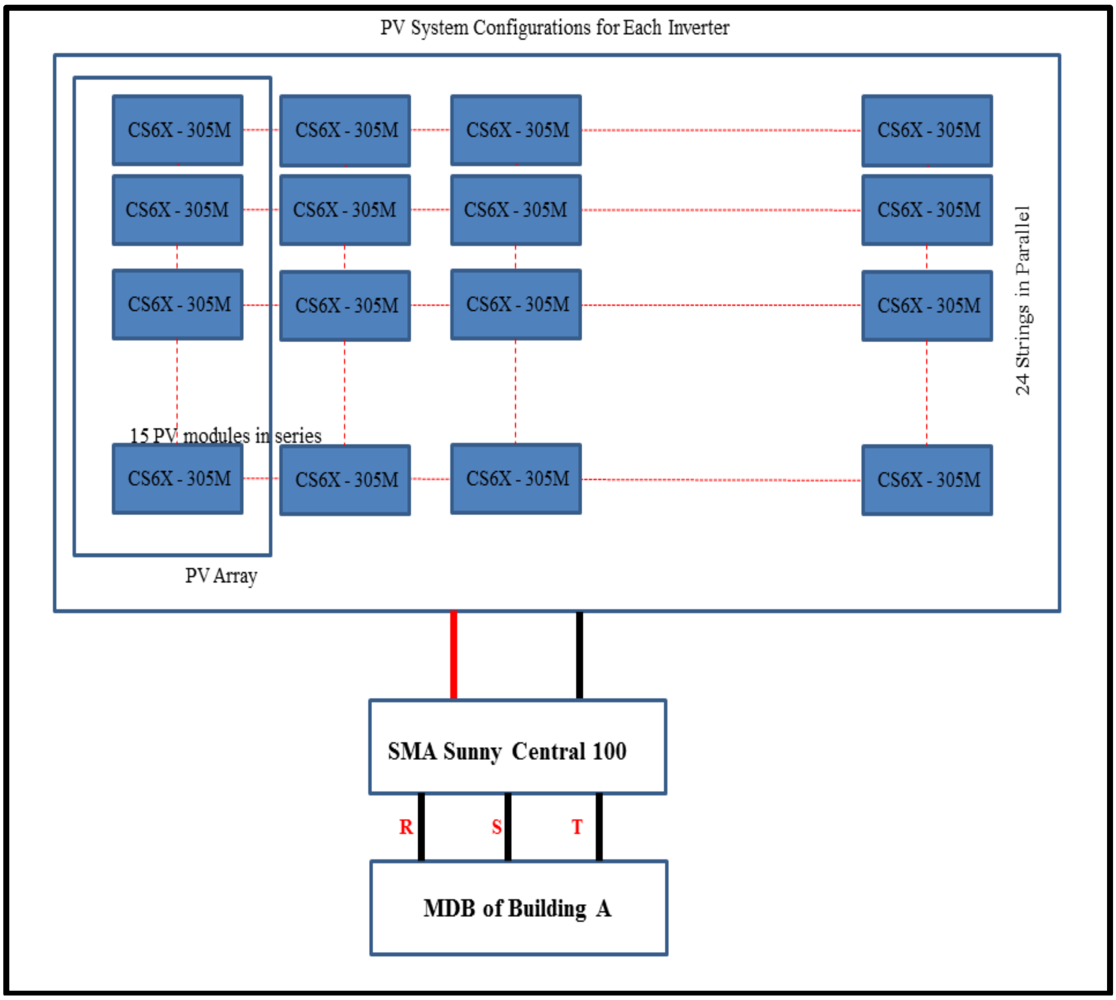

Figure (4.4): Building (A) PV System Schematic.

4.4.2 Photovoltaic Design for Building B

Referring to figure (4.2) the area under the daily load curve represents the daily demand of Building (B) which was 2774 kWh. Using penetration level equation, the daily produced energy of PV system will be 832 kWh taking in account average solar radiation in Palestine which is equal to 5.4kWh/day then using equation (4.2) the PV system capacity will equal to 154 kWp. Considering 90% de-rating factor in the system design then Building (B) PV system capacity will be about 171 kWp to ensure the desired penetration value, but her in the case study the installed system was

104kWp.

To determine the number of PV modules that are needed for Building (B) PV system, to determine that the rating of used PV module should be considered, in Building (B) system design the used module was Amerisolar 330Wp poly-crystalline PV module so the number of needed modules can be obtained from the following equation:

$$\textbf{Npv} = \frac{104\ \text{KWp}}{0.33\text{Kwp}} = \textbf{316 modules}$$

The number of needed PV modules is 316 of Amerisolar AS-6P as mentioned before the system capacity of Building (B) is 104kWp so the grid tied inverter ratings should be compatible with PV strings and arrays ratings. Theoretically, the system could has only one inverter of 100kWp or above rating but due to the reliability issues, it’s recommended to use many smaller inverters with an accumulating rating of 104kWp at least. In the system design, Sunny Tripower 20000TL-30 of SMA was selected. At least 5 units are needed to cover the PV plant capacity and one is recommended as standby.

The SMA Sunny Tri power 20000TL-30 has internal maximum power point tracker that operates on voltages between 380-800V this should be taken into account in arrays configurations so that each array voltage should be in the MPPT range also taking into account the voltages variation due to temperature changes in winter and summer.

If an array of 16 modules were connected in series the VMPP will be around 585V which is in the MPPT range. As 16 modules array will be used then the system will has 36 strings in parallel these strings will be distributed to 5 SMA Sunny Tri power 20000TL-30 inverters. The output of each inverter will be connected the main distribution board of Building (B) using special MCCB with the proper rating. Figure (4.5) will illustrate the system schematic including PV modules, arrays, strings and inverter.

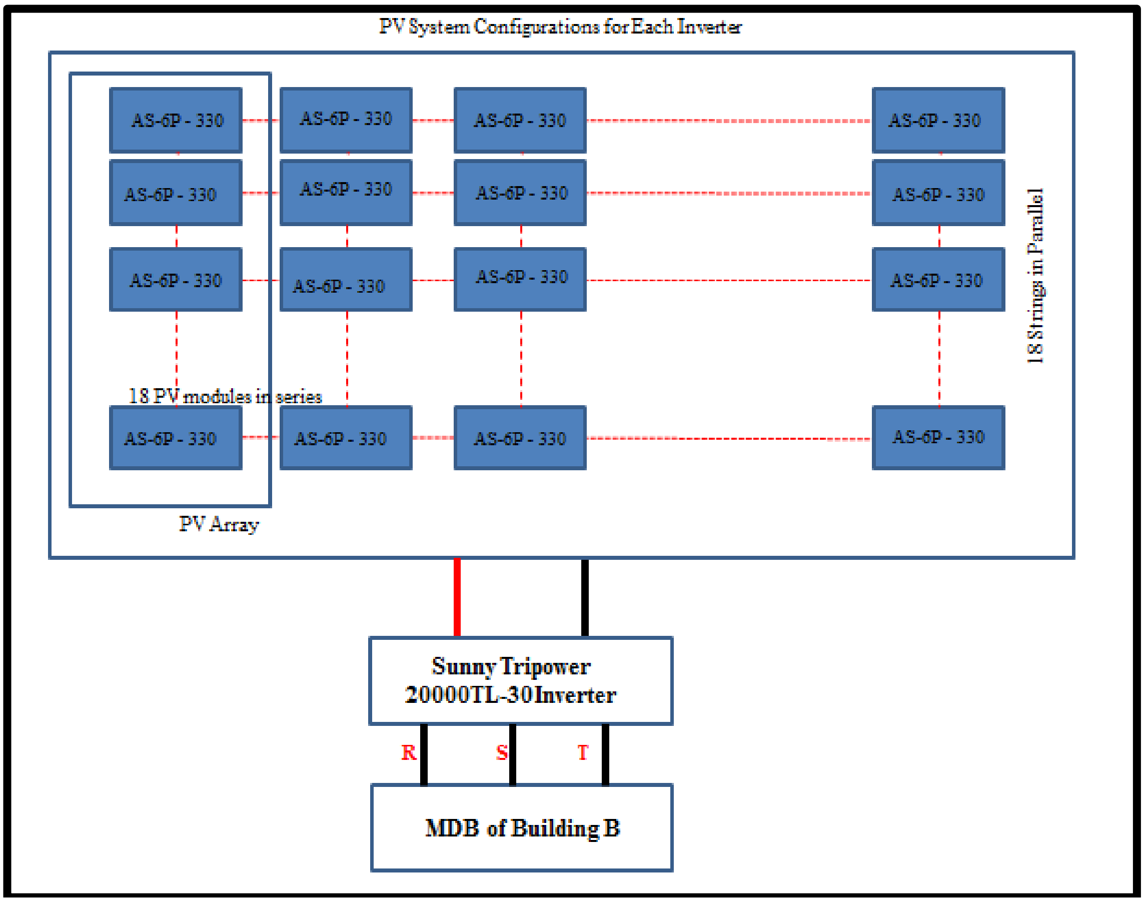

Figure (4.5): Building (B) PV System Schematic

4.4.3 Photovoltaic Design for Building (C)

Referring to figure (4.4) the area under the daily load curve represents the daily demand of Building (C) which was 8560 kWh. Using penetration level equation, the daily produced energy of PV system will be 2560 kWh taking in account average solar radiation in Palestine which is equal to

5.4kWh/day then using equation (4.2) the PV system capacity will equal to 474 kWp. Considering 90% de-rating factor in the system design then Building (B) PV system capacity will be about 520 kWp to ensure the desired penetration value.

The same module Canadian Solar Inc. CS6X - 305M is used in Building (C) system design, the number of needed modules is to be determined as followed:

$$\mathbf{Npv} = \frac{520\ \text{KWp}}{0.305\text{Kwp}} = \mathbf{1705\ modules}$$

The number of needed PV modules is 1705 of Canadian Solar Inc. CS6X - 305M this module characteristic is shown in the table (4.4). As mentioned before the system capacity of Building (C) is 520kWp so the grid tied inverter ratings should be compatible with PV strings and arrays ratings. Theoretically, the system could has only one inverter of 520kWp or above rating but due to the reliability issues, it’s recommended to use many smaller inverters with an accumulating rating of 520kWp at least. In the system design, JH 120 KE1 by Sharp was selected. At least 5 units are needed to cover the PV plant capacity and one is recommended as standby.

The Sharp JH 120 KE1 has internal maximum power point tracker that operates on voltages between 420-850V this should be taken into account in arrays configurations so that each array voltage should be in the MPPT range also taking into account the voltages variation due to temperature changes in winter and summer.

If an array of 17 modules were connected in series the VMPP will be around 622V which is in the MPPT range. As 17 modules array will be used then the system will has 92 strings in parallel these strings will be distributed to 4 Sharp JH 120 KE1 inverters.

The output of each inverter will be connected the main distribution board of Building (C) using special MCCB with the proper rating. Figure (4.6) will illustrate the system schematic including PV modules, arrays, strings and inverter.

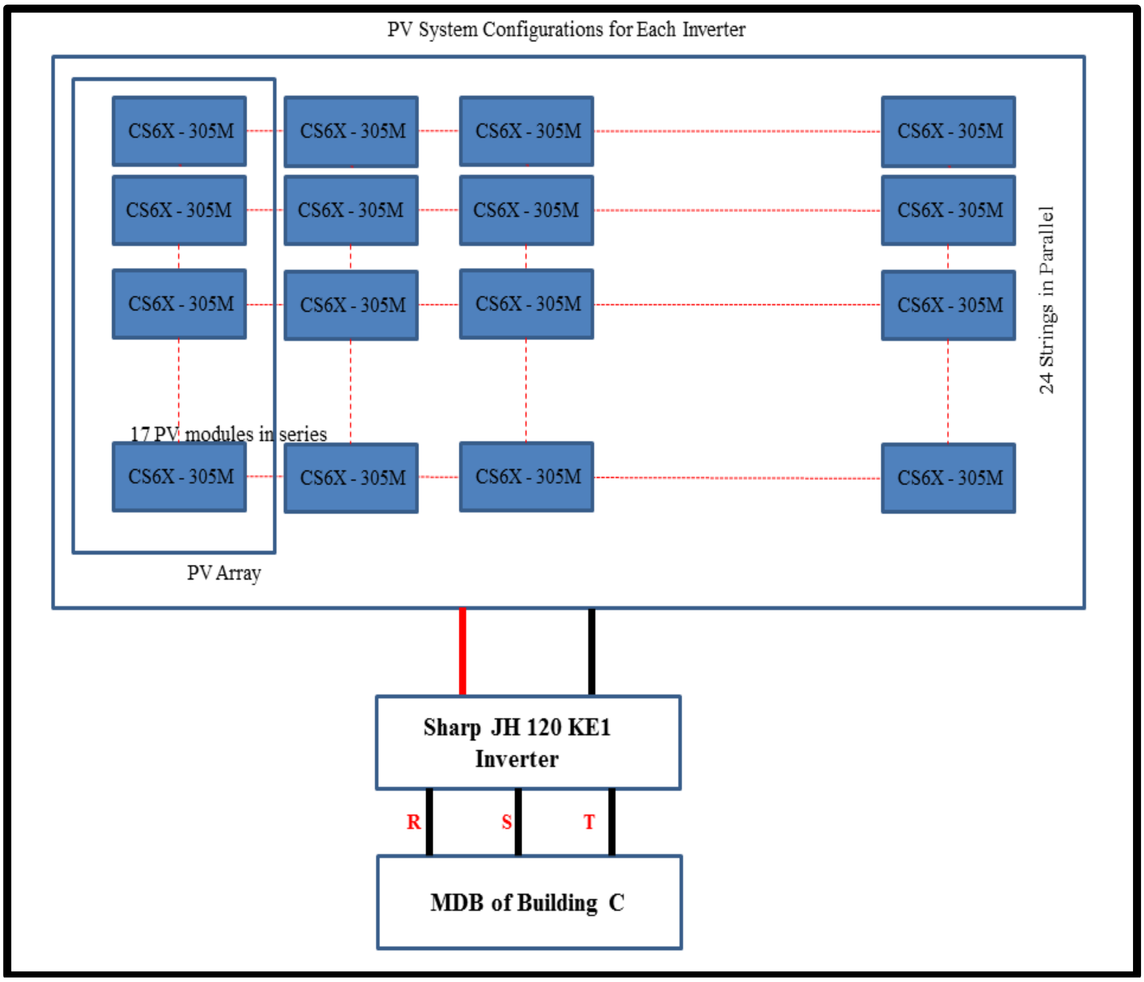

Figure (4.6): Building (C) PV System Schematic

4. 5 Simulation of PV System by Using Software Program

The simulation of the designed PV systems for building (A), (B) and (C) was presented with the use of the computer software and its performance was evaluated. The produced energy, performance ratio and the various power loss was calculated.

4.5.1 Simulation of PV for Building (A)

The optimum design for building (A)was 550kWp capacity which was shown in section 4.3.1, a computer software was used to check the performance building (A) in this simulation a real data about PV panels, inverters, tilting angels and system configuration was considered to have goof estimations results. system the main results that needed are total expected produced energy which was 1015mWh/year, the performance factor which was about 81.4% and the whole system losses which are called Collection Loss (PV-array losses) that was about 1.02 kWh/kWp/day and the System Loss (cabling, MPPT, inverter, ...) which was about 0.14 kWh/kWp/day. These data are shown in Figure 4.7 and table 4.5 that illustrate the expected produced energy, collection losses and the system losses for building (A) system for each month individually. The full simulation reports are attached in the appendix (2)

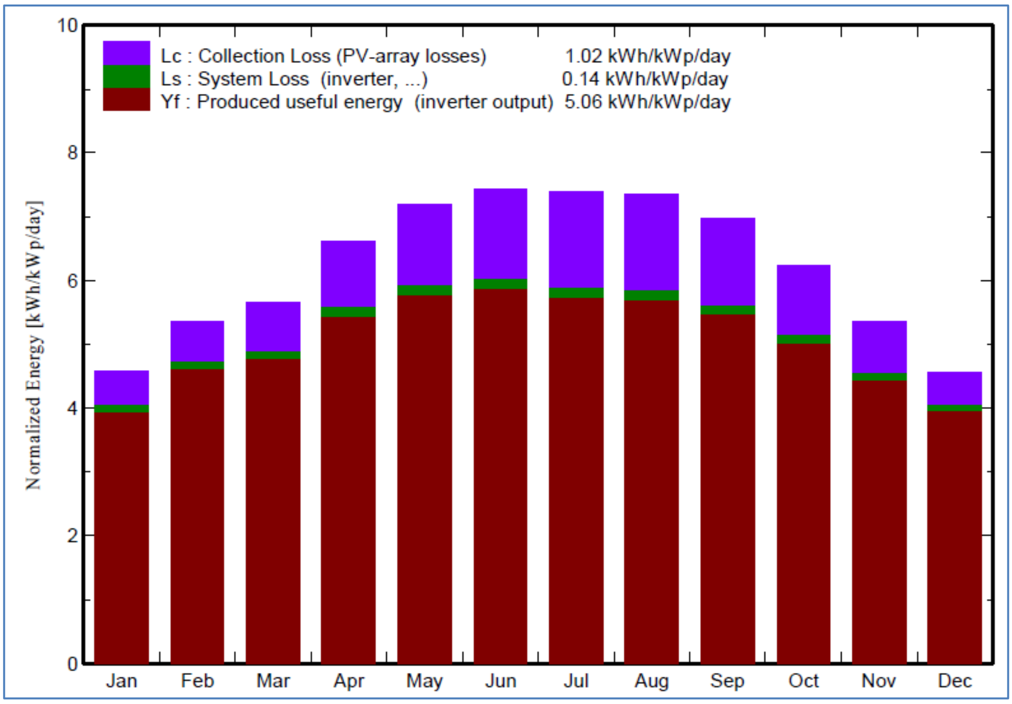

Figure (4.7): Normalized productions for building (A) (per installed kWp)

Table (4.5):Building (A) system main simulation results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	91.1	13.02	141.9	139.1	69.1	67.19	14.10	13.71
February	110.2	13.71	150.2	146.9	72.9	71.00	14.06	13.68
March	158.1	16.34	175.3	170.5	83.4	81.16	13.78	13.40
April	188.6	19.21	198.1	192.6	92.1	89.56	13.46	13.09
May	231.4	22.40	222.8	216.1	101.1	98.32	13.13	12.77
June	241.2	25.05	222.7	216.0	99.5	96.77	12.93	12.58
July	243.3	27.63	229.1	222.3	100.5	97.71	12.70	12.35
August	224.3	27.93	227.9	221.5	99.7	97.02	12.67	12.33
September	185.8	26.06	208.9	203.7	92.6	90.10	12.83	12.49
October	147.6	23.68	192.9	188.5	87.7	85.40	13.17	12.81
November	104.4	18.89	160.5	157.6	75.2	73.13	13.56	13.19
December	84.8	15.09	141.1	138.3	69.2	67.35	14.19	13.82
Year	2010.8	20.79	2271.5	2213.3	1043.0	1014.70	13.29	12.93

Legends: GlobHor Horizontal global irradiation; T Amb Ambient Temperature; GlobInc Global incident in coll. plane; GlobEff Effective Global, corr. for IAM and shadings; EArray Effective energy at the output of the array; E_Grid Energy injected into grid; EffArrR Effic. Eout array / rough area; EffSysR Effic. Eout system / rough area

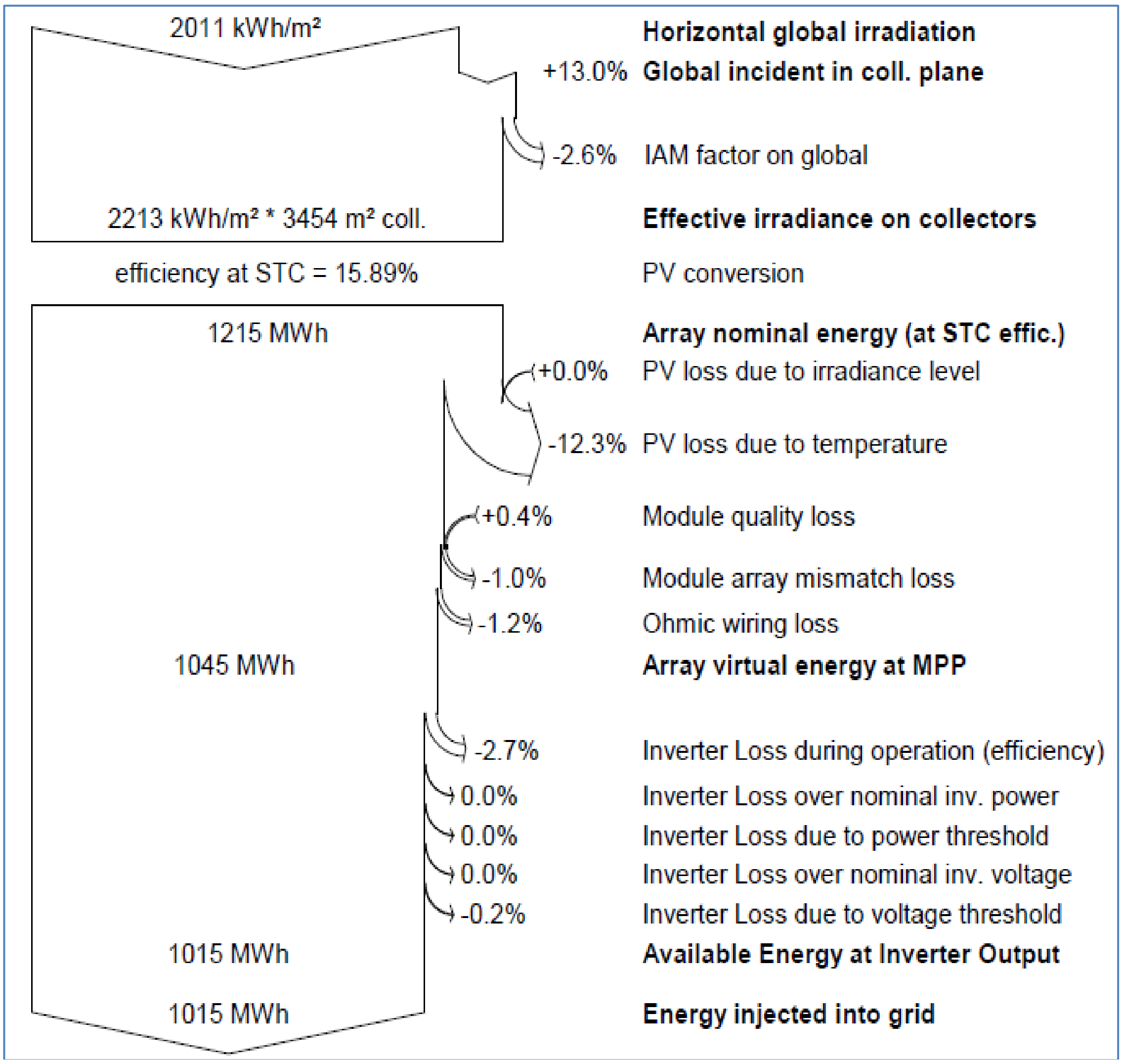

Figure (4.8): Building (A) PV system losses breakdown.

4.5.2 Simulation of PV System for Building (B)

The optimum design for building (B) was104kWp capacity which was shown in section 4.3.2, the same procedure as building (A) was used to check the performance building (B) in this simulation a real data about PV panels, inverters, tilting angels and system configuration was considered to have good estimations results. system the main results that needed are total expected produced energy which was 187374kWh/year, the performance factor which was about 81.6% and the whole system losses which are called Collection Loss (PV-array losses) that was about 0.99 kWh/kWp/day and the System Loss (cabling, MPPT, inverter, ...) which was about 0.1 kWh/kWp/day. These data are shown in Figure 4.9 and table 4.6 that illustrate the expected produced energy, collection losses and the system losses for building (B) system for each month individually. The full simulation reports are attached in appendix A2.

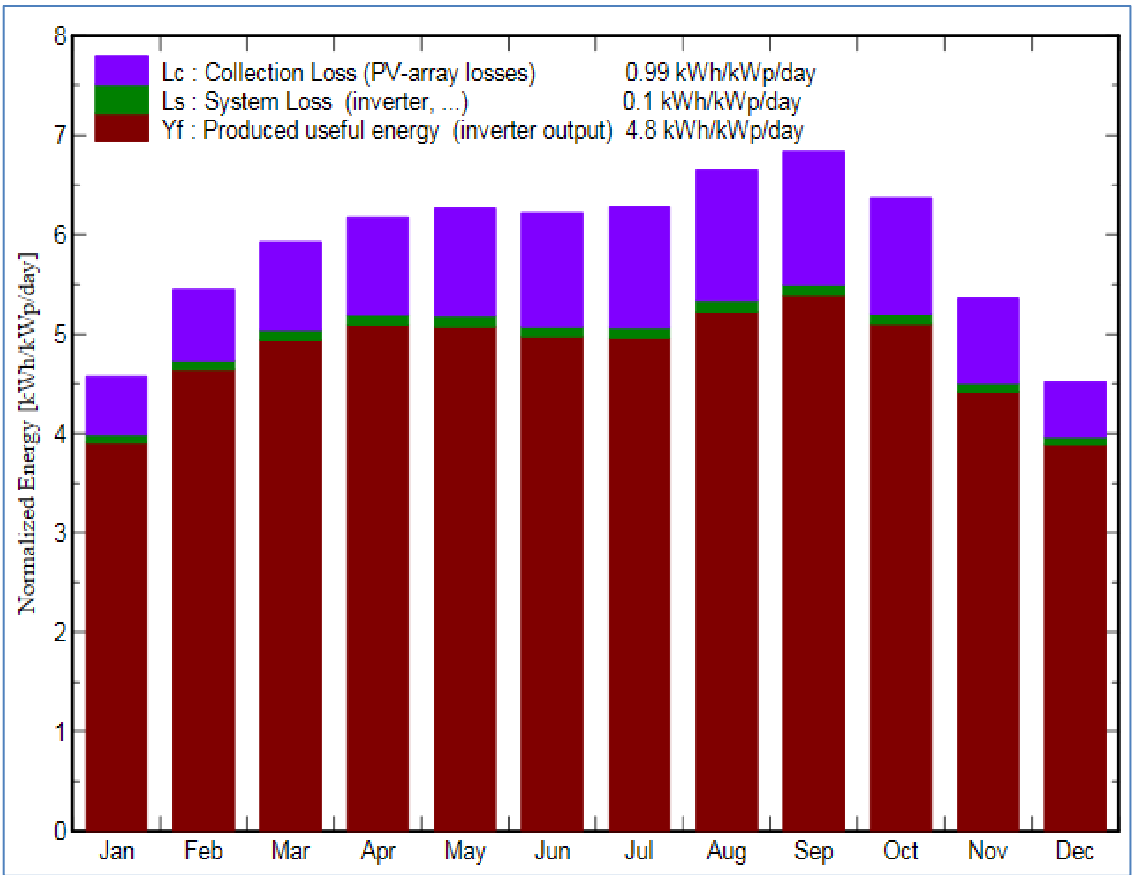

Figure (4.9): Normalized productions for building (B) (per installed kWp)

Table (4.6):Building (B) system main simulation results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	91.1	13.02	141.8	140.6	13232	12965	15.01	14.71
February	110.2	13.71	152.6	151.1	14171	13896	14.94	14.65
March	158.1	16.34	183.6	181.5	16710	16372	14.64	14.34
April	188.6	19.21	185.1	182.3	16651	16317	14.47	14.18
May	231.4	22.40	194.2	190.3	17175	16834	14.23	13.94
June	241.2	25.05	186.5	182.3	16293	15967	14.05	13.77
July	243.3	27.63	194.7	190.7	16779	16440	13.86	13.58
August	224.3	27.93	206.2	202.8	17672	17314	13.79	13.51
September	185.8	26.06	205.1	202.7	17636	17284	13.83	13.56
October	147.6	23.68	197.5	195.6	17249	16906	14.05	13.77
November	104.4	18.89	160.8	159.6	14450	14158	14.45	14.16
December	84.8	15.09	140.0	138.7	13142	12894	15.10	14.82
Year	2010.8	20.79	2147.9	2118.3	191160	187347	14.32	14.03

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

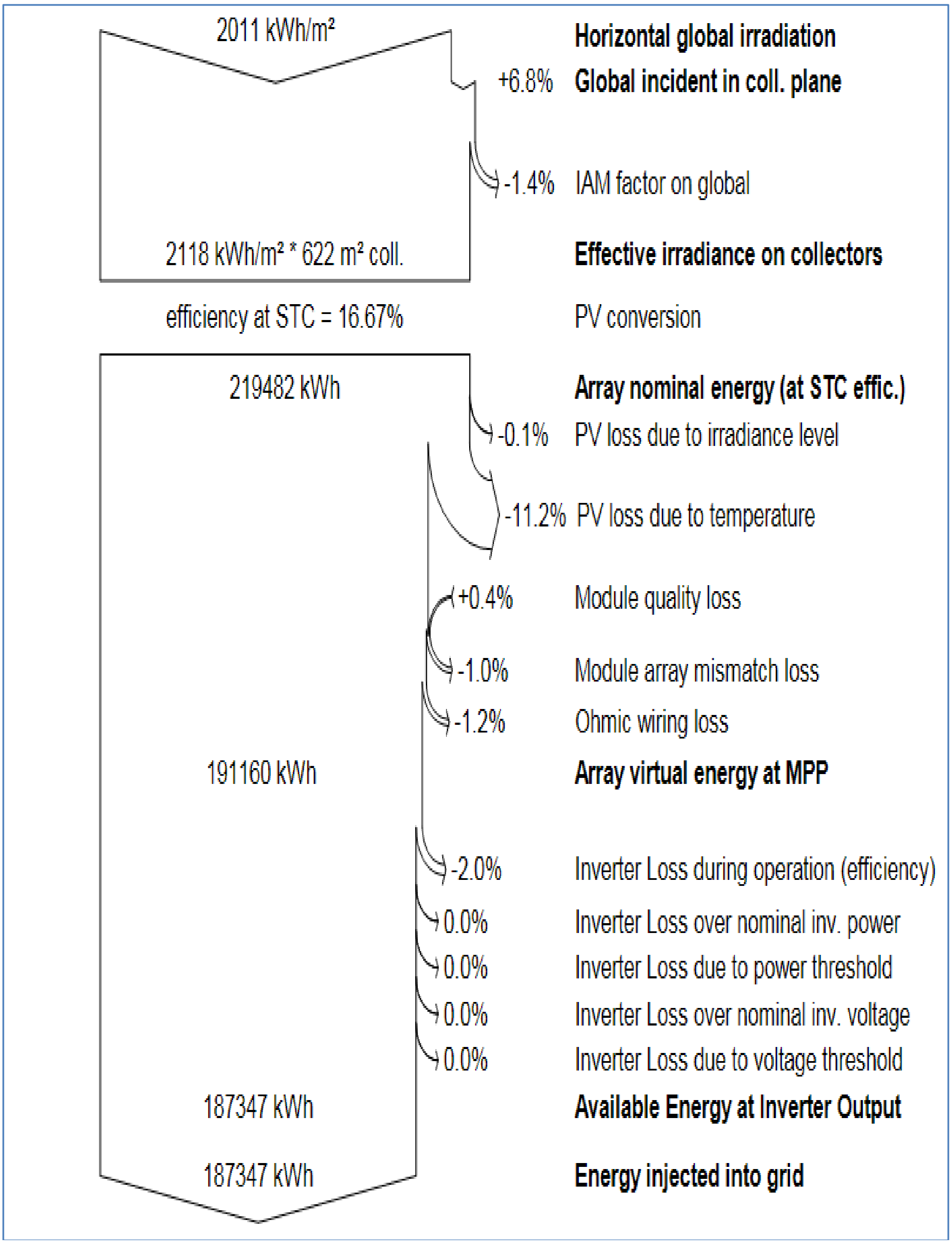

Figure (4.10): Building (B) PV system losses breakdown.

4.5.3 Simulation of PV System for Building (C)

The optimum design for building (C) was520kWp capacity which was shown in section 4.3.3, the same procedure as building (A) was used to check the performance building (C) in this simulation a real data about PV panels, inverters, tilting angels and system configuration was considered to have good estimation results. system the main results that needed are total expected produced energy which was 954MWh/year, the performance factor which was about 80.7% and the whole system losses which are called Collection Loss (PV-array losses) that was about 0.94 kWh/kWp/day and the System Loss (cabling, MPPT, inverter, ...) which was about0.26 kWh/kWp/day. These data are shown in Figure 4.11 and table 4.7 that illustrate the expected produced energy, collection losses and the system losses for building (B) system for each month individually. The full simulation reportsare attached in appendix A2.

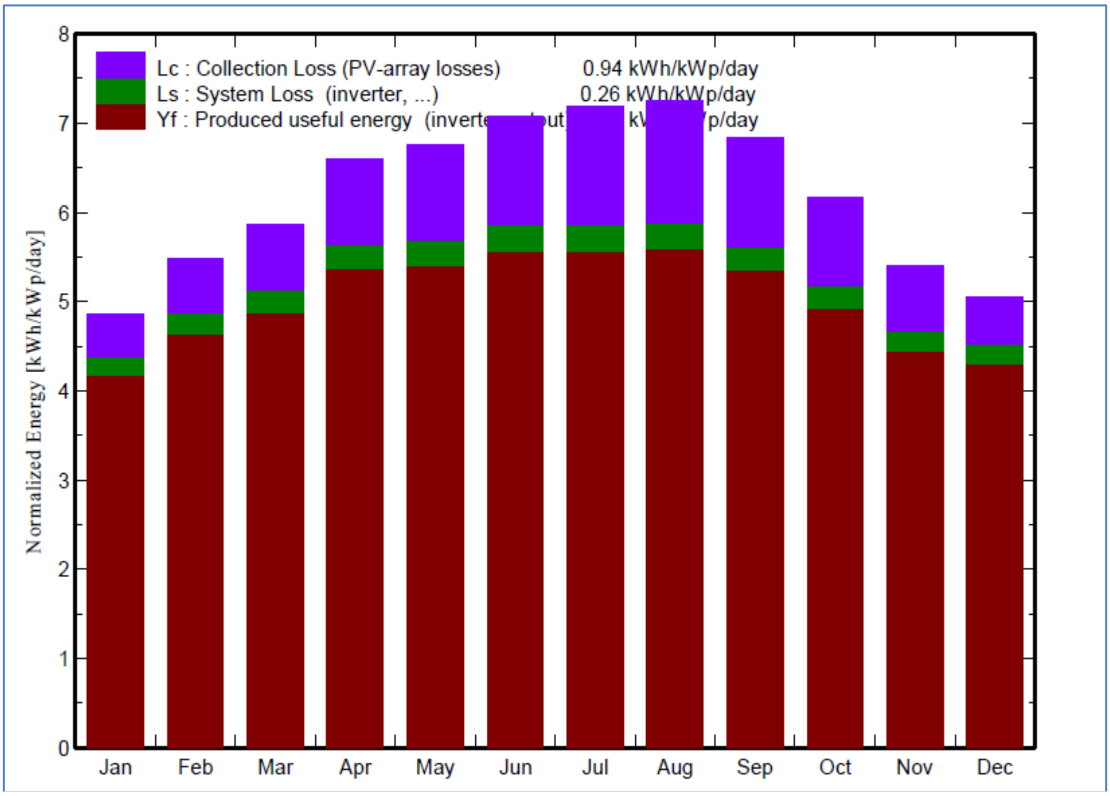

Figure (4.11): Normalized productions for building (C) (per installed kWp)

Table (4.7):Building (C) system main simulation results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	96.3	13.10	150.6	149.3	70.90	67.39	15.07	14.33
February	112.0	14.43	153.6	152.1	71.13	67.74	14.83	14.12
March	162.5	17.12	181.6	179.2	82.83	78.69	14.60	13.87
April	188.7	19.89	198.0	195.0	88.27	83.87	14.27	13.56
May	218.4	23.25	209.7	206.2	91.93	87.16	14.03	13.30
June	229.8	26.06	212.2	208.6	91.63	86.95	13.82	13.12
July	236.8	28.65	222.8	219.1	94.65	89.83	13.60	12.91
August	221.2	28.85	224.8	221.4	94.92	90.23	13.52	12.85
September	182.4	26.74	205.0	202.6	87.80	83.65	13.71	13.06
October	146.1	24.05	191.1	189.3	83.62	79.56	14.00	13.32
November	105.4	18.88	162.2	161.0	73.05	69.48	14.42	13.71
December	91.8	15.11	156.7	155.4	72.97	69.58	14.91	14.22
Year	1991.4	21.38	2268.2	2239.3	1003.69	954.11	14.17	13.47

Legends:
- GlobHor: Horizontal global irradiation
- T Amb: Ambient Temperature
- GlobInc: Global incident in coll. plane
- GlobEff: Effective Global, corr. for IAM and shadings
- EArray: Effective energy at the output of the array
- E_Grid: Energy injected into grid
- EffArrR: Effic. Eout array / rough area
- EffSysR: Effic. Eout system / rough area

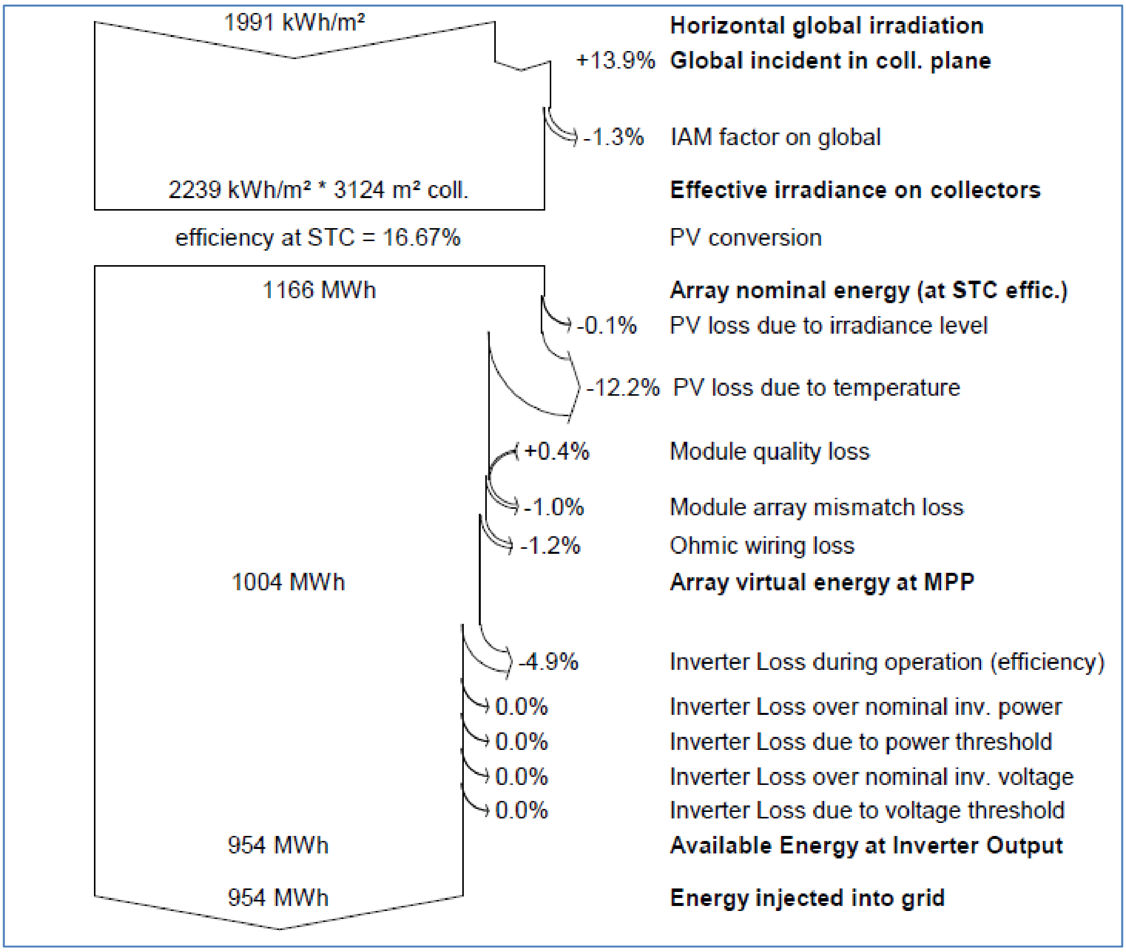

Figure (4.12): Building (C) PV system losses breakdown.

Chapter Five

Demand Side Management for An-Najah National University Hospital

5.1 Introduction

As mentioned in chapter three the peak demand reduction is one of the important issues in this study as it has many key points such as Reliability and network issues as this will reduce the Loss of Power Supply Probabilities (LPSP) due to overload cases in peak hours, Cost reduction as the DSM will reduce the peak demand penalties and Environmental improvement as energy efficiency and DSM may be pursued to achieve environmental goals by reducing energy use leading to reduced greenhouse gas emissions.

The installation of the grid-tied PV system in An-Najah Hospital buildings will affect the daily load curve for each building. This will be illustrated for each one individually in the following section (5.3, 5.4 and 5.5) this will be by simulating the designed system of each one, taking into account the whole system efficiency.

5.2 Proposed Demand Side Management for An-Najah Hospital

In An-Najah Hospital system we proposed to use load shifting technique to manage and reduce peak demands period using the grid-tied PV system and battery bank system that integrated by smart monitoring and control system. This proposed system will reform the daily load curve especially the reduction in peak demand values and periods .An-Najah Hospital system consists of a PV, a battery and grid power. The PV provides renewable energy and is the primary power source of the system while the battery is used for energy storage. Grid power is assumed to be always available, thus guaranteeing the stability of the electrical power supply .The energy flow in the system will mainly depend on the smart controller that decides where the flow have to be, based on many factors such as solar radiation, phase loads, batteries State of Charge SOC, and many other factors may be added in future as tariff policy that may use. Figure 5.2 will illustrate the proposed DSM system configuration.

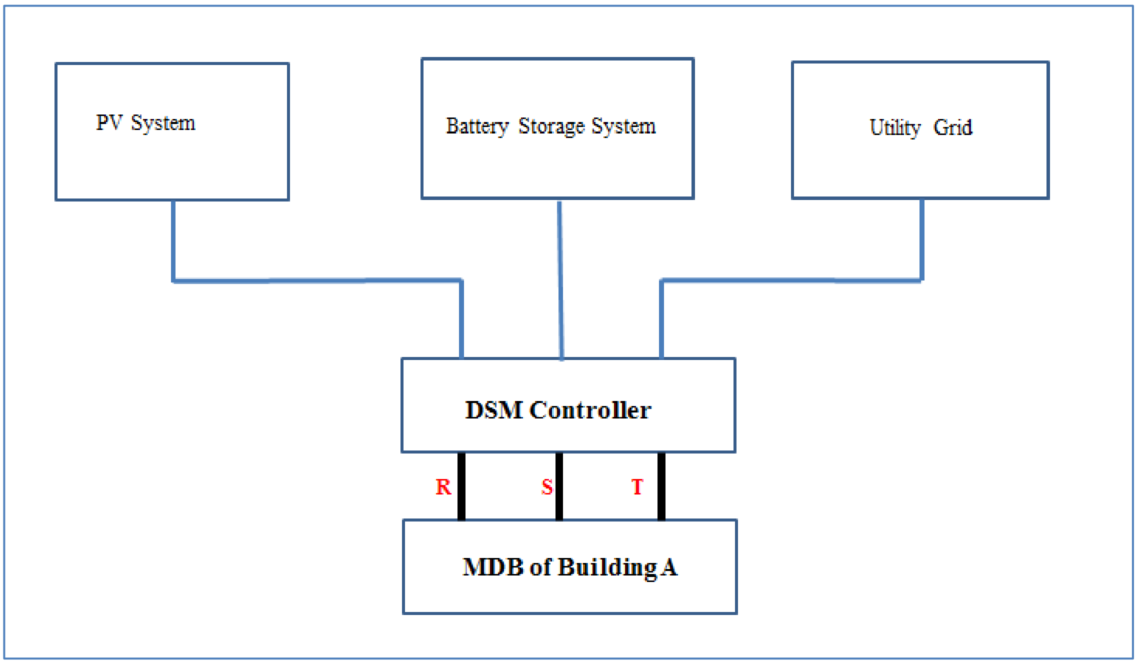

Figure (5.1): Proposed Demand Side Management System Configuration.

The load shifting can be achieved by using batteries storage integrated PV system with storage also the control system as mentioned and describe before. In thecase of DSM system failure, the PV system should operate as normal grid-tied PV system and the produced energy should be injected to the utility regardless of the building demand status this will be achieved by the control system.

The main and valuable expected result on the daily load curve after the installation of the PV system is the whole reformation and the decreases in peak demand value and peak result this will be illustrated for each building individually in this chapter.

5.3 Demand Side Management for Building (A)

In chapter three the proposed system for building (A) was about 550kWp this was to achieve 30% penetration value. To illustrate the effect of inserting PV on the system the expected produced energy will be computed using computer software then it will be compared with old the daily load curve and the new daily load curve will be shown.

The original daily load curve of building (A) is shown in figure 5.2 which will be compared with the output of building (A) PV system that shown 5.3 the subtraction between the two curves will result in the new daily load curve that illustrated in figure 5.4.

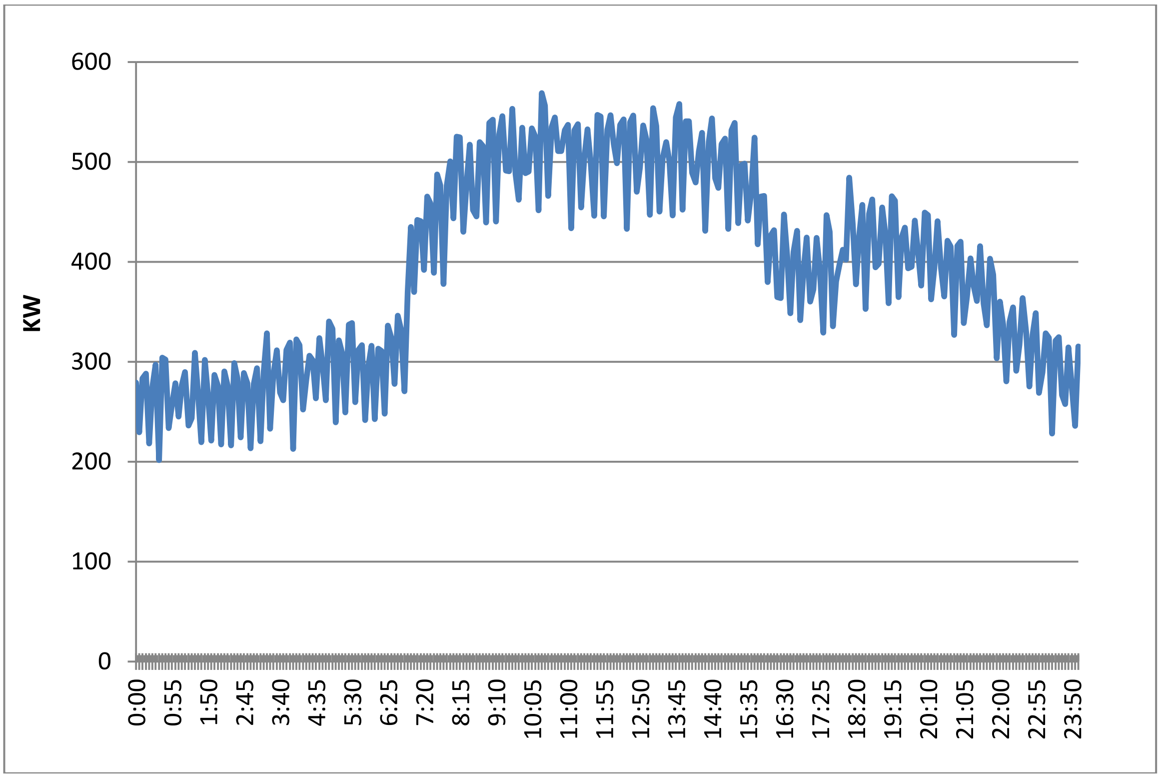

Figure (5.2): Daily Load Curve of Building (A).

From this curve the consumed energy was about 9048 kWh and the peak demand period was between 8:00AM -8:00 PM, while the maximum demand of building (A) was about 585kW at 10:25AM and minimum demand, was about 198kW at 00:40 AM.

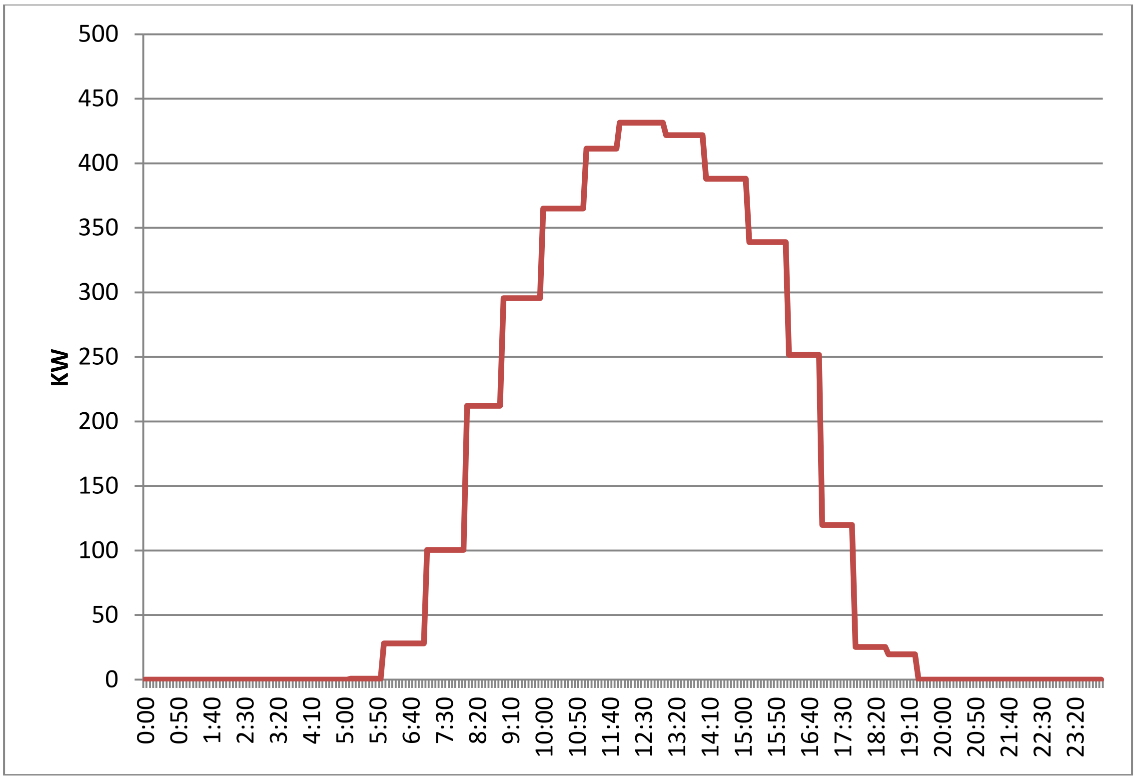

Figure (5.3): Building (A) PV System Output.

Figure 5.3 shows the output of building (A) PV system in a certain sunny day at which the panels started producing energy about 6:00AM until 6:30 PM, here this sunny day was on August with Sun Shine Hours about 8.6 and the produced energy of building (A) system was about 4066kWh.

The resulting new daily load curve for building (A) will be achieved by subtracting the produced energy of building (A) system from the consumed energy of building (A). And the resulting new daily load curve is shown in figure 5.4.

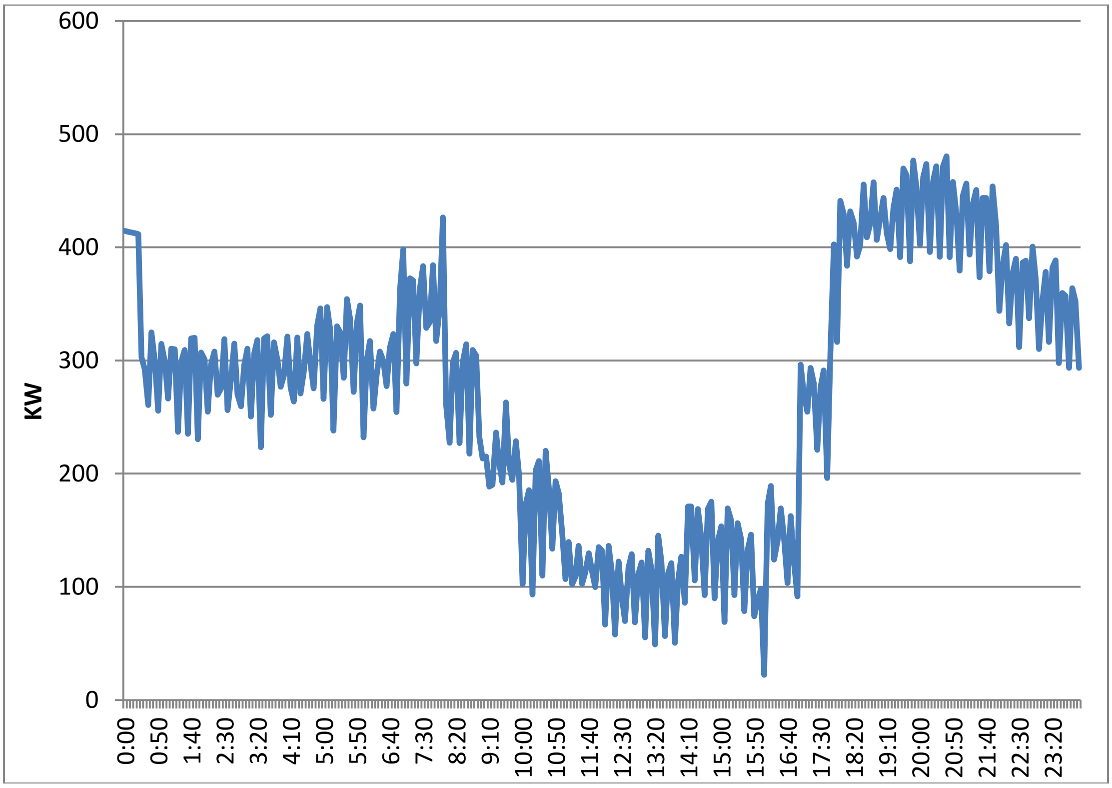

Figure (5.4): New Daily Load Curve of Building (A).

Figure 5.4 illustrate the new daily load curve after inserting the output of the grid tied PV system of building (A) this new curve has a big variation between the maximum and minimum demands which has a maximum demand about 480kW at 8:40PM and minimum demand about 22kW at 4:05PM this is not accepted as we still has a high maximum demand also a very low demand between 10:00AM and 4:00PM. The new daily load curve still needs some modifications which can be achieved using a smart interactive storage system which will be discussed in section Five.

5.4 Demand Side Management for Building (B)

In chapter three the proposed system for Building (B) was about 104kWp this which was installed for Building (B) to achieve 30% penetration value. To illustrate the effect of inserting PV on the system the expected produced energy will be computed using computer software then it will be compared with the old daily load curve and the new daily load curve will be shown.

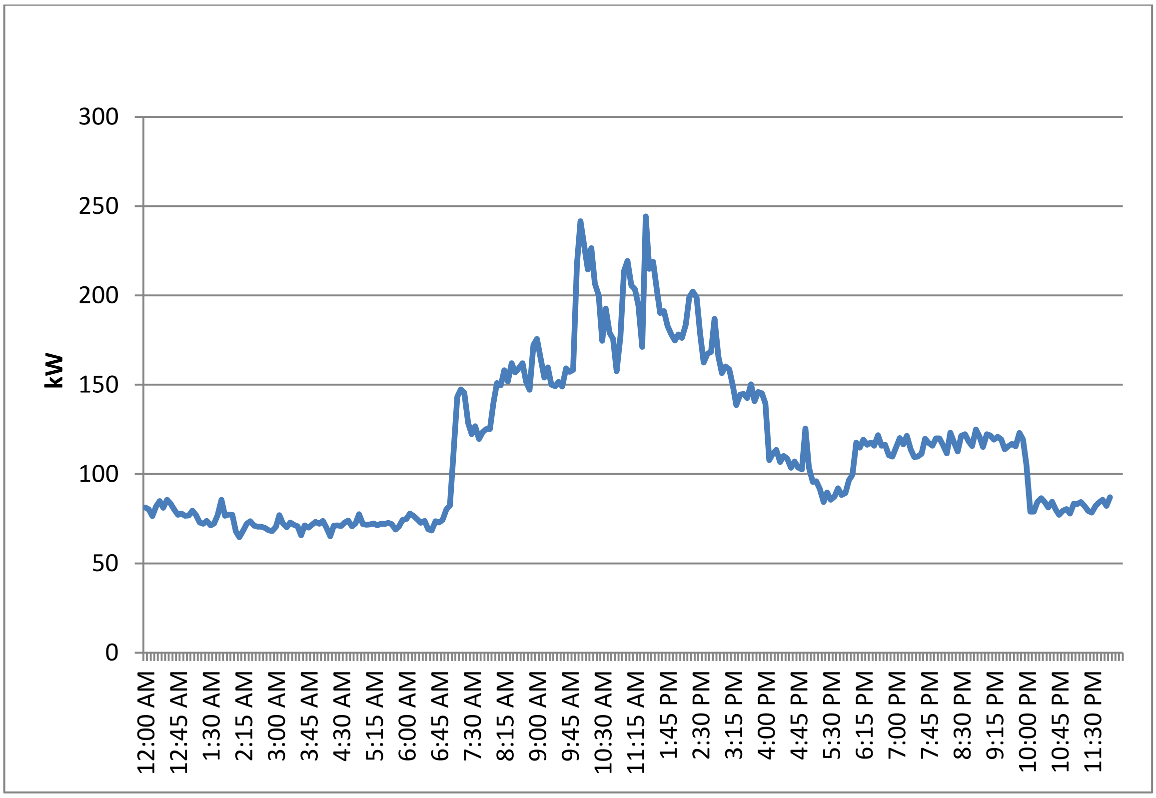

Figure (5.5): Daily Load Curve of Building (B).

Figure 5.5 shows the original daily load curve of Building (B) before the installation of the PV system this curve will has some changes after inserting the PV to the system. The installed PV system will has output power which is shown in figure 5.6 the resulting daily load curve of Building (B) will be in figure 5.7 which is the subtraction between the old daily load curve and the PV generator outputs.

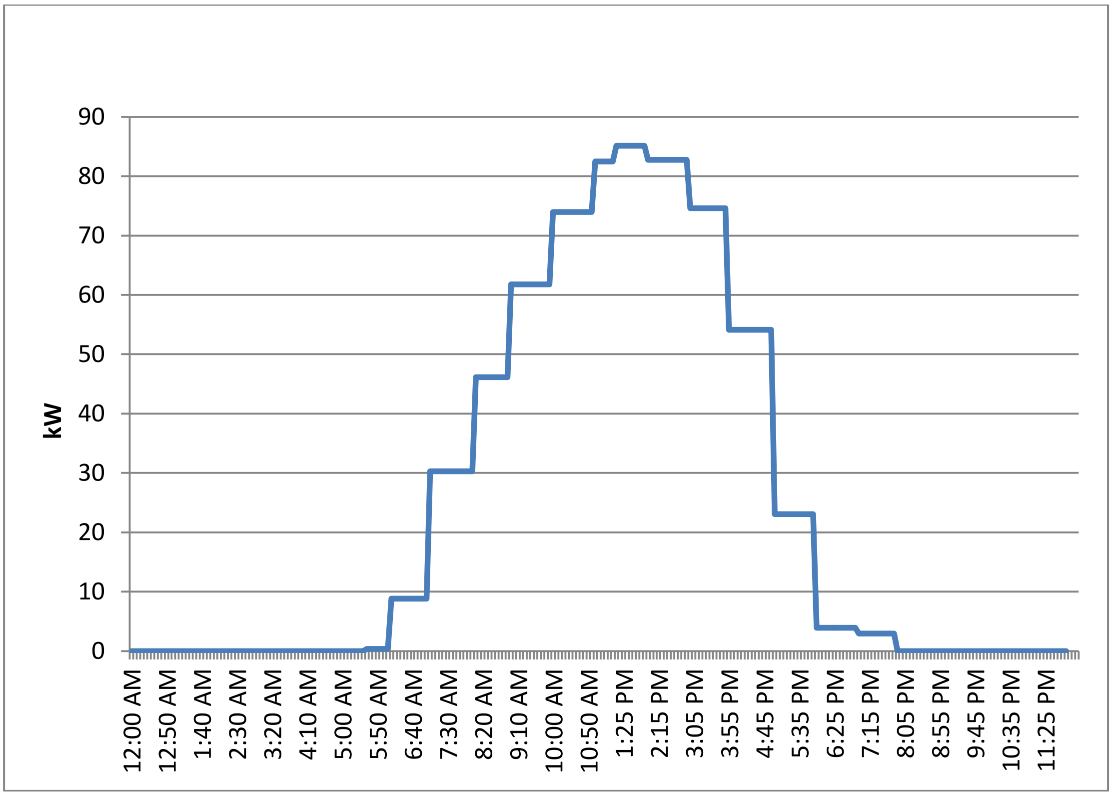

Figure (5.6): Building (B) PV System Output.

Figure 5.6 shows the output of building (A) PV system in a certain sunny day at which the panels started producing energy about 6:00AM until 6:30 PM, here this sunny day was on August with Sun Shine Hours about 8.6 and the produced energy of Building (B) system was about 780kWh.

As mentioned before to reach the expected daily load curve of Building (B) this will be achieved by subtracting the produced energy of Building (B) system from the consumed energy of Building (B). and the resulting new daily load curve is shown in figure 5.7.

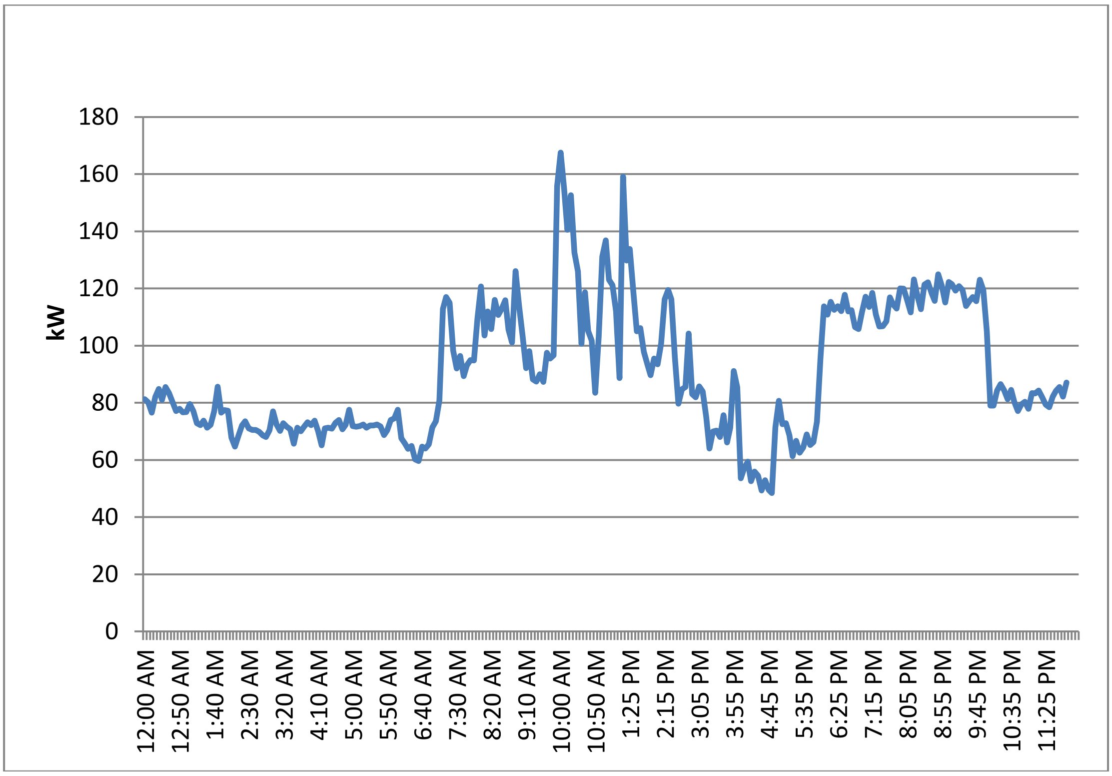

Figure (5.7): New Daily Load Curve of Building (B).

Figure 5.7 illustrate the new daily load curve after inserting the output of the grid tied PV system of Building (B) this new curve has a big variation between the maximum and minimum demands which has a maximum demand about 170kW at 10:00PM and minimum demand about 50kW at 4:35PM which is good but it can be better using a smart integrated DSM system including batteries. These modifications which can be achieved using a smart interactive storage system will be discussed in section six.

5.5 Demand Side Management for Building (C)

For Building (C) the proposed PV system capacity was about 474kWp which will achieve 30% penetration value. To illustrate the effect of adding PV system for Building (C) same procedure that used in building (A) and (B) will be used.

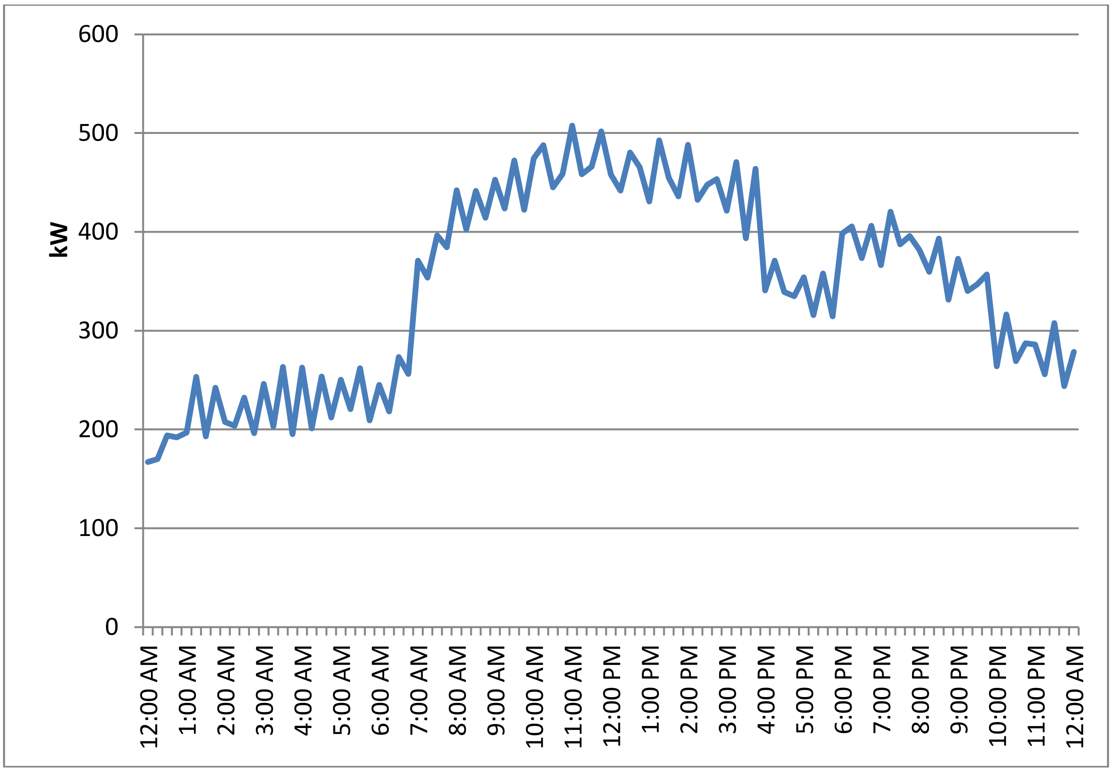

Figure (5.8): Daily Load Curve of Building (C).

Figure 5.8 shows the original daily load curve of Building (B) before the installation of the PV system this curve will has some changes after inserting the PV to the system. The installed PV system will has output power which is shown in figure 5.9 the resulting daily load curve ofBuilding (B) will be in figure 5.10 which is the subtraction between the old daily load curve and the PV generator output.

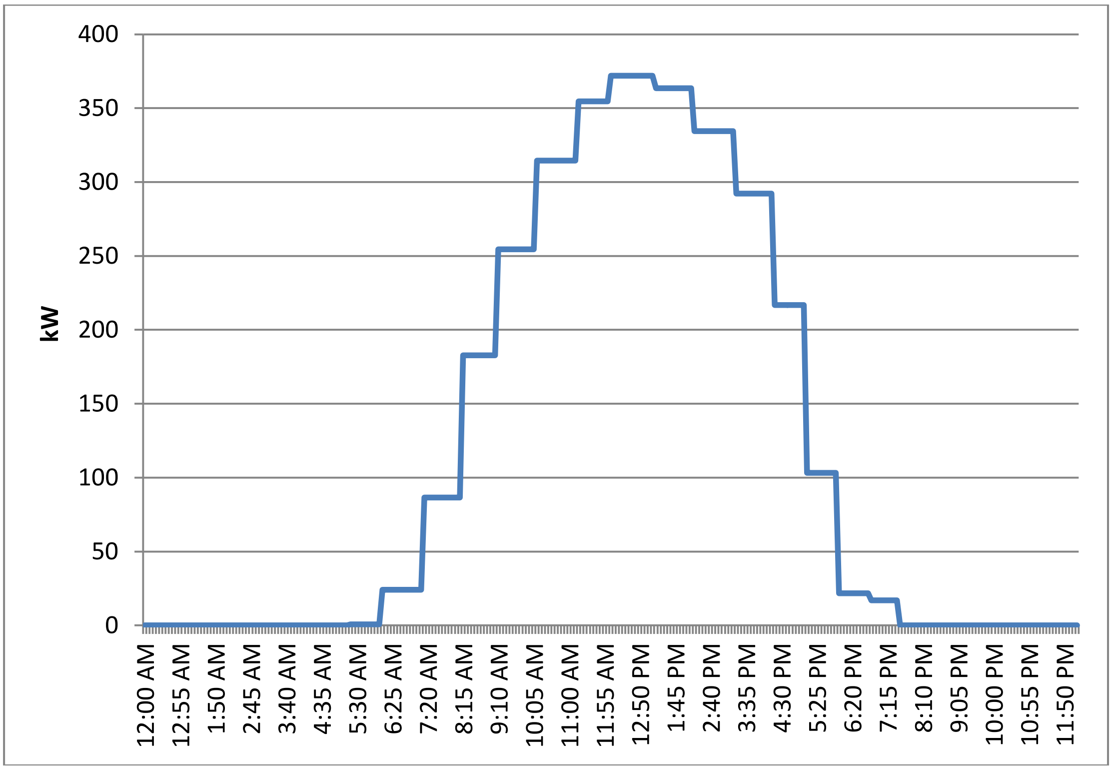

Figure (5.9): Building (C) PV System Output.

Figure 5.9 shows the output of Building (C) PV system in a certain sunny day at which the panels started producing energy about 6:00AM until 6:30 PM, here this sunny day was on August with Sun Shine Hours about 8.6 and the produced energy of Building (C) system was about 3460kWh.

As mentioned before to reach the expected daily load curve of Building (C) this will be achieved by subtracting the produced energy of Building (C) system from the consumed energy of Building (C). and the resulting new daily load curve is shown in figure 5.10.

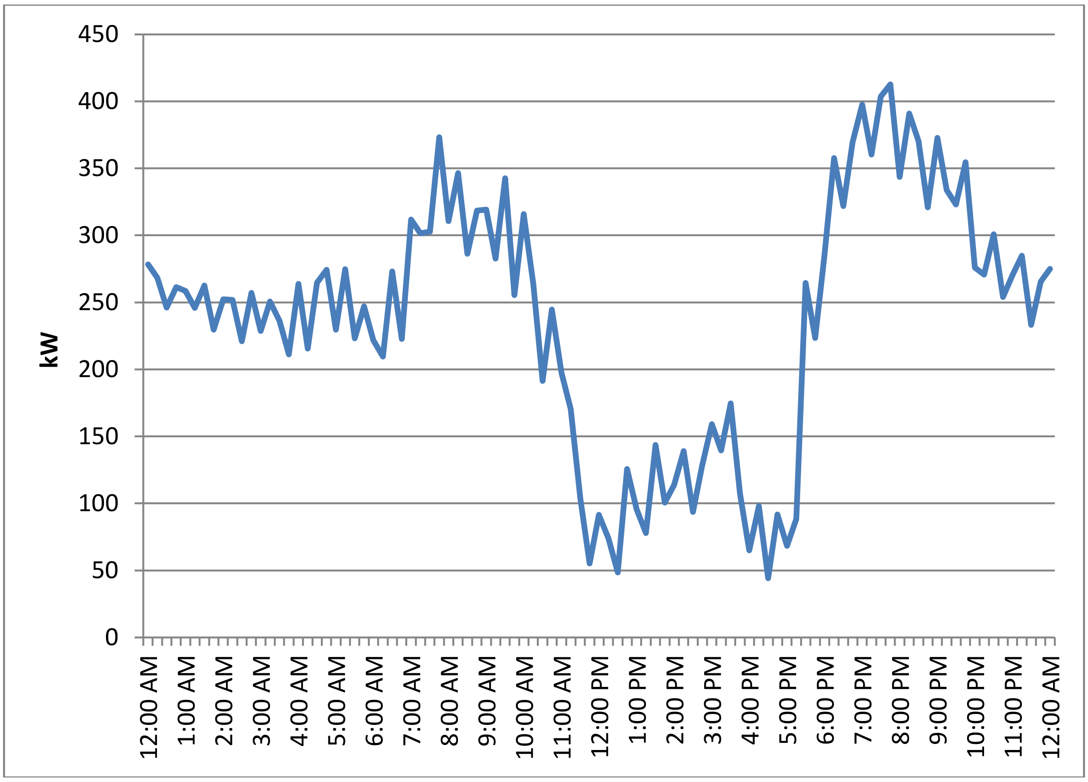

Figure (5.10): New Daily Load Curve of Building (C).

Figure 5.10 illustrate the new daily load curve after inserting the output of the grid tied PV system of Building (B) this new curve has a big variation between the maximum and minimum demands which has a maximum demand about 412kW at 7:30PM while it was about 507kW at 11:00PM and minimum demand about 44kW at 4:30PM while it was about 170kW at 12:15PM. The expected daily load curve is not perfect as the minimum demand was very low and the variation on the max demand not very large if a smart DSM system is used the system will has better and perfect daily load curve this will be discussed in section six.

5.6 Demand Side Management and Energy Management System (EMS)

5.6.1 Demand Side Management Using EMS for Building (A)

In sections(5.3, 5.4 and 5.5) the impacts of the PV system installation was great but the daily load curve still has a large deviation in minimum and maximum values to minimize this variation it is recommended to use battery system to storage excess energy produced from the system and to reuse it in cases of utility drop and other max demands periods.

Figure 5.11 illustrate the daily load curve before and after PV system installation for Building (A) before inserting the PV system the average demand was about 413kVA, 585kVA of maximum demand and 220kVA of minimum demand. After inserting PV without EMS average demand was 272kVA, maximum demand was 480kVA and minimum demand of 220kVA.

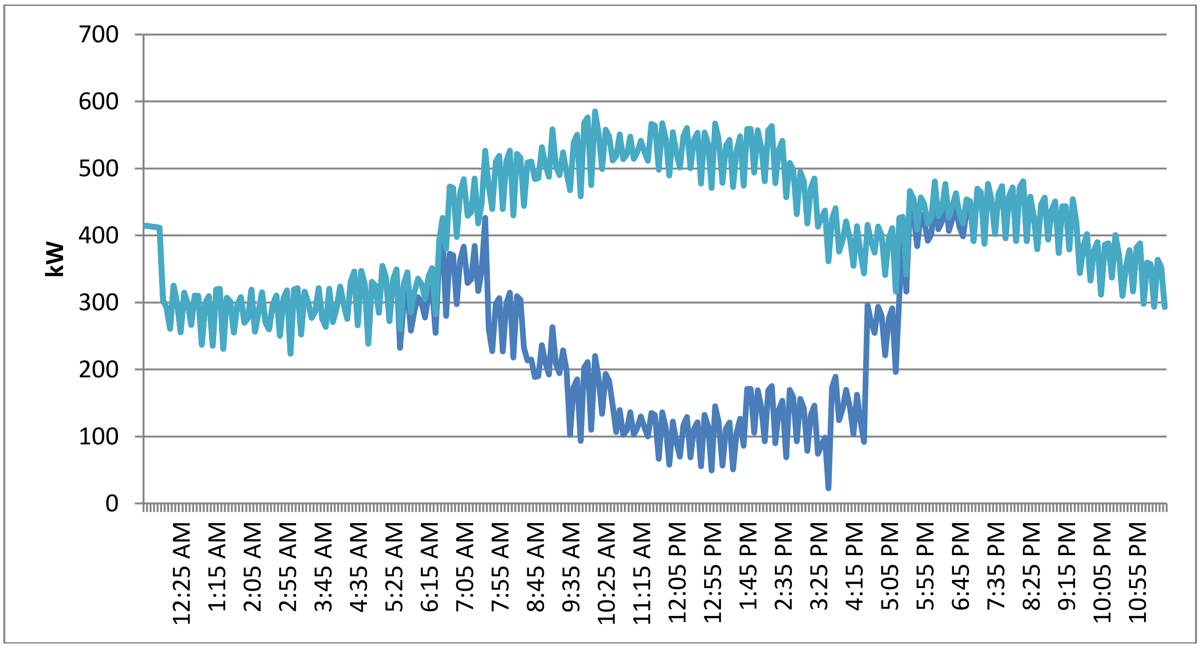

Figure (5.11): Daily Load Curve of Building (A) before and after PV Installation.

To modify this big deviation in minimum and maximum value a EMS is proposed to be used in DSM to have an acceptable average demand which is about 340kw to achieve this a EMShas to storage about 380kWh per day and to use this energy on other max demand periods especially at new peak demand periods. Figure 5.12 illustrate the proposed daily load curve of building (A) after the use of EMS, the curve has a maximum demand of 450kW and minimum demand.

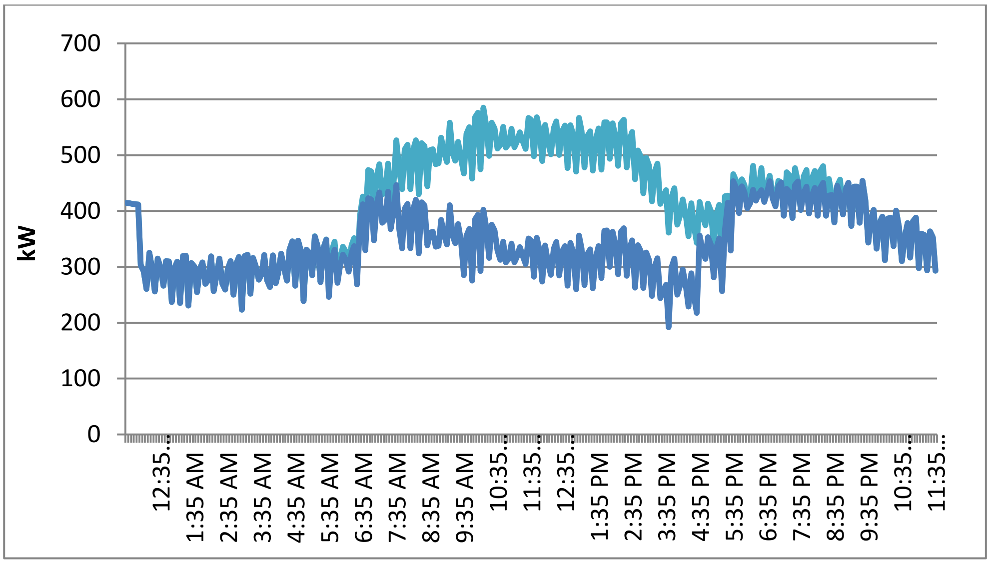

Figure (5.12): Proposed Daily Load Curve for Building (A) Using EMS.

Table (5.1) shows LF, maximum demand, and average demand of building (A) in the normal case, with PV only and with PV with EMS.

Table (5.1): Building (A) Technical Comparison.

Case	Average Demand	Maximum Demand	Load Factor
Normal Case	413kVA	585kVA	0.70
With PV Only	272kVA	480kVA	0.56
With PV &EMS	340kVA	450kVA	0.76

These results that shown in the table (5.1) illustrate the technical enhancements on maximum demand and LF due to the usage of PV system and EMS, thisenhancement will be reflected on the energy bill if max demand billing strategy was used by NDECO.

5.6.2 Demand Side Management Using Battery Storage System for Building (B)

Figure 5.13 illustrate the daily load curve before and after PV system installation before inserting the PV system the average demand was about 115kVA, 244kVA of maximum demand and 64kVA of minimum demand. After inserting PV without EMS average demand was about 90kVA, maximum demand was 170kVA and minimum demand of 54kVA

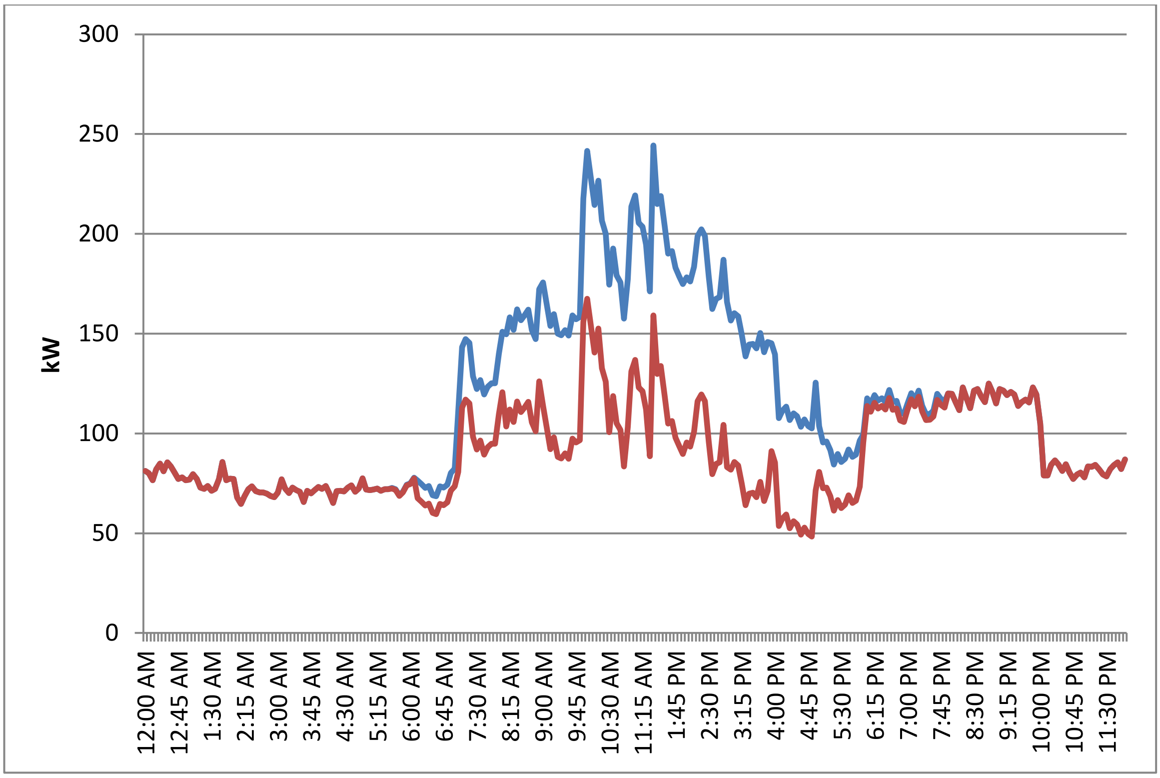

Figure (5.13): Daily Load Curve of Building (B) before and after PV Installation.

As building (A) case we have a large deviation in demand values so an EMS is recommended to be added the system to reduce this variation in demand and to use the excess energy in another period of the day especially high demand periods. To achieve this EMShas to storage about 68kWh per day and to use this energy on other max demand periods especially at new peak demand periods . Figure 5.14 illustrates the proposed daily load curve for building (B).

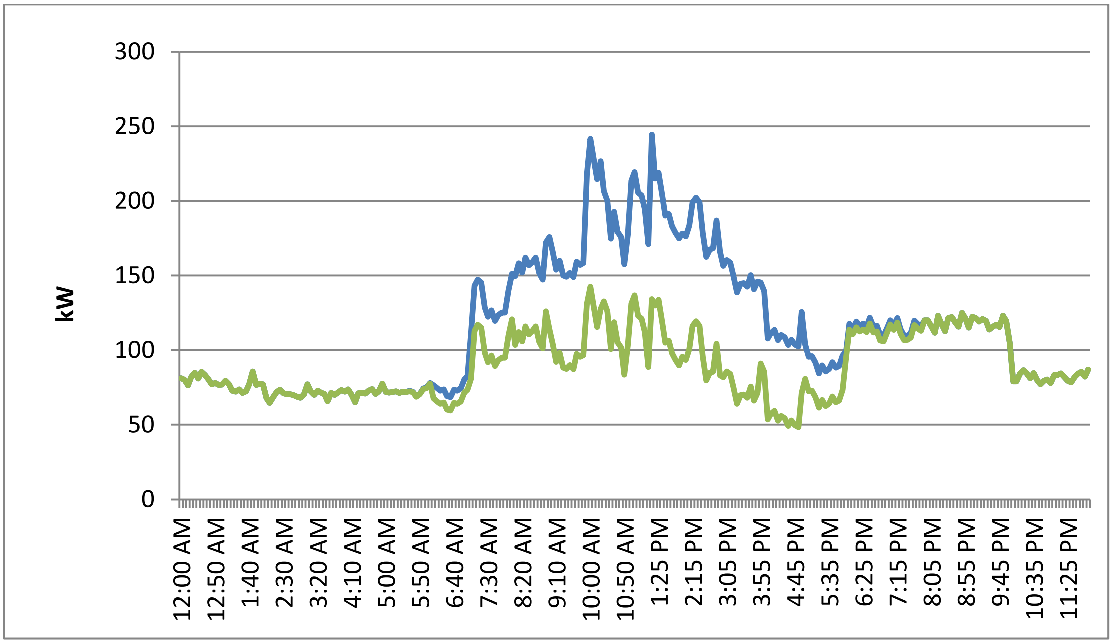

Figure (5.14): Proposed Daily Load Curve for Building (B) Using EMS.

After inserting EMS to building (B) system the average demand was about 89kVA and maximum demand was about 142kVA.

Table (5.2) shows LF, maximum demand, and average demand of building (B) in the normal case, with PV only and with PV with EMS.

Table (5.2): Building (B) Technical Comparison.

Case	Average Demand	Maximum Demand	Load Factor
Normal Case	115kVA	244kVA	0.47
With PV Only	90kVA	170kVA	0.53
With PV &EMS	89kVA	142kVA	0.62

These results that shown in table (5.2) illustrate the technical enhancements on maximum demand and LF due to the usage of PV system and EMS, this enhancement will be reflected on the energy bill if max demand billing strategy was used by NDECO.

5.6.3 Demand Side Management Using Battery Storage System for Building (C)

For building figure, 5.15 illustrate the daily load curve before and after PV system installation. Before inserting the PV system the average demand was about 350kVA, 494kW of maximum demand and 211kVA of minimum demand. After inserting PV without EMS average demand was 227kVA, maximum demand was 412kVA and minimum demand of 211kVA.

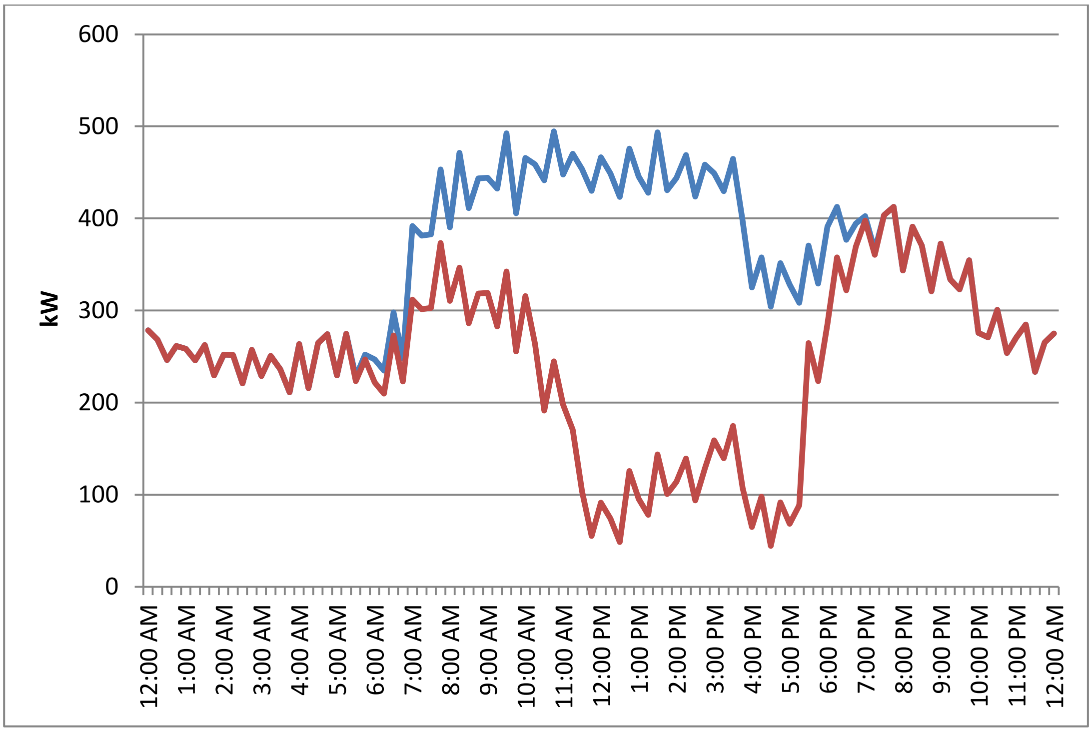

Figure (5.15): Daily Load Curve of Building (C) before and after PV Installation.

In figure 5.16after inserting EMS to building (C) system the average demand which was about 292 kVA, to achieve this average demand the

EMS should has storage value about 313kWh per day. And this energy will be used on maximum demand periods especially at night. The new daily load curve after inserting the EMS is shown in figure 5.16 with a maximum demand of 392kVA and minimum demand of 174kVA.

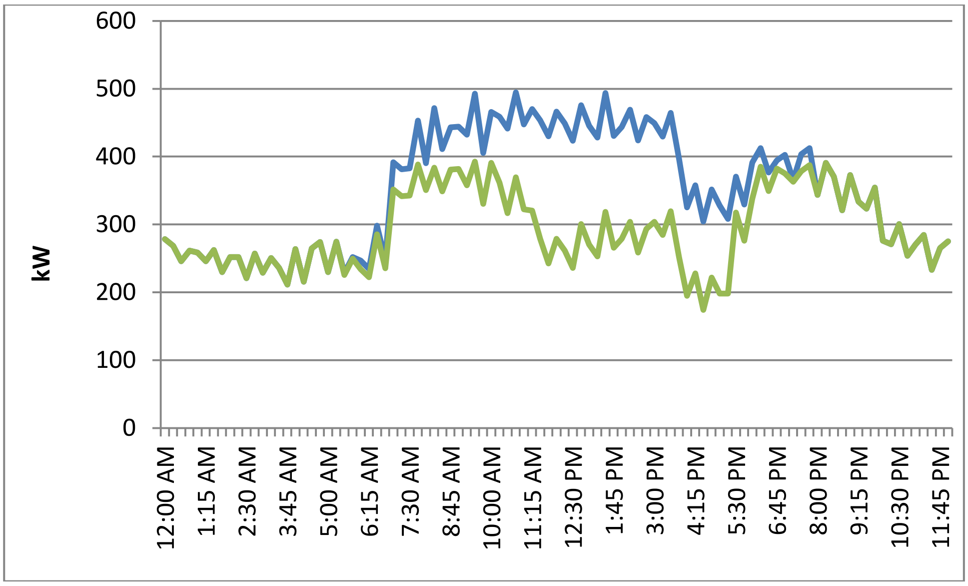

Figure (5.16): Proposed Daily Load Curve for Building (C) Using EMS.

Table (5.3) shows LF, maximum demand, and average demand of building (B) in the normal case, with PV only and with PV with EMS.

Table (5.3): Building (C) Technical Comparison.

Case	Average Demand	Maximum Demand	Load Factor
Normal Case	350kVA	494kVA	0.71
With PV Only	227kVA	412kVA	0.55
With PV &EMS	292kVA	392kVA	0.74

These results that shown in the table (5.3) illustrate the technical enhancements on maximum demand and LF due to the usage of PV system and EMS, this enhancement will be reflected on the energy bill if max demand billing strategy was used by NDECO.

5.7 Battery Storage System Design and Selection

In this section, an optimum design of EMS will be considered and the selection of batteries types, quantities and inverters also will be considered.

5.7.1 Battery Storage System Design and Selection for Building (A)

In section 5.3 the calculated excess energy of building (A) PV system was about 380kWh per day this energy will be considered in the selection of batteries types and quantities taking into account that the storage time is 3 hours.

The storage battery can be calculated using the following equation 5.1 [13]:

$$\text{Ah capacity} = \text{Ah} = \frac{\text{Daily excess energy}}{\text{DODxBattery efficiency x BB voltage}} \qquad (5.1)$$

Where daily excess energy for building (A) is 380kWh, DOD is the depth of discharge can be taken about 0.8 the efficiency of batteries to be 0.7 and the system voltage to be 48v.

$$\text{Ah} = \frac{380000\text{wh}}{0.8\text{x}0.75 \text{ x } 48} = 13200$$

Using the previous equation the needed Ah storage bank equal to 13200Ah and using a special type of lead acid block battery that has 2500 Ah capacity then the needed battery banks can be calculated using equation 5.2.

$$\text{No. of BB} = \frac{\text{Needed Storage Ah}}{\text{Battery block capacity Ah}} \qquad (5.2)$$

$$\text{No. of BB} = \frac{13200}{2500} = 5.3$$

Due high cost of batteries it worth to take 5 BB instead of 6 so the needed battery will equal to the number of BB multiplied by 24 as to 48v, we need 24 battery in each block. So the total needed battery equal to 120 battery of block battery type.

5.7.2 Battery Storage System Design and Selection for Building (B)

In section 5.4 the calculated excess energy of building (B) PV system was about 68kWh per day this energy will be considered in the selection of batteries types and quantities taking into account that the storage time is 3 hours.

The storage battery can be calculated using the following equation 5.1. Where daily excess energy for building (B) is 68 kWh, DOD is the depth of discharge can be taken about 0.8 the efficiency of batteries to be 0.75 and the system voltage to be 48v.

$$\text{Ah} = \frac{68000\text{wh}}{0.8\text{x}0.75\ \text{x}\ 48} = 2360$$

Using the previous equation the needed Ah storage bank equal to 2360Ah and using a special type of lead acid block battery that has 2500 Ah capacity then the needed battery banks can be calculated using equation

$$\text{No. of BB} = \frac{2360}{2500} = 0.9$$

For building (B) system only one is needed so the needed battery will equal to 24 as to 48v we need 24 battery in each block.

5.7.3 Battery Storage System Design and Selection for Building (C)

In section 5.5 the calculated excess energy of building (C) PV system was about 313kWh per day this energy will be considered in the selection of batteries types and quantities taking into account that the storage time is 3 hours.

The storage battery can be calculated using the following equation 5.1. Where daily excess energy for building (C) is 313 kWh, DOD is the depth of discharge can be taken about 0.8 the efficiency of batteries to be 0.75 and the system voltage to be 48v.

$$Ah = \frac{313000wh}{0.8x0.75 \ x\,48} = 10870$$

Using the previous equation the needed Ah storage bank equal to 2360Ah and using a special type of lead acid block battery that has 2500 Ah capacity then the needed battery banks can be calculated using equation 5.2.

$$\text{No. of BB} = \frac{10870}{2500} = 4.34$$

Due high cost of batteries it worth to take 4 BB instead of 5 so the needed battery will equal to the number of BB multiplied by 24 as to 48v, we need 24 battery in each block. So the total needed battery equal to 96 battery of block battery type.

Chapter Six

Economic Analysis of Installation on Grid PV Systems in An-Najah National Hospital

Economic Analysis of Installation on Grid PV Systems and DSM in An-Najah National Hospital

An economic analysis that will evaluate the feasibility of installation on-grid PV system and DSM in An-Najah national hospital will be based on life cycle costing (LCC) method, which taking into account all costs associated with the system over its lifetime, also, LCC is taking into account the time value of money, while the price of the PV system and its installation are important factors in the economics of PV systems. Which includes the prices of PV modules, inverters, DSM, maintenance, and all other auxiliaries.

For An-Najah National Hospital system, the life cycle cost will be estimated as follows:

1. The lifecycle of the components will be considered as 20 years for PV panels, 20 years for dual inverters and 10 years for the batteries.
2. The interest rate is to be considered 10%.

6.1 Life Cycle Cost [16]

Life Cycle Cost (LCC) is an economic technique the used in the analysis for all costsrelated to certain project including installation, operating, and maintaining a defined period of time. The (LCC) evaluation of grid-connected PV system depends on the following factors:

- The initial costs of grid-connected PV system.
- Maintenance and Operations costs.
- The salvage value of the system.

The initial costs of the grid connected PV system consisting of the following:

- PV panel costs.
- Inverters costs.
- DSM system costs.
- Batteries costs.
- Miscellaneous cost.

The initial cost of PV system = ∑ (PV System Components Costs).

The maintenance and operations costs are all costs during the project life cycle which are 20 years and it can be considered about 2% of the PV system initial cost.

The salvage value of the project can be defined as the estimated value that the project asset will realize at the end of the project lifecycle, salvage value is used in economic evaluation to determine depreciation amounts in the project and it can be considered as (15-20) % of project initial cost. [17]

Figure (6.1) illustrate the cash flow of initial cost, O&M costs, batteries replacement cost and the salvage value.

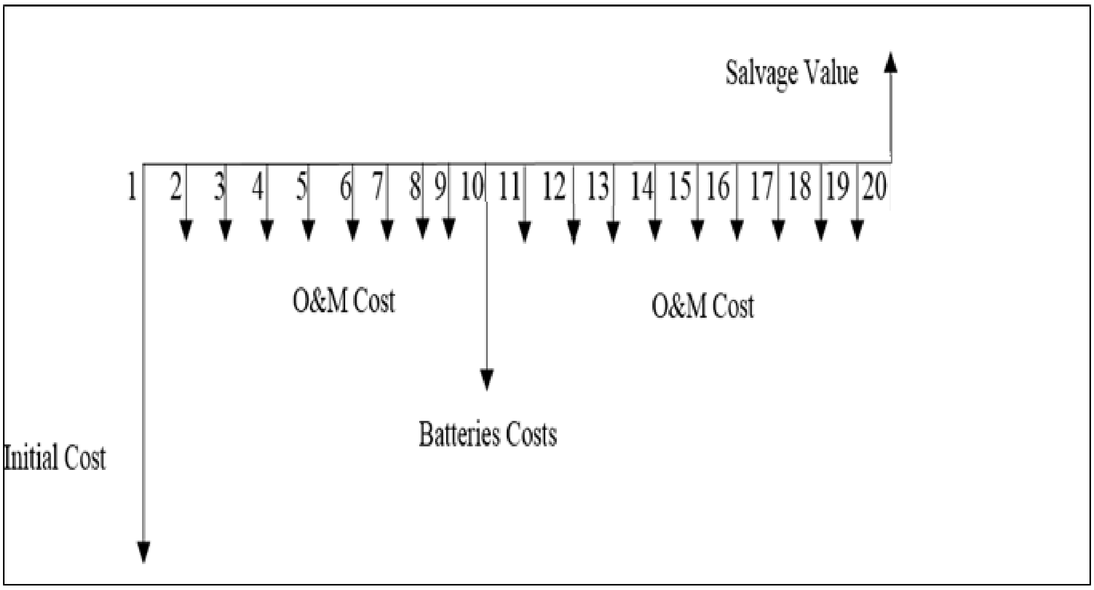

Figure (6.1): Cash Flow for on Grid PV System and DSM.

To find the LCC of on-grid PV system and DSM; the annuity of O&M cost, batteries replacement cost, and the salvage value has to be converted to present worth using equation (6.1) and (6.2).[16]

The present value of annuity (P/A) can be obtained by the following equation:

$$\boldsymbol{P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \quad ; i \neq 0} \tag{6.1}$$

Where i is the interest rate and n is the number of years.

The present value of future value (P/F) can be obtained by the following equation:

$$\boldsymbol{P = F\left[\frac{1}{(1+i)^n}\right]} \tag{6.2}$$

Where i is the interest rate and n is the number of years.

LCC = Initial Cost + Present Value of O&M + Present Value of Battery Replacement – Present Value of salvage Value (6.3)

Table (6.1) illustrates quantities and costs of each component of the building (B) of An-Najah national hospital PV system.

Table (6.1): Bill of Quantity and Costs of Building (B) System.

Item	Quantity	Unit Price	Total Cost
PV Panels	104kWp	1000$/kWp	104000$
Dual Inverter	5	5000$	25000$
Batteries	24	1200$	28800$
Civil Work	1	23000$	23000$
Other Cost	1	6000$	6000$

The initial cost can be calculated from the BOQ and prices that shown in table (6.1)

Initial Cost = PV panels cost + Inverter cost + Batteries cost + Civil Work+ other costs (6.4)

Initial Cost = 104000 + 25000 + 28800 + 23000+5000 = 186800$

The O&M costs can be determined as 2% of the initial cost which equals to 3736$ and the salvage value of the system which is equal to 15% of the initial cost can be obtained and equals to 28020$ and its present value of it P/F will equal to 4191$.

To realize the cash flow the annual worth of O&M cost has to be determined; which can be determined using equation (6.5).

$$\boldsymbol{A = P[\frac{i}{(1+i)^n - 1}]} \quad \textbf{(6.5)}$$

From equation (6.3) and (6.4) the AW of O&M equals to 438$/year and batteries replacement costs equal to 74700$.

Figure (6.2) illustrate the realized cash flow for building (B) PV system and DSM.

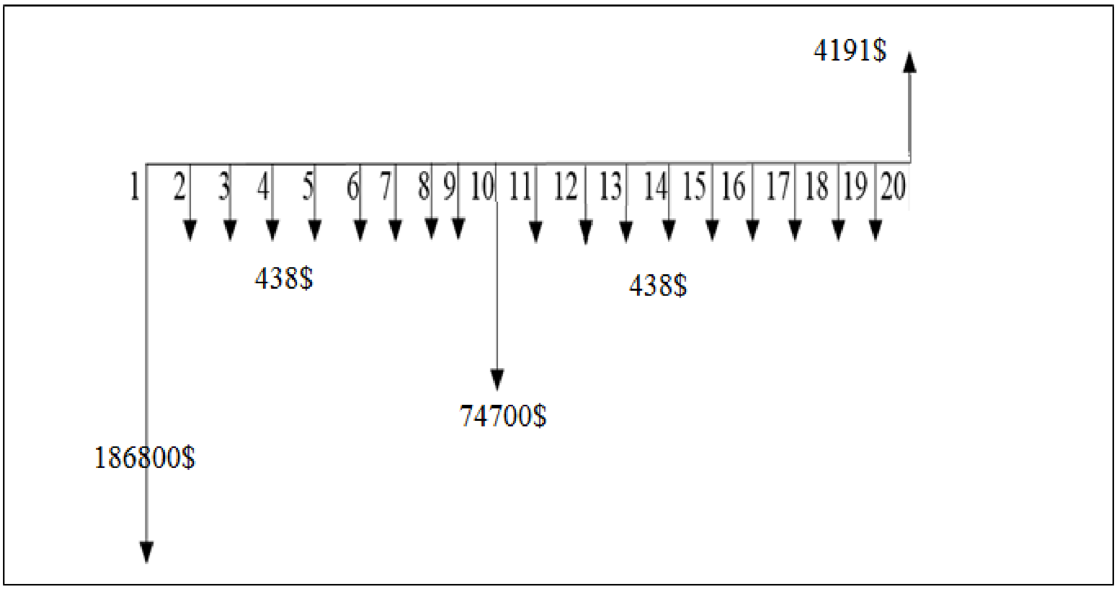

Figure (6.2): Real Cash Flow of Building (B) PV System

From cash flow which that shown in figure (6.2), the LCC of the project can be calculated using equation (6.3)

LCC = 186800$ + 3736$ + 74700$ - 4191$

LCC = 261045$

6.2 LevelizedCost of Energy [18-20]

The Levelized cost of energy (LCOE) can be defined as the total LCC of a certain energy generation project expressed in dollars per kilowatt-hour of electricity generated by the system over its life the LCOE technique allows alternative technologies to be compared when different scales of operation, different investment and operating time periods. The LCOE could be used to compare the cost of energy generated by a renewable resource with that of a standard fossil fueled generating unit. Equation (6.6) can be used to calculate the LCOE.

$$LCOE = \frac{\text{Annual Production Cost}}{\text{Annual Produced Energy}} \quad \textbf{(6.6)}$$

Solar PV module prices were around 75% lower than their levels at the end of 2009. This affects the utility-scale PV systems installation costs to be fallen by 29% to 65%, depending on the region. The LCOE of utility-scale PV has fallen by half in four years. The most competitive utility-scale PV projects are now regularly delivering electricity for just USD 0.08 per kilowatt-hour (kWh) without financial support, compared to a range of USD 0.045 to USD 0.14/kWh for fossil fuel power plants. Even lower costs for utility-scale PV, down to USD 0.06/kWh, are possible where excellent resources and low-cost finance are available. [20]

The LCC of An-Najah National Hospital PV system was equal to 261045$ and the yearly produced energy was estimated using computer software about 187348kWh to find LCOE the AW of LCC has to be estimated using (A/P, i ,n) factor where i=10% and n=20. The annual cost will equal to 36600$/year, then the LCOE can be calculated using equation (6.6).

$$\mathbf{LCOE = \frac{36600\$}{187348kWh} = 0.19\$/kWh}$$

If the lifetime were supposed to be 25 year, then the LCOE can be calculated using equation (6.6) taking into account the new annual worth of energy production cost, the AW for 25 years can be calculated using (A/P, i, n) where n = 25, then the annual cost will equal to 28750$/year.

$$\textbf{LCOE} = \frac{28750\$}{187348kWh} = \textbf{0.15\$/kWh}$$

These results illustrate that the lifetime of the project had played a big role in LCOE but in both cases the value of LCOE was a little bit higher than average, this was due to the DSM part and batteries. If the DSM and batteries were discarded a new calculation of LCOE can be handled in the same procedure.

LCC (without DSM and Batteries) = 158000 + 3736 – 4191 = 157545$

The annual worth also can be calculated in the same procedure using (A/P, i, n) factor where I = 10% and n = 20 years. AW will equal to 18440$/year

$$\textbf{LCOE} = \frac{18440\$}{187348kWh} = \textbf{0.099\$/kWh}$$

In this case, the LCOE value was about 0.1$/kWh this means that the value is in the range of the international average LCOE of utility-scale PV this is due to the extra fallen of modules, inverters, frames and PV systems accessories in last few years also the land leasing may affect the LCOE value.

6.3 Rate of Return[17]

The Rate of Return (ROR) is an economic technique that used in project feasibility evaluation and it is a well-accepted way of determining if the project or investment is economically acceptable. ROR can be defined as the gain or loss on an investment over a specified period, ROR expressed as a percentage increase over the initial investment cost also, the ROR can be defined as or the rate of interest earned on the unrecovered balance of the investment.

The ROR value can be determined in a different way compared to the PW or AW value for a series of cash flows, here it will be estimated using the PW technique depending on the lifetime cash flow that shown in figure (6.3) which illustrate project initial cost, O&M costs, batteries replacement cost, salvage value and annually produced energy saving (revenues). In revenues calculation, the energy cost will be considered as 0.2$/kWh.

Annual Revenues = Annual Produced Energy (kWh) x Energy Cost (6.7)

Using equation (6.7) the annual revenue of produced energy will be as follow:

Annual Revenues = 187348 x 0.2 = 37470$

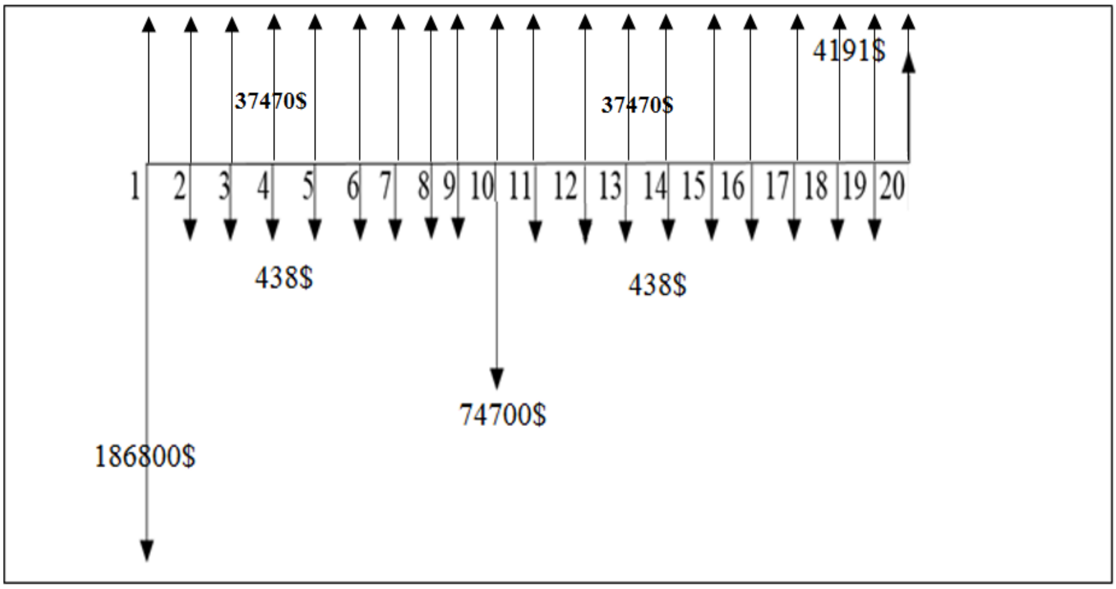

Figure (6.3): Lifetime Cash Flow of Building (B).

From cash flow that shown in figure (6.3), the initial cost, batteries replacement cost, and O&M cost will be considered as outcomes. While the annual revenues and the salvage value will be considered as incomes.

PW (Outcomes) = Initial Cost + (P/A, i, 20) of O&M + (P/F, i, 12) of Batteries Replacement.

PW (Outcomes) = 186800$ + 438$*(P/A, i, 20) + 72000$*(P/F, i, 12)

PW (Incomes) = (P/A, i, 20) of Energy Revenues + (P/F, i, 20) of Salvage value.

PW (Incomes) = 37470*(P/A, i, 20) + 4191*(P/F, i, 20).

To find the ROR the PW of incomes will equal to PW of outcomes and trial and error has to be used. Using Microsoft excel and the IRR function the ROR was found and it was equal to 23% this mean that this project will return 23% of its initial cost every year which makes the project feasible

6.4 Simple Payback Period [17]

Simple Payback Period (SPBP) is another technique can be used to analysis the project feasibility and it can be defined as the length of time required to recover the capital cost or the (LCC) of an investment. If the SPBP was lower than the project lifetime this mean the project is feasible otherwise is not. The SPBP can be estimated using equation (6.8).

$$\mathbf{SPBP} = \frac{\textit{Capital Cost of the Project}}{\text{Annual Saving or Revenues}} \qquad \mathbf{(6.8)}$$

Using equation (6.8) it can be easy to find the SPBP of the project as follow:

$$SPBP = \frac{261045\$}{37470\$/year} = 6.9 \text{ years}$$

In this evaluation all costs were taken in into account, such as O&M and batteries replacements This SPBP which equals to 7 years means that all project cost will be recovered by the first 7 years of the lifetime and the other 13 years it will profit which mean the project is not only feasible it is extremely feasible

6.5 Economic Analysis of DSM for TOU Tariff Structure Case

After the foundation the Palestinian Electricity Transmission Ltd. (PETL) which works to organize the electricity transmission and connections point in Palestine the tariff structure maybe affected and changed to TOU tariff as PETL buy electricity from IEC in TOU tariff structure so they might sell electricity for the distribution companies such as NEDCO, HEPCO and SELCO in TOU tariff structure while JEDCO is using the TOU tariff structure which will be considered as a reference in the economic analysis. [4]

An important key point of installing DSM and PV system is to take advantage of the TOU tariff structure as the system will work in strategy that minimizes energy injection on thegrid at low tariff periods while maximizing grid energy injection at high tariff periods. Also, it will be great to shift loads (if it possible) to low tariff period also reduce loads (if it possible) from high tariff periods.

6.6 JEDCO TOU Tariff Structure

Time of Use Tariff (Sliding Scale) The Time of Use tariff was specified to cover all the days of the year based on the seasons, table (6.2) illustrate the TOU of JEDCO. [22]

Table (6.2): JEDCO TOU Tariff Structure.

TOU Interval \ Season	Winter	Summer	Autumn & Spring
Interval A (USD/kWh)	0.05	0.05	0.05
Interval B (USD/kWh)	0.15	0.17	0.13
Interval C (USD/kWh)	0.25	0.26	0.2

- Winter Season Tariff(01/12-31/03)

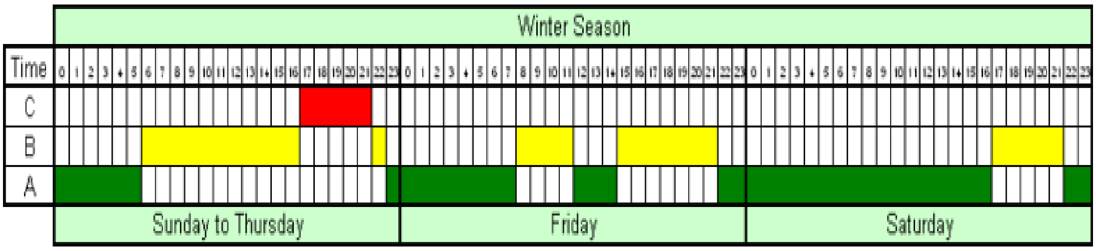

Figure (6.4): Winter Season Tariff

- Spring Season Tariff (01/04-30/06)

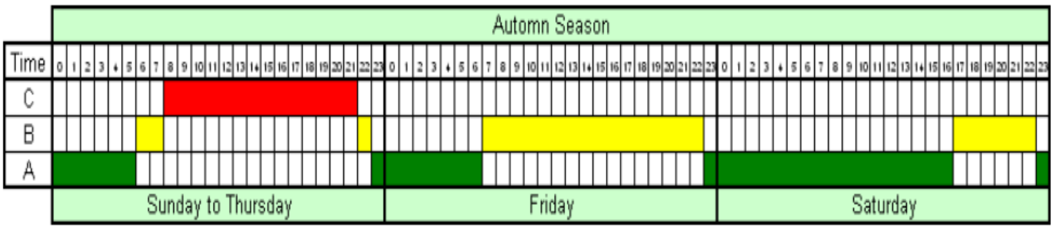

Figure (6.5): Spring Season Tariff

- Summer Season Tariff (01/07-30/09)

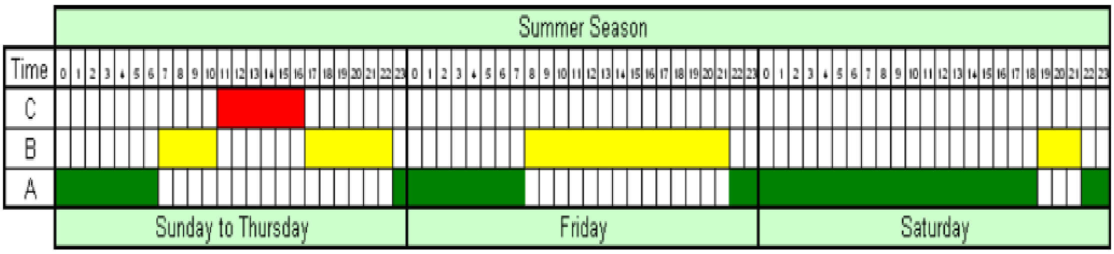

Figure (6.6): Summer Season Tariff

- Autumn Season Tariff (01/10-30/11)

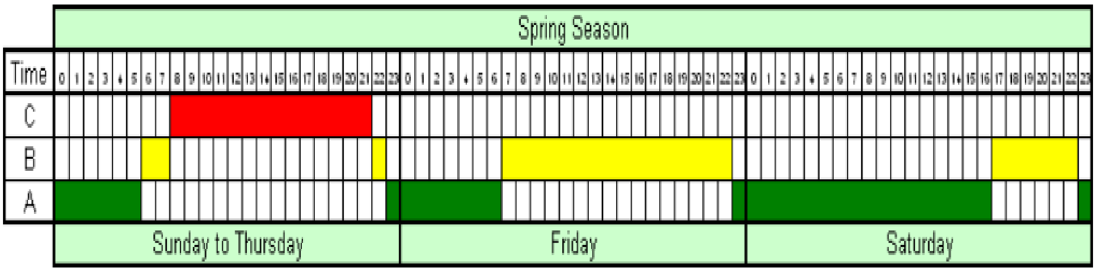

Figure (6.7): Autumn Season Tariff

Rate of Return (ROR) for DSM in TOU Case

In this economic analysis of the usage DSM in TOU tariff structure as shown in the table (6.2) the average tariff at high tariff period was 0.23USD/kWh this value will be considered in the evaluation of ROR analysis.

Using equation (6.7)

Annual Revenues = Annual Produced Energy (kWh) x Energy Cost = 187348x0.23=43090$ this new value will be used instead the old value which was about 37470$. This will be reflected in the net cash flow which illustrated on figure (6.8).

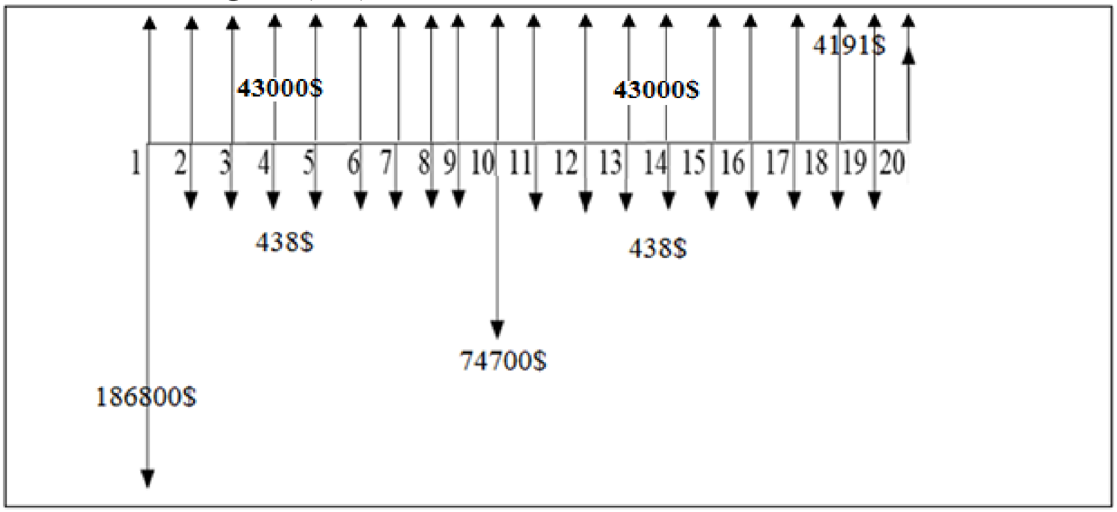

Figure (6.8): New Lifetime Cash Flow of Building (B) for TOU case.

From cash flow that shown in figure (6.8), the initial cost, batteries replacement cost, and O&M cost will be considered as outcomes. While the annual revenues and the salvage value will be considered as incomes.

PW (Outcomes) = Initial Cost + (P/A, i, 20) of O&M + (P/F, i, 12) of Batteries Replacement.

PW (Outcomes) = 186800$ + 438$*(P/A, i, 20) + 72000$*(P/F, i, 12)

PW (Incomes) = (P/A, i, 20) of Energy Revenues + (P/F, i, 20) of Salvage value.

PW (Incomes) = 43000*(P/A, i, 20) + 4191*(P/F, i, 20).

To find the ROR the PW of incomes will equal to PW of outcomes and trial and error has to be used. Using Microsoft excel and the IRR function the ROR was found and it was equal to 27% this mean that this project will return 27% of its initial cost every year which makes the project feasible

Simple Payback Period for DSM in TOU Case

The same procedure that used in section 6.4 the SPBP estimated using equation (6.8) it can be easy to find the SPBP of the project as follow:

$$SPBP = \frac{261045\$}{43000\$/year} = 6 \text{ years}$$

This SPBP which equals to 6 years means that all project cost will be recovered by the first 6 years of the lifetime and the other 14 years it will profit which means is extremely feasible.

6.7Environmental Impacts of Using PV System

In general, the most power plant in the world operates on fossil fuel such as coal, natural gas, oil, and other fossil fuel. And the burning of this fossil fuel will produce many kinds of pollutants as CO_2 ,$SO_{X,}$ $NO_{X,}$ and many other pollutants Coal is the most popular fuel that used in the generation of electricity. There are two main reasons that make coal on the top of fossil fuel especially in industry and electricity generations. The first reason that coal availability (around 120 years of proven reserves of current consumption).The second one is the cost; coal is the cheapest fossil fuel. [23]

Studies proved that 500 MWh coal-fired power plants have the following amounts of pollutants per year: [24]

- About 700 tons of carbon monoxide.
- About 4 million tons of carbon dioxide.
- About 10,200 tons of nitrogen oxide.
- About 10,000 tons of sulfur dioxide.
- About 500 tons of small particles.
- About 200 tons of hydrocarbons.
- Other traces of uranium and other elements.

Typically coal-fired power plants produce about 949g of CO_2 per kWh, about 2070g of SO_Xper MWh and about 2300 g of NO_X per MWh these values will be considered in the estimation of emission reduction. [25]

In the estimation of the emissions reductions that may achieve by the installation of grid-tied PV depends on the supply power plant fuel type, in this study the evaluation will consider coal-fired power plants and compared with PV systems. The following equations will be used in the estimation of pollutant reduction due to the usage of PV system for An-Najah Hospital:

CO_2Mass = Energy produced from PV × CO_2 Mass produced by coal-fired power plant……..……....... (6.9)

NOx Mass = Energy produced from PV × NOx Mass produced by coal-fired power plant……......……..... (6.10)

SO_x Mass = Energy produced from PV × SO_x Mass produced by coal-fired power plant…………..…... (6.11)

CO_2 Mass = 187340kWh × 0.959kg =179.6 ton of CO_2

NOx Mass = 187340kWh × 2.06g =386kg of NOx

SOx Mass = 187340kWh × 2.30g =430kg of SOx

Each kg of SOx, NOx, are equivalent to 22,800kg and 298kg of CO_2 respectively [26]. So the total reductions in CO_2 from SOx and NOx equal to 9804 ton and 115 ton of CO_2.

These results shows a great environmental benefits in emission reductions and increase the opportunity to use PV instead of traditional power plant especially for areas that have a good solar potential. Also this reduction in CO_2can be defined as saving in money taking the social cost of carbon which is about 50$ per metric ton of CO2 this saving will be about 500 thousands $ per year. [27]

Chapter Seven

Conclusion and Recommendation

7.1 Conclusion

Based on this study the following conclusions can be made:

- Palestine has an excellent solar energy potential that can be used in electricity production.
- The usage on-grid PV can reduce the lack of supply on the electrical network in Palestine.
- Energy management hasvaluable impacts on electrical grid enhancement especially in peak demand reduction and LF improvements which reflect the quality of supply.
- The economic analysis of using PV systems and energy management systems shows that it is feasible to use PV in electricity production and has a good LCOE which was between (0.15-0.19)$ and this cost was less than IEC price.
- The usage of time-based tariff structure will motivate theconsumer to use energy management systems.
- The simple payback period of An-Najah Hospital project was about 6-7 years which means it is a good investment.
- Reduction of the emission of CO_2 was about 180 ton per annum.

7.2 Recommendation

Based on this study and analysis the following recommendations can be made:

- It is recommended to increase the usage on PV in electricity production especially using the on-grid systems.

- Modify the used tariff structure and to apply the TOU tariff structure for large consumers such as hospitals, factory, and university.
- Encourage consumer to use energy management systems.

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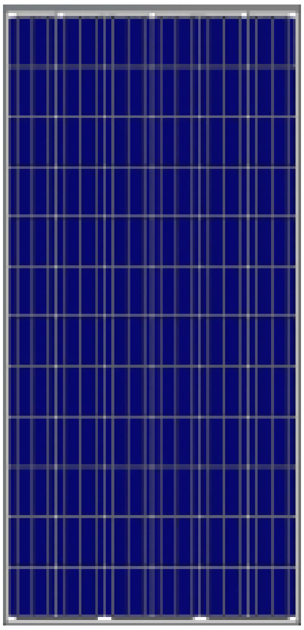
Appendix (1)

New Energy

New World

Worldwide Energy and Manufacturing USA Co., Limited

AS-6P



Amerisolar's photovoltaic modules are designed for large electrical power requirements. With a 30-year warranty, AS-6P offers high-powered, reliable performance for both on-grid and off-grid solar projects.

Key Features

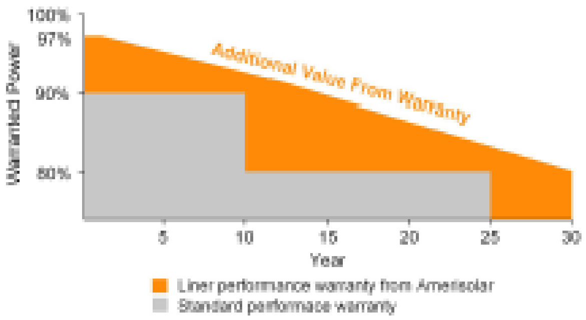
- High module conversion efficiency up to 17.01% through superior manufacturing technology.
- Low degradation and excellent performance under high temperature and low light conditions.
- Robust aluminum frame ensures the modules to withstand wind loads up to 2400Pa and snow loads up to 5400Pa.
- Positive power tolerance of 0 ~ +3 %.
- High ammonia and salt mist resistance.

Quality Certificates

- IEC61215, IEC61730, IEC62716, IEC61701, UL1703, JET, CE, MCS, CEC, Israel Electric, Kemco
- ISO9001:2008: Quality management system
- ISO14001:2004: Environmental management system
- OHSAS18001:2007: Occupational health and safety management system

Special Warranties

- 12 year limited product warranty.
- Limited power warranty: 12 years 91.2% of the nominal power output, 30 years 80.6% of the nominal power output.



Passionately committed to delivering innovative energy solution

www.weamerisolar.com

Electrical Characteristics

Electrical parameters at STC								
Nominal Power (P_{max})	295W	300W	305W	310W	315W	320W	325W	330W
Open Circuit Voltage (V_{OC})	45.2V	45.3V	45.4V	45.5V	45.6V	45.7V	45.8V	45.9V
Short Circuit Current (I_{SC})	8.60A	8.68A	8.76A	8.85A	8.93A	9.00A	9.08A	9.16A
Voltage at Nominal Power (V_{mp})	36.6V	36.7V	36.8V	36.9V	37.0V	37.1V	37.2V	37.3V
Current at Nominal Power (I_{mp})	8.07A	8.18A	8.29A	8.41A	8.52A	8.63A	8.74A	8.85A
Module Efficiency (%)	15.20	15.46	15.72	15.98	16.23	16.49	16.75	17.01

STC: Irradiance 1000W/m², Cell temperature 25°C, AM1.5

Electrical parameters at NOCT								
Nominal Power (P_{max})	215W	219W	223W	226W	230W	234W	237W	241W
Open Circuit Voltage (V_{OC})	41.6V	41.7V	41.8V	41.9V	42.0V	42.0V	42.1V	42.2V
Short Circuit Current (I_{SC})	6.97A	7.03A	7.10A	7.17A	7.23A	7.29A	7.35A	7.42A
Voltage at Nominal Power (V_{mp})	33.3V	33.4V	33.5V	33.6V	33.7V	33.8V	33.9V	34.0V
Current at Nominal Power (I_{mp})	6.46A	6.56A	6.66A	6.75A	6.83A	6.93A	7.00A	7.09A

NOCT: Irradiance 800W/m², Ambient temperature 20°C, Wind speed 1 m/s

Mechanical Characteristics

Cell type	Polycrystalline 156x156mm
Number of cells	72(6x12)
Module dimension	1956x992x50mm
Weight	27kg
Front cover	4.0mm low-iron tempered glass
Frame	Anodized aluminum alloy
Junction box	IP67, 6 diodes
Cable	4mm², 1000mm
Connector	MC4 or MC4 compatible
Standard packaging	20pcs/pallet
Module quantity per container	440pcs/40'HQ

Temperature Characteristics

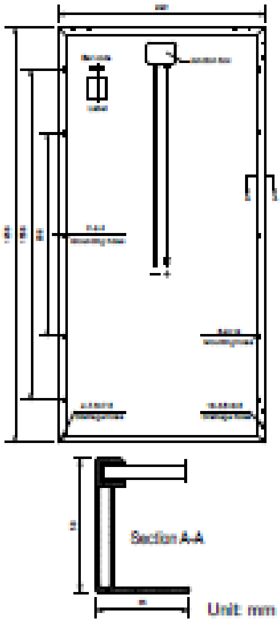
Nominal Operating Cell Temperature (NOCT)	45°C±2°C
Temperature Coefficients of P_{max}	-0.43%/°C
Temperature Coefficients of V_{OC}	-0.33%/°C
Temperature Coefficients of I_{SC}	0.056%/°C

Maximum Ratings

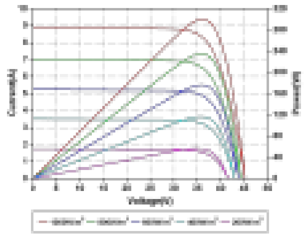
Operating Temperature	-40°C to +85°C
Maximum System Voltage	1000V DC
Maximum Series Fuse Rating	15A

Specifications in this datasheet are subject to change without prior notice.

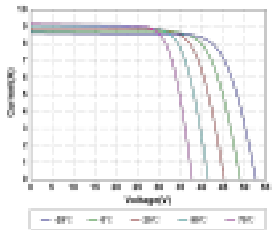
Drawings



I-V Curves



Current-Voltage and Power-Voltage Curves at Different Irradiances



Current-Voltage Curves at Different Temperatures

Worldwide Energy and Manufacturing USA Co., Limited
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10 Technical Data

DC Input

	STP 20000TL-30	STP 25000TL-30
Maximum DC power at cos φ = 1	20,440 W	25,550 W
Maximum input voltage	1,000 V	1,000 V
MPP voltage range	320 V to 800 V	390 V to 800 V
Rated input voltage	600 V	600 V
Minimum input voltage	150 V	150 V
Initial input voltage	188 V	188 V
Maximum input current, input A	33 A	33 A
Maximum input current, input B	33 A	33 A
Number of independent MPP inputs	2	2
Strings per MPP input	3	3
Overvoltage category as per IEC 60664-1	II	II

AC Output

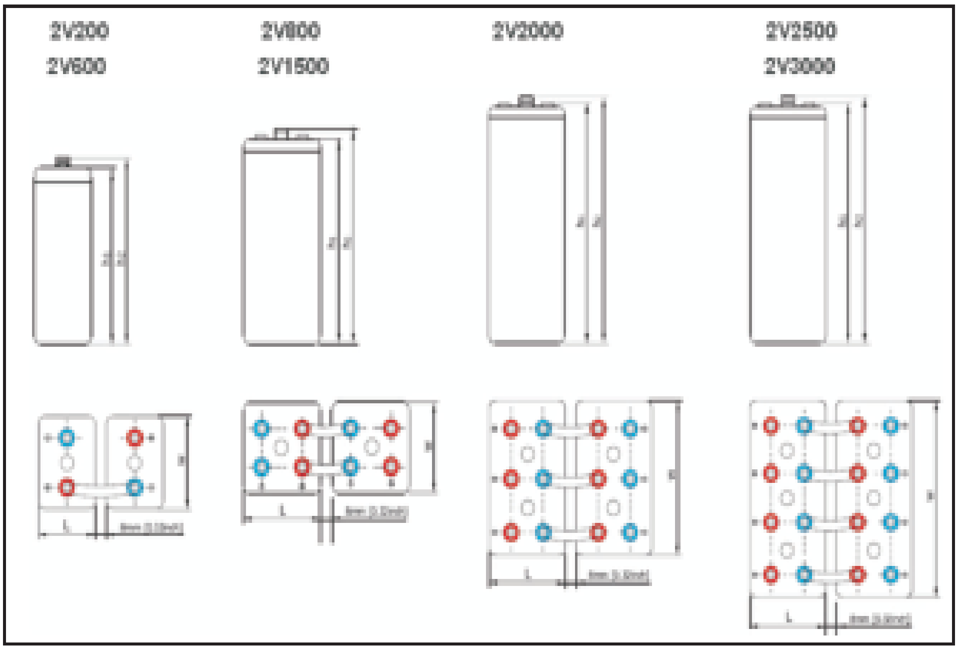
	STP 20000TL-30	STP 25000TL-30
Rated power at 230 V, 50 Hz	20,000 W	25,000 W
Maximum apparent AC power	20,000 VA	25,000 VA
Rated grid voltage	230 V	230 V
Nominal AC voltage	220 V / 230 V / 240 V	220 V / 230 V / 240 V
AC voltage range*	180 V to 280 V	180 V to 280 V
Nominal AC current at 220 V / 230 V / 240 V	29 A	36.2 A
Maximum output current	29 A	36.2 A
Maximum output current under fault conditions	50 A	50 A
Total harmonic distortion of the output current with total harmonic distortion of the AC voltage < 2%, and AC power > 50% of the rated power	≤ 3%	≤ 3%
Rated power frequency	50 Hz	50 Hz
AC power frequency*	50 Hz / 60 Hz	50 Hz / 60 Hz

8. Product Parameters and Drawing

1.OPzV Battery Parameters

Model No.	Voltage (V)	Capacity (Ah)	Pole	Dimension				Weight (Kg)
				Length (mm)	Width (mm)	Height (mm)	Total Height (mm)	
OPzV2-200	2	200	1	103	206	354	392	18
OPzV2-800	2	800	2	191	210	645	687	64
OPzV2-1000	2	1000	2	233	210	645	687	75
OPzV2-1200	2	1200	2	275	210	645	687	90
OPzV2-1500	2	1500	2	275	210	795	838	110
OPzV2-2000	2	2000	3	399	212	772	813	150
OPzV2-2500	2	2500	4	487	212	772	813	190
OPzV2-3000	2	3000	4	576	212	772	813	220

2.OPzV Battery Drawing with Terminal Position



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Grid-Connected System: Simulation parameters

Project :	**Building A 550**				
Geographical Site		**Gilat**		Country	**Israel**
Situation		Latitude	31.3°N	Longitude	34.7°E
Time defined as		Legal Time	Time zone UT+2	Altitude	152 m
		Albedo	0.20		
Meteo data:		**Bet Dagan**	Synthetic - MeteoNorm 7.1 station		

Simulation variant :	**New simulation variant**		
		Simulation date	12/11/15 22h09

Simulation parameters

Coll. plane: Seasonal tilt adjustment		Azimuth	0°	Winter season	O-N-D-J-F-M
		Summer Tilt	25°	Winter Tilt	55°
Models used		Transposition	Perez	Diffuse	Erbs, Meteonorm
Horizon		Free Horizon			
Near Shadings		No Shadings			

PV Array Characteristics

PV module	Si-mono	Model	**CS6X - 305M**		
Original PVsyst database		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	15 modules	In parallel	120 strings
Total number of PV modules		Nb. modules	1800	Unit Nom. Power	305 Wp
Array global power		Nominal (STC)	**549 kWp**	At operating cond.	487 kWp (50°C)
Array operating characteristics (50°C)		U mpp	485 V	I mpp	1004 A
Total area		Module area	**3454 m²**	Cell area	3096 m²
Inverter		Model	**Sunny Central 100**		
		Manufacturer	SMA		
Characteristics		Operating Voltage	450-820 V	Unit Nom. Power	100 kWac
Inverter pack		Nb. of inverters	5 units	Total Power	500 kWac

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	8.3 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

Appendix (2)

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Grid-Connected System: Main results

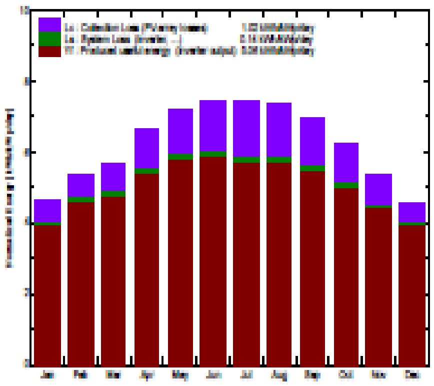
Project : **Building A 550**

Simulation variant : **New simulation variant**

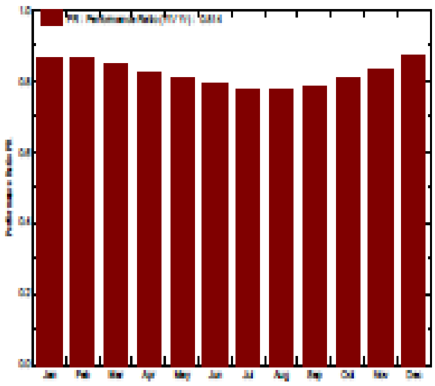
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Seasonal tilt summer/winter	25°/55°	azimuth	0°
PV modules	Model	CS6X - 305M	Pnom	305 Wp
PV Array	Nb. of modules	1800	Pnom total	**549 kWp**
Inverter	Model	Sunny Central 100	Pnom	100 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**500 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**1015 MWh/year**	Specific prod.	1848 kWh/kWp/year
	Performance Ratio PR	81.4 %		

Normalized productions (per installed kWp): Nominal power 549 kWp



Performance Ratio PR



New simulation variant

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	MWh	MWh	%	%
January	91.1	13.02	141.9	139.1	69.1	67.19	14.10	13.71
February	110.2	13.71	150.2	146.9	72.9	71.00	14.06	13.69
March	158.1	16.34	175.3	170.5	83.4	81.16	13.78	13.40
April	189.6	19.21	196.1	192.6	92.1	89.56	13.48	13.09
May	231.4	22.40	222.8	218.1	101.1	98.32	13.13	12.77
June	241.2	25.05	222.7	218.0	99.5	96.77	12.93	12.58
July	240.3	27.63	228.1	222.3	100.5	97.71	12.70	12.35
August	224.3	27.93	227.9	221.5	99.7	97.02	12.67	12.33
September	185.8	26.06	208.9	203.7	92.6	90.10	12.83	12.49
October	147.6	23.68	192.9	188.5	87.7	85.40	13.17	12.81
November	104.4	18.89	160.5	157.6	75.2	73.13	13.58	13.19
December	84.8	15.09	141.1	138.3	69.2	67.35	14.19	13.82
Year	2008.8	20.79	2271.5	2213.3	1043.0	1014.70	13.29	12.93

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

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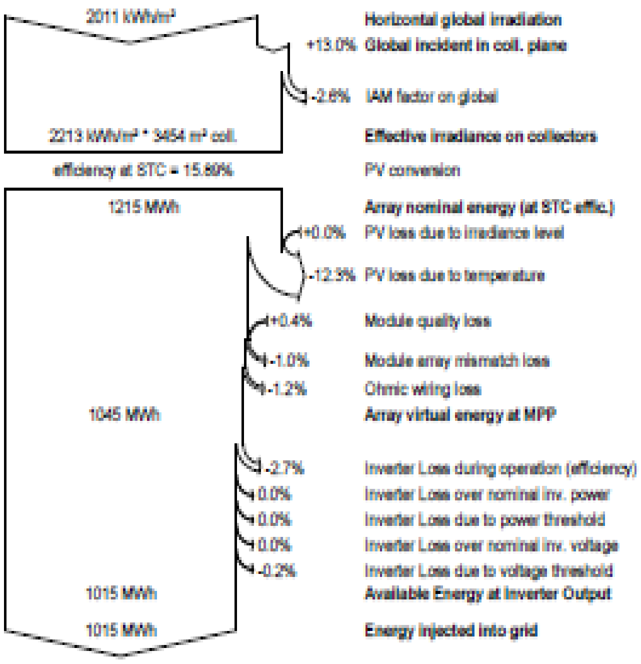
Grid-Connected System: Loss diagram

Project : **Building A 550**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Seasonal tilt summer/winter	25°/55°	azimuth	0°
PV modules	Model	CS6X - 305M	Pnom	305 Wp
PV Array	Nb. of modules	1800	Pnom total	**549 kWp**
Inverter	Model	Sunny Central 100	Pnom	100 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**500 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Building B - An-Najah Hospital**			
Geographical Site	**Bet Dagan**		Country	**Israel**
Situation	Latitude	32.0°N	Longitude	34.8°E
Time defined as	Legal Time	Time zone UT+2	Altitude	37 m
	Albedo	0.20		
Meteo data:	**Bet Dagan**	Synthetic - MeteoNorm 7.1 station		

Simulation variant :	**Building B104KWp**	
	Simulation date	14/01/16 22h58

Simulation parameters

Collector Plane Orientation	Tilt	45°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Erbs, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module	Si-poly	Model	**AS-6P**		
Custom parameters definition		Manufacturer	Amerisolar		
Number of PV modules		In series	18 modules	In parallel	18 strings
Total number of PV modules		Nb. modules	324	Unit Nom. Power	330 Wp
Array global power		Nominal (STC)	**107 kWp**	At operating cond.	92.4 kWp (50°C)
Array operating characteristics (50°C)		U mpp	586 V	I mpp	158 A
Total area		Module area	**622 m²**	Cell area	568 m²

Inverter	Model	**Sunny Tripower 20000TL-30**		
	Manufacturer	SMA		
Characteristics	Operating Voltage	320-800 V	Unit Nom. Power	20.0 kWac
Inverter pack	Nb. of inverters	5 units	Total Power	100 kWac

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	63 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP

Incidence effect, user defined profile

10°	20°	30°	40°	50°	60°	70°	80°	90°
1.00	1.00	1.00	1.00	1.00	0.99	0.93	0.73	0.00

User's needs : Unlimited load (grid)

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Grid-Connected System: Main results

Project : **Building B- An-Najah Hospital**

Simulation variant : **Building B104KWp**

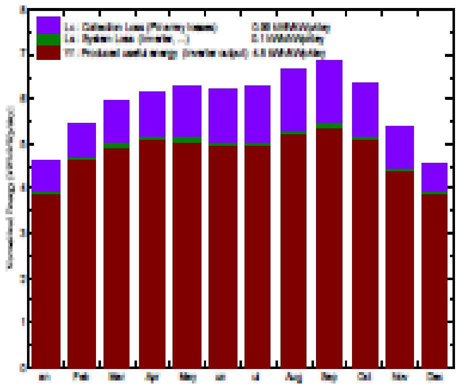
Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	45°	azimuth	0°
PV modules	Model	AS-6P	Pnom	330 Wp
PV Array	Nb. of modules	324	Pnom total	**107 kWp**
Inverter	Model	Sunny Tripower 20000TL-30		20.00 kW ac
Inverter pack	Nb. of units	5.0	Pnom total	**100 kW ac**
Users needs	Unlimited load (grid)			

Main simulation results

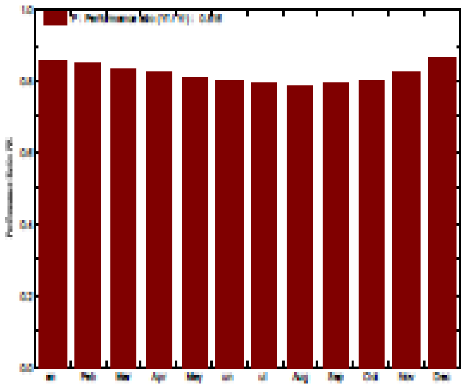
System Production — **Produced nergy** **17347 kWh/year** — Specific prod. 1752 kWh/kWp/year

Performance atio P 81.6 %

Normalized productions per installed kWp: Nominal power 107 kWp



Performance atio P



Building B104KWp

Balances and main results

	GlobHor	T Amb	GlobEff	EArray	EGrid	EffArrR	EffSysR	
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
anuary	91.1	13.02	141.8	140.6	13232	12965	15.01	14.71
ebruary	110.2	13.71	152.6	151.1	14171	13896	14.94	14.65
March	158.1	18.34	183.6	181.5	16710	16372	14.64	14.34
April	188.6	19.21	185.1	182.3	16651	16317	14.47	14.18
May	231.4	22.40	184.2	180.3	17175	16834	14.23	13.94
une	241.2	25.05	186.5	182.3	16293	15967	14.05	13.77
uly	243.3	27.63	184.7	180.7	16779	16440	13.86	13.58
August	224.3	27.93	206.2	202.8	17673	17314	13.79	13.51
Septemer	185.8	26.06	205.1	202.7	17606	17264	13.83	13.56
Octoer	147.8	23.68	187.5	185.6	17249	16906	14.05	13.77
Novemer	104.4	18.89	160.8	159.6	14450	14158	14.45	14.16
Decemer	84.8	15.09	140.0	138.7	13142	12894	15.10	14.82
Year	2010.8	20.79	2147.9	2118.3	191180	187347	14.32	14.03

Legends:	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	EGrid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrEffic	Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysEffic	Eout system / rough area

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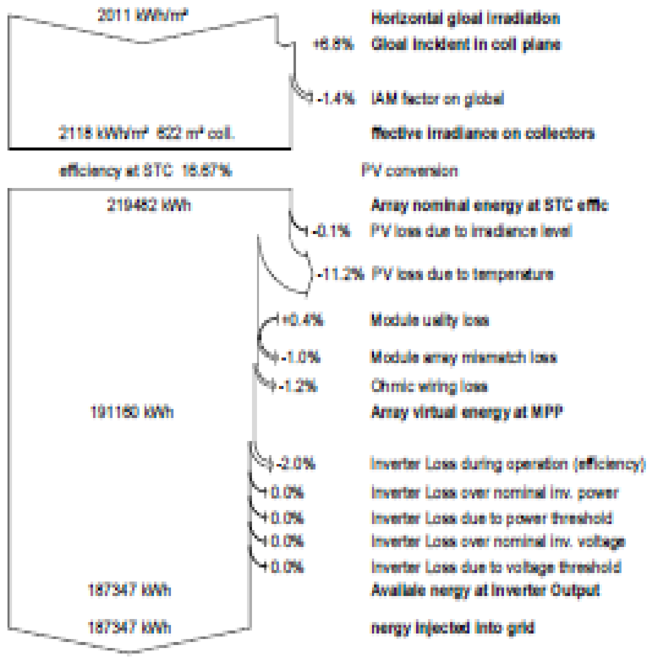
Grid-Connected System: Loss diagram

Project : **Building B- An-Najah Hospital**

Simulation variant : **Building B104KWp**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	tilt	45°	azimuth	0°
PV modules	Model	AS-6P	Pnom	330 Wp
PV Array	Nb. of modules	324	Pnom total	**107 kWp**
Inverter	Model	Sunny Tripower 20000TL-30		**20.00 kW ac**
Inverter pack	Nb. of units	5.0	Pnom total	**100 kW ac**
Users needs	Unlimited load (grid)			

Loss diagram over the whole year



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Grid-Connected System: Simulation parameters

Project :	**Building C 474**			
Geographical Site		Gilat	Country	Israel
Situation	Latitude	31.3°N	Longitude	34.7°E
Time defined as	Legal Time	Time zone UT+2	Altitude	152 m
	Albedo	0.20		
Meteo data:	Bet Dagan	Synthetic - MeteoNorm 7.1 station		

Simulation variant :	**New simulation variant**			
	Simulation date	15/11/15 00h48		

Simulation parameters

Coll. plane: Seasonal tilt adjustment	Azimuth	0°	Winter season	O-N-D-J-F-M
	Summer Tilt	25°	Winter Tilt	55°
Models used	Transposition	Perez	Diffuse	Erbs, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			

PV Array Characteristics

PV module	Si-mono	Model	**CS6X - 305M**		
Original PVsyst database		Manufacturer	Canadian Solar Inc.		
Number of PV modules		In series	17 modules	In parallel	92 strings
Total number of PV modules		Nb. modules	1564	Unit Nom. Power	305 Wp
Array global power		Nominal (STC)	**477 kWp**	At operating cond.	423 kWp (50°C)
Array operating characteristics (50°C)		U mpp	549 V	I mpp	770 A
Total area		Module area	**3001 m²**	Cell area	2690 m²

Inverter	Model	**JH 120 KE1**		
	Manufacturer	Sharp		
Characteristics	Operating Voltage	420-850 V	Unit Nom. Power	120 kWac
Inverter pack	Nb. of inverters	4 units	Total Power	480 kWac

PV Array loss factors

Thermal Loss factor	Uc (const)	20.0 W/m²K	Uv (wind)	0.0 W/m²K / m/s
Wiring Ohmic Loss	Global array res.	12 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.4 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Incidence effect, ASHRAE parametrization	IAM =	1 - bo (1/cos i - 1)	bo Param.	0.05

User's needs : Unlimited load (grid)

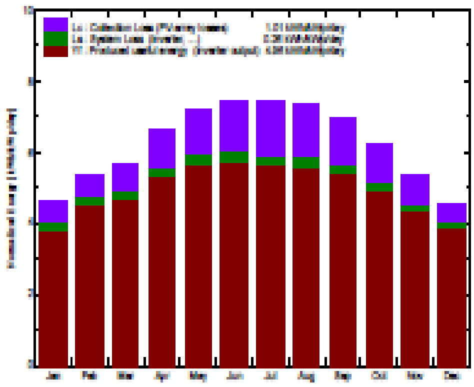
Grid-Connected System: Main results

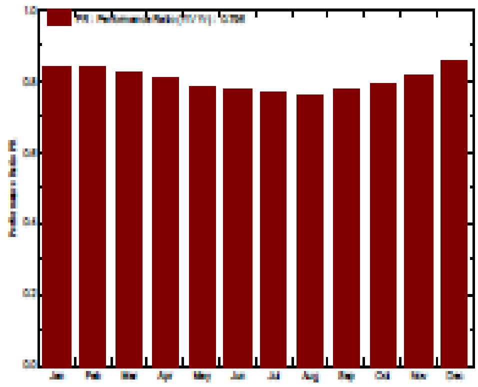
Project : **Building C 474**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Seasonal tilt summer/winter	25°/55°	azimuth	0°
PV modules	Model	CS6X - 305M	Pnom	305 Wp
PV Array	Nb. of modules	1564	Pnom total	**477 kWp**
Inverter	Model	JH 120 KE1	Pnom	120 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**480 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**862.7 MWh/year**	Specific prod.	1809 kWh/kWp/year
	Performance Ratio PR	79.6 %		





New simulation variant
Balances and main results

	GlobHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	EffArrR %	EffSysR %
January	81.1	13.02	141.9	139.1	60.04	56.90	14.10	13.36
February	110.2	13.71	150.2	146.9	63.38	60.27	14.06	13.37
March	158.1	16.34	175.3	170.5	72.53	68.86	13.78	13.09
April	188.6	19.21	198.1	192.6	80.05	75.98	13.48	12.78
May	231.4	22.40	222.8	216.1	87.64	83.44	13.15	12.48
June	241.2	25.05	222.7	216.0	86.61	82.20	12.98	12.30
July	243.3	27.83	228.1	222.3	87.79	83.30	12.77	12.12
August	234.3	27.93	227.9	221.5	87.18	82.82	12.75	12.11
September	185.8	26.08	208.9	203.7	80.88	76.96	12.90	12.28
October	147.6	23.08	190.9	186.5	76.42	72.66	13.20	12.55
November	104.4	18.09	160.5	157.6	65.35	62.13	13.57	12.90
December	84.8	15.09	141.1	138.3	60.10	57.21	14.19	13.51
Year	2010.8	20.79	2271.5	2213.3	908.37	862.74	13.30	12.66

Legends:				
	GlobHor	Horizontal global irradiation	EArray	Effective energy at the output of the array
	T Amb	Ambient Temperature	E_Grid	Energy injected into grid
	GlobInc	Global incident in coll. plane	EffArrR	Effic. Eout array / rough area
	GlobEff	Effective Global, corr. for IAM and shadings	EffSysR	Effic. Eout system / rough area

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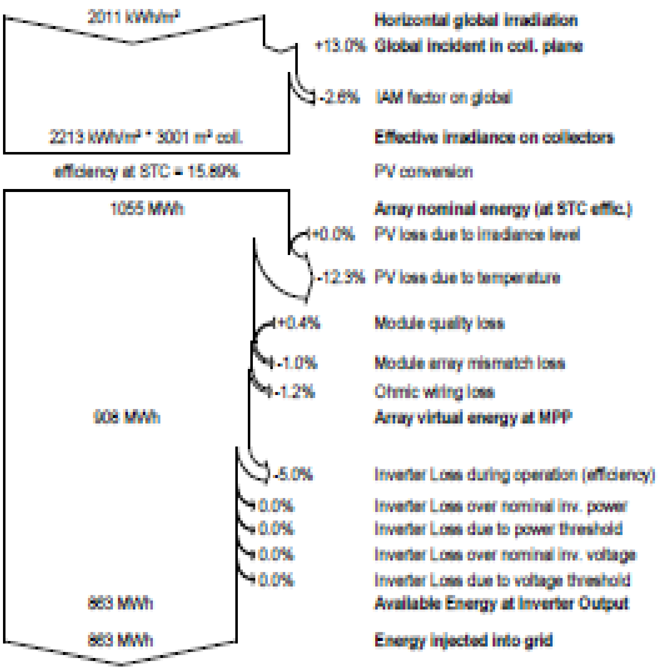
Grid-Connected System: Loss diagram

Project : **Building C 474**

Simulation variant : **New simulation variant**

Main system parameters	System type	**Grid-Connected**		
PV Field Orientation	Seasonal tilt summer/winter	25°/55°	azimuth	0°
PV modules	Model	CS6X - 305M	Pnom	305 Wp
PV Array	Nb. of modules	1564	Pnom total	**477 kWp**
Inverter	Model	JH 120 KE1	Pnom	120 kW ac
Inverter pack	Nb. of units	4.0	Pnom total	**480 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



جامعة النجاح الوطنية

كلية الدراسات العليا

التحليل الفني والاقتصادي وإدارة الطاقة لأنظمة الخلايا الشمسية المربوطة على شبكة الكهرباء "مستشفى النجاح الوطني كحالة للدراسة"

إعداد

أحمد يوسف خالد خلوف

إشراف

د. عماد بريك

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

2016

التحليل الفني والاقتصادي وإدارة الطاقة لأنظمة الخلايا الشمسية المربوطة على شبكة الكهرباء "مستشفى النجاح الوطني كحالة للدراسة"

إعداد

أحمد يوسف خالد خلوف

إشراف

د. عماد بريك

الملخص

هذه الدراسة قامت على تحليل أداء تركيب أنظمة الطاقة الكهروضوئية على الشبكات الكهربائية ودراسة أنظمة إدارة الطاقة في فلسطين، من الناحية الفنية والمالية. و تصميم ومحاكاة نظام شمسي بقدرة 104 كيلووات متصل على شبكة الكهرباء كما انه تم تصميم ومحاكاة استخدام أنظمة إدارة الطاقة الكهربائية وإدارة الأحمال لمستشفى النجاح وكانت نتائج المحاكاة إيجابية حيث انه تم تخفيض ذروة الأحمال من 240 كيلووات إلى 160 كيلووات.

ويتألف هذا النظام الكهروضوئية ونظام إدارة الطاقة من العناصر التالية. مجموعة من الخلايا الكهروضوئية بقد330واط، موصلة مع بعضها البعض عن تريق التوالي والتوازي بحيث تصل قدرتها الإجمالية إلي ما يقارب 104 كيلووات. وبالإضافة إلى ذلك، هناك خمسة محولات ثنائية العمل بقدرة 20 كيلووات ، كما انه يوجد نظام لتخزين الطاقة بسعة 68 كيلووات - ساعة والتي تستخدم في إدارة الطاقة.

من المتوقع ان يقوم النظام بانتاج ما يقارب على 187000 كيلووات - ساعة سنويا. من وجهة نظر اقتصادية فان الأنظمة الكهروضوئية وأنظمة ادارة الطاقة ذات تكلفة ابدتائية عالية حيث كانت ما يقارب 187،000 دولار أمريكي، ولكن التقييم الاقتصادي للنظام تبين أن تكلفة الوحدة من نظام كان حوالي 0.19 دولار لكل كيلووات ساعة مع استخدام انظمة ادارة الطاقة و0.1 دولار لكل كيلووات ساعة في حال عدم استخدام انظمة ادارة الطاقة وقد كانت في كلتا الحالتان أقل من من تكلفة الطاقة التي يتم شرائها من شركة كهرباء الشمال التي تبيع الطاقة للمستهلك بسعر 0.21 دولار لكل كيلووات في الساعة وهذا يعني أن تكلفة الوحدة هي مقبولة في كلتا الحالتين، حيث انه يوجد ادخار سنوي بما يقارب 40000 دولار في فواتير الطاقة الكهربائية. ايضا فانه في دراسة

الجدوى الاقتصادية فقد تبين معدل العائد كان حوالي 23% و فترة الاسترداد ما يقارب الست سنوات مما يعني أن هذه الانظمة لها إيرادات عالية وانها مجدية جدا.