Palestine Polytechnic University

College of Engineering

Title

Economic Analysis Of PPU Hybrid Energy Systems

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الإهداء

إلى من جرع الكأس فارغاً ليسقيني قطرة حب

إلى من كلّت أنامله ليقدم لنا لحظة سعادة

إلى من حصد الأشواك عن دربي ليمهد لي طريق العلم

إلى من ارضعتني الحب والحنان

إلى رمز الحب وبلسم الشفاء ....(والدتي الحبيبة)

إلى من أزال اشواك الحياة ومهد طريقنا للنجاح وزينه بالورود العطرة .... (ابي الغالي)

إلى القلوب الطاهرة الرقيقة والنفوس البريئة إلى رياحين حياتي

إلى من يحملون في عيونهم ذكريات طفولتي وشبابي .... إخوتي وأخواتي

الى من سرنا سويا ونحن نشق الطريق معا نحو النجاح والإبداع .... زملائي وزميلاتي

إلى من ضحوا بحريتهم من اجل حرية غيرهم .... الاسرى والمعتقلين

الى من هم أكرم منا مكانة .... شهداء فلسطين

إلى هذا الصرح العلمي الفتي والجبار .... جامعة بوليتكنك فلسطين

إلى من احتضنتني كل هذا الكم من السنين .... فلسطين الحبيبة

شكر وتقدير

(قل اعملوا فسيرى الله عملكم ورسوله والمؤمنون) صدق الله العظيم

إلهي لا يطيب الليل إلى بشكرك ولا يطيب النهار إلا بطاعتك.. ولا تطيب اللحظات إلا بذكرك.. ولا تطيب الأخرة إلا بعفوك.. ولا تطيب الجنة الى برؤيتهِ جل جلاله.......

لابد لنا ونحن نخطو خطواتنا الأخيرة في الحياة الجامعية من وقفة نعود إلى أعوام قضيناها في رحاب الجامعة مع اساتذتنا الكرام الذين قدموا لنا الكثير باذلين بذلك جهودا كبيرة في بناء جيل الغد لتبعث الامة من جديد...

وقبل أن نمضي نقدم أسمى آيات الشكر والامتنان والتقدير والمحبة إلى الذين حملوا أقدس رسالة في الحياة ......

إلى الذين مهدوا لنا طريق العلم والمعرفة .....

إلى جميع أساتذتنا الأفاضل.....

كن عالما ... فإن لم تستطيع فكن متعلما، فإن لم تستطع فأحب العلماء، فإن لم تستطع فلا تبغضهمْ

ونخص بالتقدير والشكر إلى من قدم لنا يد العون وكان لنا سنداً والذي علمنا التفاؤل والمضي إلى الأمام، إلى من رعانا وحافظ علينا، إلى من وقف إلى جانبنا عندما ضللنا الطريق

.... الدكتور فؤاد الزرو ....

Abstract

This project presents economic study for Palestine Polytechnic University electrical energy consumption as well as its electrical load,three scenario for feeding the university by electrical energy have been proposed and discussed. On grid system, the fist scenario, Photovoltaic System and Main Grid. The second scenario is Photovoltaic System, Wind Turbine and Main Grid. For the off grid system: Photovoltaic System, Wind Turbine, Diesel Generator and Batteries.

In this study, Homer Software will be used, which requires the introduction of information related to electrical load and energy sources used in solar radiation, wind speed and coordinates of the location. Homer Software offers many solutions and fixes the best economic solution. We figured out that the best scenario is Photovoltaic System and Main Grid.

Keywords: Hybrid power systems; renewable energy; wind energy; solar energy; batteries; optimization; sensitivity analysis; HOMER.

الملخص

يقدم هذا المشروع دراسة اقتصادية لاستهلاك الطاقة الكهربائية و سعر تكلفة كيلو واط ساعةوكذلك دراسة الحمل الكهربائي للجامعة. تم وضع ثلاث سيناريوهات ومناقشتها لامداد الجامعه بالطاقة الكهربائية. النظام المتصل بالشبكة: السيناريو الاول النظام الكهروضوئي والشبكة الرئيسية. السيناريو الثاني النظام الكهروضوئي، وتوربينات الرياح والشبكة الرئيسية. أما بالنسبة للنظام المنفصل عن الشبكة: النظام الكهروضوئي، توربينات الرياح، مولدات الديزل والبطاريات.

في هذه الدراسة ، تم استخدام برنامج الهومر، والذي يتطلب إدخال المعلومات المتعلقة بالحمل الكهربائي ومصادر الطاقة المستخدمة وايضا معلومات عن الإشعاع الشمسي وسرعة الرياح واحداثيات الموقع. اتضح لدينا ان أفضل سيناريو من حيث الاقتصاد هو النظام الكهروضوئي والشبكة الرئيسية.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Introduction

The Palestinian people have been under occupation since the beginning of the last century, where people are suffering in various areas of life, including in the field of electricity, where people suffer from periodic power outages. Where it affects the lives of citizens, companies and institutions, which may incur heavy losses in some cases, may also lead to the loss of some people for their lives in case of power outages of hospitals. It was therefore necessary to find practical solutions that could be applied to the basic human condition, such as the installation of a hybrid energy system. The hybrid energy system consists of renewable energy sources (wind and solar energy) and conventional energy sources.

One of the benefits of this system is to provide different sources of electricity production, as it has economic benefits.And this type of hybrid energy system can be used to build clean energy system, which can control the global warming and reduce the pollutant emissions. The purpose of this thesis is to improve and simulate the hybrid power supply system of the Polytechnic University of Palestine, which consumes large electrical power due to the large number of buildings and equipment used.

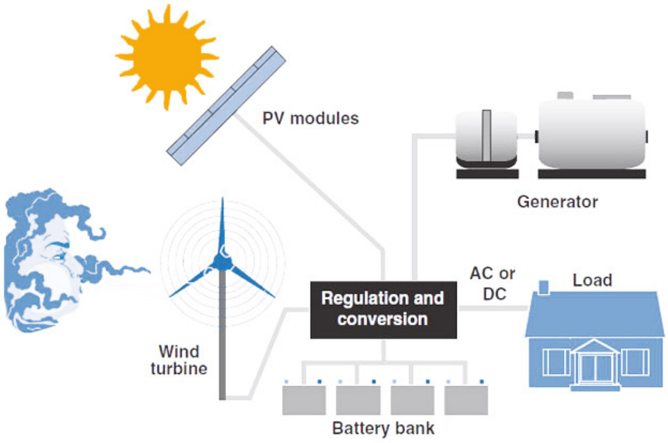


Figure 1.1: Hybrid-power-systems[1].

1.2 Related Literature of Hybrid Power Generation System

M. B. M. Rozlan,A. F. Zobaa, S. H. E. Abdel Aleem.

Global organizations are aware that in this paper, Perhentian Island has been chosen as case study area. It is located in Terengganu it is approximately 20 km away from the mainland, far away from grid utilities.

This island is exposed to vary season to season wind speed of 2 m/s to 13m/s . Since the island has high wind potential, it would be advantageous for wind turbine The current average estimation of daily energy consumption of this island is 1253 kWh/day. However, the current technology still costly and emit pollutants. Thus, the idea of proposing a new energy system technology which is cost-effective, environmental friendly is important.

HOMER software has been chosen to carry out this article; The optimisation results , are presented at current fuel price $ 0.57 per litre, and at scaled annual average wind of 7.78 m/s, and solar of 5.24 kWh/d.[2]

Ahmad Rohani, Kazem Mazlumi, Hossein Kord.

In this paper, near Shiraz (South, Iran, 29° 36' N, 53° 40' E) has been chosen as case study area This data has been analyzed to assess utilization of hybrid PV/WG/battery/FC power systems to meet the load requirements of a typical remote village (with annual energy demand average of 623 (kWh/d)) , the monthly average daily solar radiation ranges from 3.26 to 7.61 (kWh/m2).

In this case using HOMER SIMULATION MODEL In the present work, the selection and sizing of components of hybrid power system has been done using NREL's HOMER software. The simulation results indicated that a hybrid power system comprising of 150 (kWpeak) photovoltaic system together with 100 (kW) wind generator system, 25 (kW) fuel cell, and battery storage of 6 hours of autonomy (equivalent to 6 hours of average load), would be a feasible solution for distributed generation of electric power for stand-alone applications at remote locations. The cost of generating energy from the above hybrid PV/WG/FC/battery system has been found to be 0.398 (US$/kWh).

The hybrid $PV/WG/FC/battery$ power system offers several benefits such as: utilization rate of PV generation is high; load can be satisfied in the optimal way; reliable power supply; and a reduction in the capacities of PV, FC and battery (while matching the peak loads) can occur. Also it has been found that the unmet load was only 654 (kWh) per year. The environmental friendly nature of the hybrid system can also be depicted from annual emission of the system.[3]

Deepak Kumar Lal, Bibhuti Bhusan Dash, and A. K. Akella.

India is a highly populated country in the world, and hence its energy need is also more and growing with time. In Hence it is necessary to interconnect other renewable/alternative energy sources for reliability and consistence power supply .

Here a case study is given based on the practically available data with analysis using computer software HOMER.

The study area under consideration is located in the Sundargarh district of Orissa state, India. The district covers an area of 9712 Sq Kms The authors have adopted a new approach to the PV/Wind/ diesel hybrid system including a hydro resource and comparing it with excluding it. The paper is organized as follows. Study area and water resources availability is discussed . Energy demand and resources for the proposed scheme are discussed .

The hybrid system proposed is consists of micro hydro plant, wind turbine and solar photovoltaic (PV) panels. Diesel generators and battery bank are included as part of back-up and storage system. Mathematical modeling of hybrid energy system components are given and analysis by Homer hybrid model is The project lifetime is estimated for about 25 years. The results obtained from Homer simulation is discussed. Also simulation is done and presented without hydro plants and discussed.[4]

1.3 Objectives

1. This project presents the various plans of the hybrid system (solar, wind power and diesel). Includes the university's annual load measurement, year seasons and data a group of solar and wind energy.

2. This project suggests building three different electricity supply scenarios and discussing the levelized cost of energy and cost of system components. The case study for this work is based on Palestine Polytechnic University data.

3. The project aims to determine the most ideal system and economic study for each scenario through calculation and analysis,where Several hypotheses have been made that use different energy sources namely:

   - Photovoltaic System and Main Grid.
   - Photovoltaic System, Wind Turbine and Main Grid
   - Photovoltaic System, Wind Turbine,Diesel Generator and Batteries.

4. Working on the project simulation and to define different systems The ideal system for analyzing energy supplies, quality and economic impact

1.4 Statement of the Problem

A Palestine Polytechnic University suffers from the payment of large amounts of electricity bills and with the installation of the solar system, which does not cover all the needs of the University of electricity, we will present in this research a hybrid energy system and design, depending on the university site. The research will solve the following questions: How is the feasibility of hybrid renewable power system in PPU ? How to design different alternative plans of the hybrid energy system? How to get the optimal system? How about the power supply quality, capital cost, operation cost, and pollutant emissions of the system?

1.5 Significance of the Study

Since solar energy and wind energy are different from one place to another, the goal is to find a hybrid system that provides stable energy, reduces bills, and increases the reliability and quality of the electrical power system of Palestine Polytechnic University. It is necessary to build a simulation system. The importance of the study is focused on feasibility and strength Supply quality, capital cost and operating cost to build a hybrid system which helps in developing a successful investment plan.

Chapter 2

Homer software

2.1 Introduction to HOMER

2.1.1 What is HOMER

HOMER (Hybrid Optimization of Multiple Electric Renewable), the micropower optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. When you design a power system, you must make many decisions about the configuration of the system: what components does it make sense to include in the system design? How many and what size of each component should you use? The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations.[5]

2.2 How to use HOMER

To use HOMER, you provide the model with inputs, which describe technology options, component costs, and resource availability. HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that you can view as a list of feasible configurations sorted by net present cost. HOMER also displays simulation results in a wide variety of tables and graphs that help you compare configurations and evaluate them on their economic and technical merits. You can export the tables and graphs for use in reports and presentations. When you want to explore the effect that changes in factors such as resource availability and economic conditions might have on the cost-effectiveness of different system configurations, you can use the model to perform sensitivity analyses. To perform a sensitivity analysis, you provide HOMER with sensitivity values that describe a range of resource availability and component costs. HOMER simulates each system configuration over the range of values. You can use the results of a sensitivity analysis to identify the factors that have the greatest impact on the design and operation of a power system. You can also use HOMER sensitivity analysis results to answer general questions about technology options to inform planning and policy decisions.[5]

2.3 Work of Homer

2.3.1 Simulation

HOMER simulates the operation of a system by making energy balance calculations in each time step of the year. For each time step, HOMER compares the electric and thermal demand in that time step to the energy that the system can supply in that time step, and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides in each time step how to operate the generators and whether to charge or discharge the batteries. HOMER performs these energy balance calculations for each system configuration that you want to consider. It then determines whether a configuration is feasible, (i.e. whether it can meet the electric demand under the conditions that you specify), and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest.[5]

2.3.2 Optimization

HOMER Pro has two optimization algorithms. The original grid search algorithm simulates all of the feasible system configurations defined by the Search Space. The new HOMER

Optimizer? uses a proprietary derivative free algorithm to search for the least cost system. HOMER then displays a list of configurations, sorted by net present cost (sometimes called lifecycle cost), that you can use to compare system design options.[5]

2.3.3 Sensitivity Analysis

When you define sensitivity variables as inputs, HOMER repeats the optimization process for each sensitivity variable that you specify. For example, if you define wind speed as a sensitivity variable, HOMER will simulate system configurations for the range of wind speeds that you specify.[5]

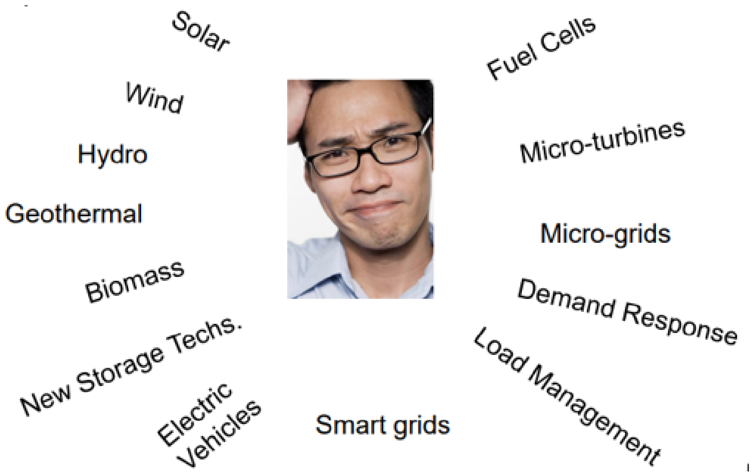


Figure 2.1: Difficult decisions[6]

A confused mind says "No!".

HOMER fits the pieces together & give you the best solution.

2.4 Overview of HOMER

HOMER can help you to design the best micropower system to suit your needs.[6]
HOMER lets you:

- Evaluate off-grid or grid-connected power system designs.
- Choose the best system based on cost, technical requirements, or environmental considerations.
- Simulate many design configurations under market price uncertainty and evaluate risk.
- Choose the best addition or retrofit for an existing system.
- The HOMER Support Site has many resources to help you wit.
- Create a system with a load, generator, wind turbine, batteries, and a system converter.
- Perform an economic optimization to find the best combination of battery bank, converter, generator, and wind turbine quantities and capacities.
- Perform a sensitivity analysis to investigate how results are affected by fuel price, wind speed, and load size.
- Explore the effect of interest rate on the optimal system type.

2.5 Solar Radiation and Wind Speed Data

HOMER has it own wind and solar database that gives hourly, daily, monthly and annual averages. However, the wind resources are little bit more complicated than the solar resources because their in consistence and variations.
The wind speed and direction data from at least one year of measurements is needed in order to have a good wind resource assessment and estimate. Figure**??** is showing the power flow in a system consisting of wind turbine, PV panel, storage unit and a load, while Figure 2.2 is giving the solar radiation for a selected location.[7]

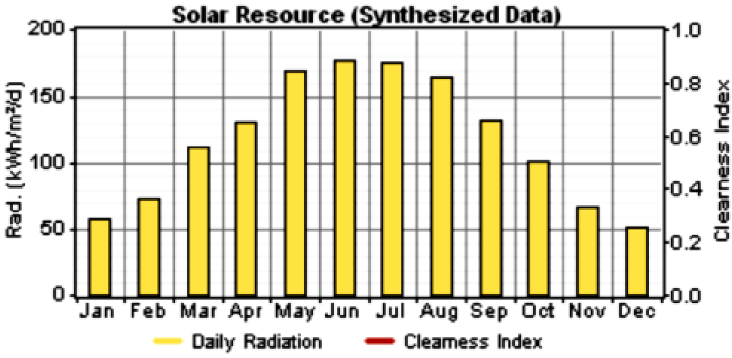


Figure 2.2: Typical yearly profile of the solar radiation.[7]

HOMER synthesizes solar radiation values for each of the 8760 hours of the year. Its algorithms produces realistic hourly data, being easy to use, requiring only the latitude and the monthly averages, while displaying realistic day to day and hour to hour patterns. The synthetic data are created with certain statistical properties that reflect global average value. However, generated data for a particular location will not exactly replicate the characteristics of the real solar radiation. But tests show that synthetic solar data produce virtually the same simulation results as real data. HOMER synthetic wind data generator is little different to use than the solar data as it requires four parameters, in order to generate wind statistics for this specific site. A user starts by specifying system parameters and hourly electrical load, wind and solar resource data. For each simulated hour the software calculates global irradiation at the photovoltaic array titled surface, calculates the output energy from the array, and performs energy balance at the DC and AC buses to determine amount of energy taken from or transferred to the electrical grid. Energy balance at the DC bus takes in consideration the storage component when present. The software keeps record of hourly, daily monthly and one year simulation results. It displays these results in a tabular format. Results also include economic analysis that takes into account investment costs and financial benefits projected over the life time of the project.[7]

2.6 HOMER Hybrid Power System Analysis

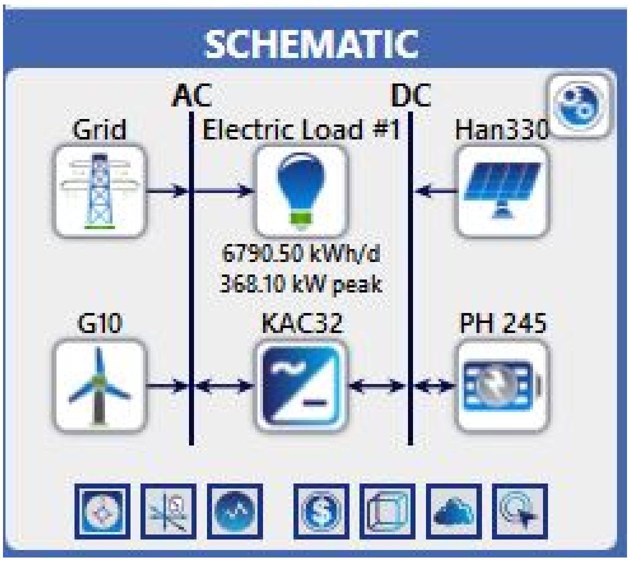


Figure 2.3: Configuration in HOMER of a PV-Wind hybrid power system.

To realize the potential of distribution generation, generation and load must be taken as a subsystem. This system may use any combination of generation, load and storage technologies and can operate in grid connected mode or autonomous mode. Some examples of micro power system or micro-grid are solar-battery serving a remote load, wind-diesel system serving an isolated village, a grid connected natural gas micro-turbine providing heat to a factory. Micro-power system consists of electric and thermal loads and any combination of PV modules, wind turbine, small hydro, biomass power generation, micro-turbines, fuel cells, reciprocating engine generators, batteries and hydrogen storage. The analysis and design of micro-power system is challenging due to large number of design options and uncertainty in key parameters such as load size and future fuel price. Renewable energy sources add further complexity because the output may be intermittent, seasonal and non-dispatch-able and the availability is uncertain. Once HOMER is open the user may start by adding/removing buttons on the upper left, enabling the equipment and components to be used in simulation and analysis, as one shown in Figure 2.3.

2.7 Load Profile

An important consideration of any power generating system is load requirements and characteristics, not only for load itself but also for the efficiency and reliability of power transmission. The load factor for the project is important in the design process. The project team is usually distributed strategically over the 24 h period to improve the system load factor to minimize the possibility of errors and to optimize the system size and structure.The peak load requirement decides the size, structure and architecture of the proposed system. The model of each project has been developed using HOMER, consists of a PV, WG, a battery. The schematic of this hybrid power system is shown in Figure2.4. In order to verify the system performance under different situation, simulation studies have been carried out using real weather data (solar irradiance and wind speed). The goal of the optimization process is to determine the optimal value of each decision variable that interests the modeler. A decision variable is a variable over which the system designer has control and for which HOMER can consider multiple possible values in its optimization process. Decision variables in HOMER include:

1. The size of the PV array.
2. The number of WG.
3. The battery capacity.
4. The size of the DC-AC and AC-DC converters.

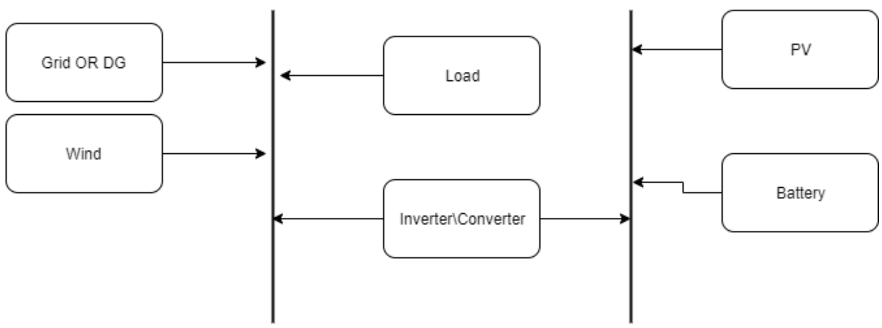


Figure 2.4: block diagram.

Chapter 3

Description and Modeling of Photovoltaic, Wind Turbine, Diesel Generator and Battery Components

3.1 Description And Modeling Of Photovoltaic

3.1.1 Photovoltaic Power Generation

Photovoltaic cells are made of semi-conducting materials and the most commonly used material is silicon. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity.

A single PV cell typically produces a small amount of power and in order to increase the operating voltage, the cells are connected in series to form a PV module. A photovoltaic array consists of a number of electrically connected PV modules, which can be connected together in series to generate a higher voltage or in parallel to get a higher current. Fig 3.1 shows the conceptual relationship between the PV cell, module and array[8].

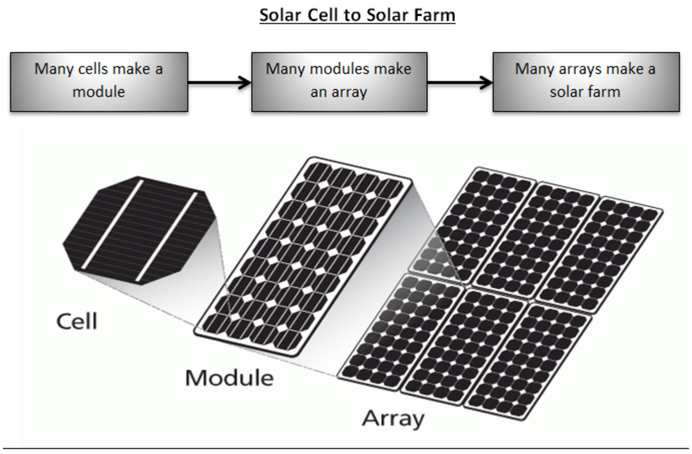


Figure 3.1: Conceptual relationship between the PV cell, module and array.[8]

The Six Main components of a Solar Panel

1. Extruded Aluminum frame.
2. Tempered Glass - 3 to 4mm thick.
3. Silicon PV cells.
4. Encapsulation - EVA film layers.
5. Polymer rear back sheet.
6. Junction box - diodes and connectors.

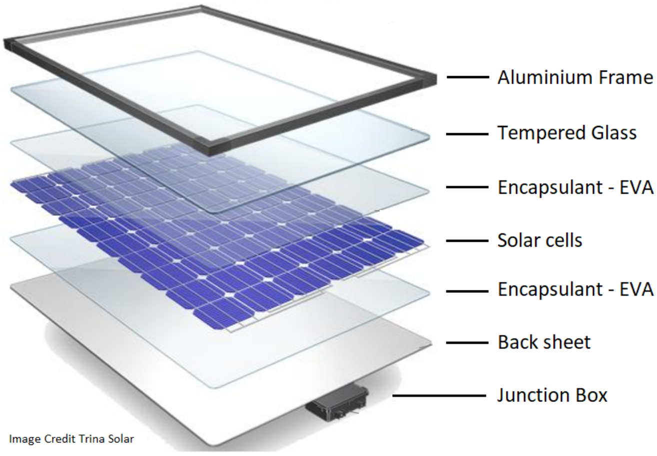


Figure 3.2: Solar Panel Construction.[9]

3.1.2 Characteristics Of Photovoltaic Module

The performance of a photovoltaic module depends on manufacturing technology and operating conditions (solar radiation and temperature). The curve of current – voltage (I-V) which determines the behavior of a photovoltaic cell is represented in figure 3.3.

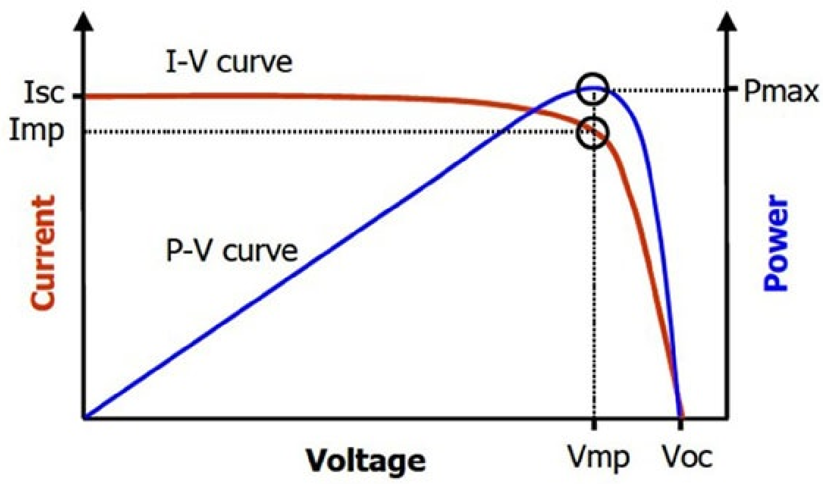


Figure 3.3: I-V and P-V characteristics of typical PV module[10].

The main electrical parameters that describe the performance of a Photovoltaic cell are:

1. Short circuit current Isc The value of (Isc) can be obtained by connecting the terminals of a module via an ammeter and measuring the current.The value of (Isc) changes in function of solar radiation and very little of temperature.

2. Open circuit voltage(Voc) It's the voltage of a PV module measured at terminals at no load.

3. Maximum power point (MPP) The maximum power point of a photovoltaic is a unique point on the (I-V) or (P-V) Characteristics and the power supplied in this point is maximum , where measured in Watts (W). its value can be calculated by the product Vmax and Imax.

4. Fill Factor (FF) The ratio of output power at maximum power point to the power computed by multiplying Isc by Voc , as illustrated in figure 3.4. The FF is obtained according the following equation:

$$FF = \frac{(Vmpp \times Impp)}{(V_{oc} \times I_{sc})} \tag{3.1}$$

It is important performance indicator.

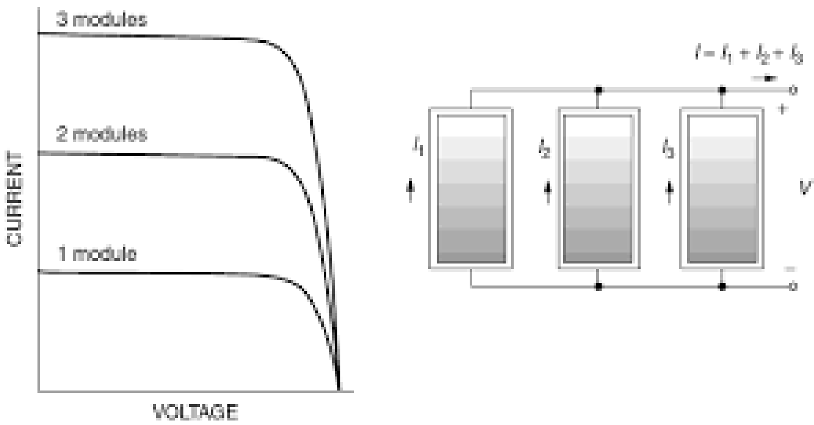


Figure 3.4: The I-V curve of a PV module for defining the FF[11].

Typically, crystalline silicon photovoltaic FF module is between 0.67 and 0.74. If the I-V curves of two individual PV modules have the same values of Isc and Voc , the array with the higher fill factor (squarer I-V curve) will produce more power. Also , any impairment that reduces the fill factor will reduce the output power.[11]

3.1.3 Modeling Of Photovoltaic Cell

The equivalent electrical circuit of one-diode model consists of a real diode in parallel with a current source. The current source produces the current Iph and the current Id flows

through diode. The current (Ic) which flows to the load is the difference between (Iph) and (Id) and it is reduced by the resistances (Rs) and Rp.[12]
Two resistances (Rs) and (Rp), are included to model the contact resistances and the internal PV cell resistance respectively. The value of these two resistances can be obtained from measurements or by using curve fitting methods based on the I-V characteristic of PV. The equivalent electrical circuit for a PV cell or module is illustrated in figure 3.5.

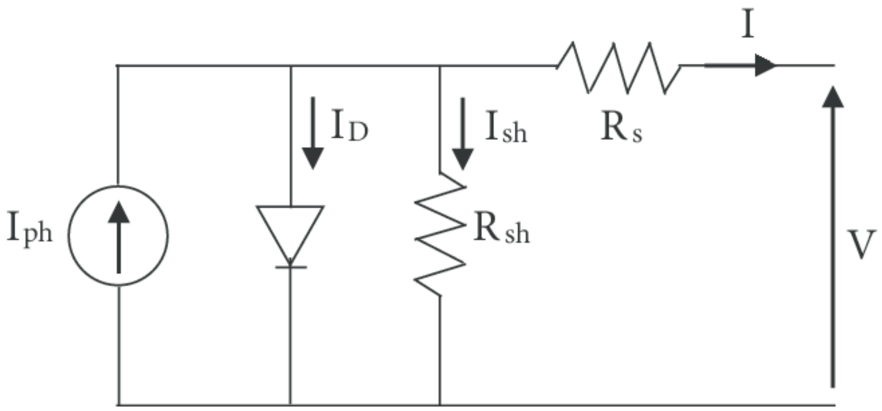


Figure 3.5: Equivalent-circuit-of-the-PV-generator.[12]

The current source (Iph) depended on the solar radiation and the ambient temperature. The (I-V) characteristics of photovoltaic cell can be determined by the following equations. The terminal current of the model (I_L) is given by:

$$(IL) = (Iph)–(Id)–(IP) \tag{3.2}$$

Where:
(Iph) : photo current from photovoltaic cell (A)
(Id): is the current passing through none linear diode (A)
(IP): current through shunt resistance (A)
The photo current (Iph) is a function of solar radiation and temperature, it is determined from equation:

$$Iph = \frac{(Isc + ki(Tc - Tr))G}{Gn} \tag{3.3}$$

Where:

(Isc) : is the short-circuit of the cell at standard test condition (STC: Gn = 1000W/m and Tr = 298.15K) [A].

Ki : is the short-circuit temperature co- efficient of the cell [A/K].

Tc and Tr : are the working temperatures of the cell and reference temperature respectively [k].

G and Gn : are the working solar radiation and nominal solar radiation respectively [w/m].

The diode saturation current Id of the cell varies with the cell temperature which is expressed in equation:

$$Id = I_o e^{\frac{(q(VL + ILRs)}{kTc}} - 1 \tag{3.4}$$

Where:

Io : reverse saturation current of the diode [A].

q: is the electron charge [1.6021×10^{-19} C].

VL: output voltage of the photovoltaic cell [V].

Rs: series resistance of cell [ohm].

A: is the ideality constant of diode depend on the PV technology.

K: Boltzmann constant [1.38×10^{-23} j/k].

The shunt current Ip is given by equation:

$$Ip = \frac{VL + IL \times Rs}{Rp} \tag{3.5}$$

Where : Rp is parallel resistance [ohm].

3.1.4 Modeling Of Photovoltaic Module

A PV module is the result of connecting several PV cells in series in order to increase the output voltage, the characteristic has the same shape except for changes in the magnitude of the open circuit voltage as shown in figure 3.6.[11]

The output voltage of a PV module is calculated by :

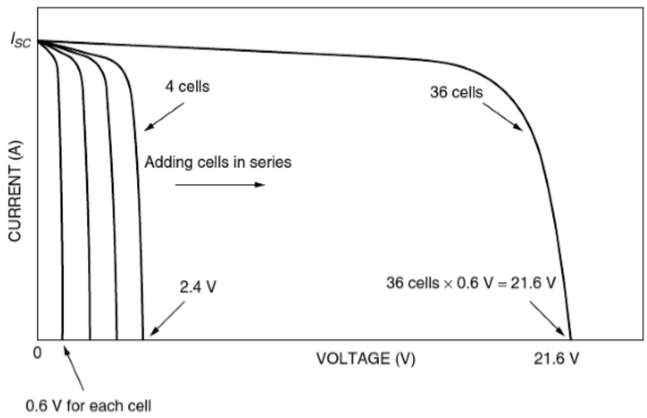


Figure 3.6: The I-V characteristics of a typical PV module consisting of 36 cells connected in series.[11]

$$Vmodule = n(Vd – IL \times Rs) \tag{3.6}$$

Where:

n: is the number pf PV cells connected in series in module.

Vd: is the voltage of the diode of the equivalent circuit of the cell [V].

3.1.5 Modeling Of Photovoltaic Array

The PV array are composed of some combination of series and parallel of PV modules. The modeling of pv arrays is the same as modeling of the PV module from the PV cells. Modules in series, the (I-V) curves are simply added along the voltage axis. The total voltage is just the sum of the individual module voltages.

For PV modules connected in parallel the total current is the sum of the currents of the modules whereby the total output voltage is equal to the voltage of the module, as shown in figure 3.7.[13]

For PV modules connected in series the total voltage is just the sum of the individual module voltages whereby the total output current is equal to the voltage of the module, as shown in figure 3.8.

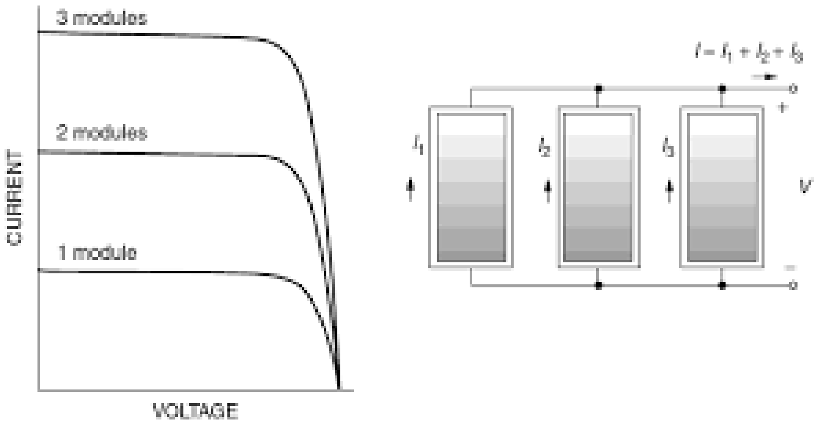


Figure 3.7: The I-V curve for 3 PV modules connected in parallel.[13]

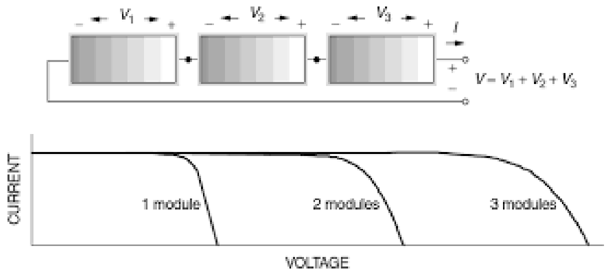


Figure 3.8: The I-V curve for 3 PV modules connected in series.[13]

Practically the PV array will consist of a combination of series and parallel modules depending on the needed output power of the system is needed.

3.1.6 Inverter

The inverter is a unit for converting direct current (DC) to alternating current (AC), which acts as the interface between the PV arrays and the utility grid[14]. In general, the inverters can be classified as in figure3.9.

- Central inverters
- String inverters
- Module integrated inverters (AC modules)
- Multi-string inverters

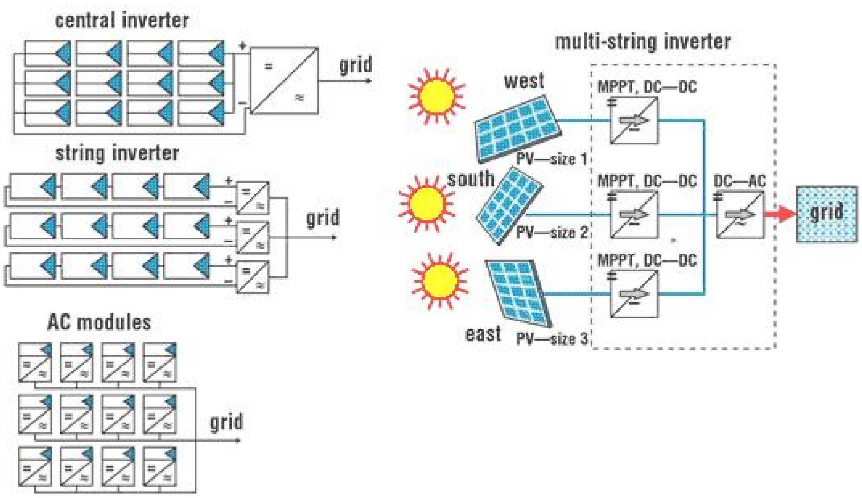


Figure 3.9: Basic design concepts for PV installations: central, string, multistring or AC module inverters.[14]

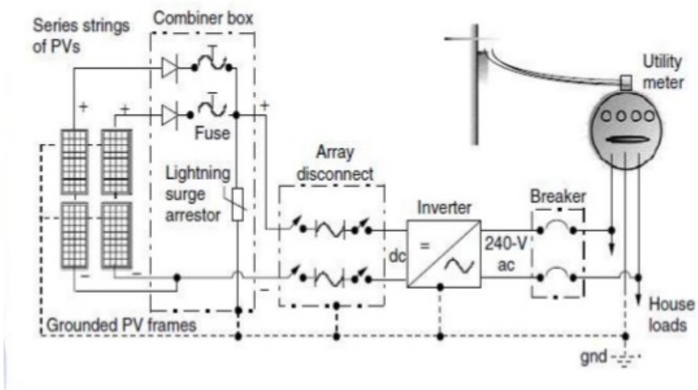


Figure 3.10: Principal components in a grid-connected PV system using a single inverter.[14]

3.2 Wind Energy Basics

3.2.1 Wind Energy and Wind Power

Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern wind turbines, can be used to generate electricity.[15]

Wind Power

Energy available in wind is basically the kinetic energy of large masses of air moving over the earth surface. Blades of the wind turbine receive this kinetic energy, which is then transformed to useful mechanical energy, which is then transformed further to mechanical or electrical energy depending on the end use.[16]
A wind rotor of cross sectional area A in m2 is exposed to wind stream with velocity V in m/s as depicted in figure 3.11 below

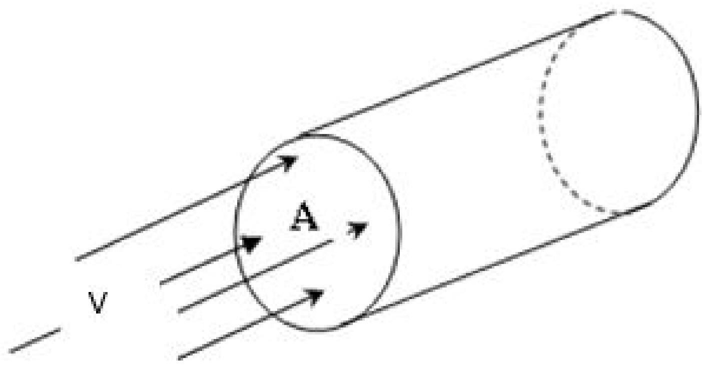


Figure 3.11: Air moving with velocity V m/s towards area A m^2.[16]

Wind is air in motion. An air mass flowing through an area $A(m^2)$ with a Velocity V(m/s) represents mass flow rate,

$$m = row \times A \times V \tag{3.7}$$

Kinetic energy per second or the power possessed by moving air is, therefore,

$$P_{wind} = \frac{1}{2} \times m \times V^2 \tag{3.8}$$

Substituting for mass flow rate in the equation for power in the wind,

$$P_{wind} = \frac{1}{2} \times row \times A \times V^3 \tag{3.9}$$

As shown in the equation above, the power of the wind is proportional to the cube of the wind speed. This means that if the wind speed is doubled the power of the wind will become eight fold.

The most accurate estimate for wind power density is given by following equation,

$$P = \frac{1}{2} \times A \times \frac{1}{n} \sum_{j=1}^{n} (row_j \times V_j^3) \tag{3.10}$$

Where n is the number of wind speed reading and rowj and Vj are the jth reading of the air density and wind speed. As shown in the equation output power is related to the area intercepting the wind, i.e. area swept by the wind turbine rotor. For horizontal axis turbine, the rotor swept area is,

$$A = \frac{\pi}{4} \times D^2 \tag{3.11}$$

Where, D is the rotor diameter in meters. Relatively small increases in blade length or in rotor diameter produce a correspondingly bigger increase in the swept area, and therefore in power. The wind turbine with the larger rotor will generate more electricity than a turbine with a smaller rotor.[16]

3.2.2 Wind Turbines

Wind turbines, like aircraft propeller blades, turn in the moving air and power an electric generator that supplies an electric current. Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.[15]

Wind Turbine Types

Modern wind turbines fall into two basic groups;

- Horizontal-axis.
- Vertical-axis.

Turbine Components

Horizontal turbine components include:

1. Blade or rotor, which converts the energy in the wind to rotational shaft energy.
2. A drive train, usually including a gearbox and a generator.
3. A tower that supports the rotor and drive train, and other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.[15]

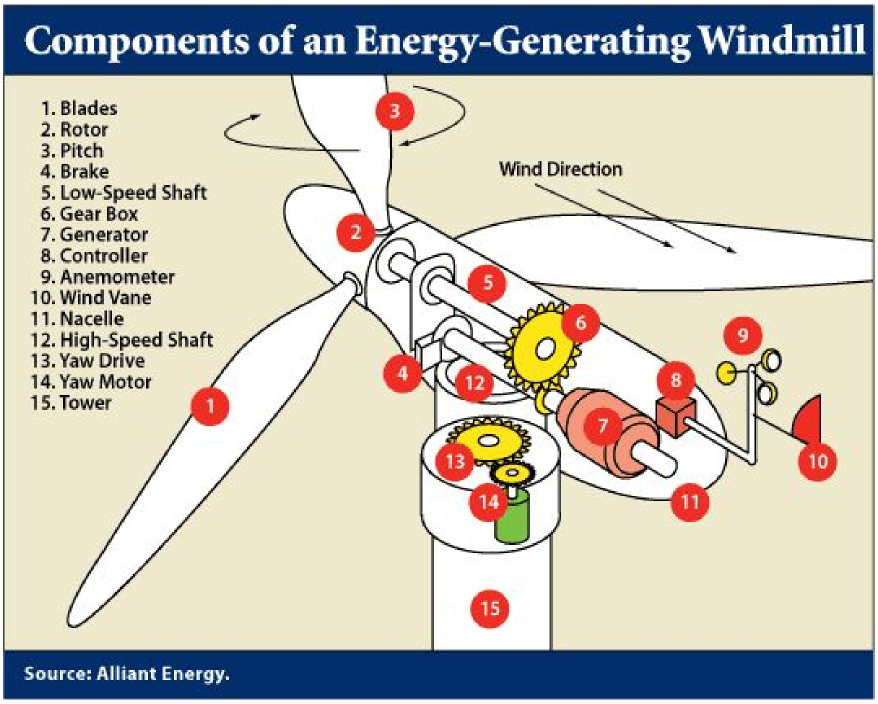


Figure 3.12: Wind turbine components.[15]

3.3 Diesel-Generator

3.3.1 What is a Diesel-Generators

A diesel-generator set is the combination of a diesel engine with an electric generator (often an alternator) to generate electrical energy. A diesel compression-ignition engine often is designed to run on fuel oil, but some types are adapted for other liquid fuels or natural gas. Diesel generating sets are used in places without connection to a power grid, or as emergency power-supply if the grid fails, as well as for more complex applications such as peak-lopping, grid support and export to the power grid.[17]

3.3.2 How does a Diesel Generator create Electricity

A diesel generator converts mechanical energy (movement) into electrical power, and channels it through power cables. It can be helpful to imagine electricity flowing through wires in much the same way water flows through pipes. A generator can be thought of as a kind of 'electrical pump' which causes the electricity to flow through the wires. It doesn't actually create or destroy the electrons that flow through the wires any more than a water pump creates new water. It just causes it to move in a useful fashion.[17]

3.3.3 Component Of Diesel Generator

1. The Engine
2. The Alternator
3. The Fuel System
4. The Voltage Regulator
5. The Cooling System
6. The Exhaust System
7. The Lubrication (oil) System

8. The Starter & Battery System

9. The Control Panel

10. The frame/Housing

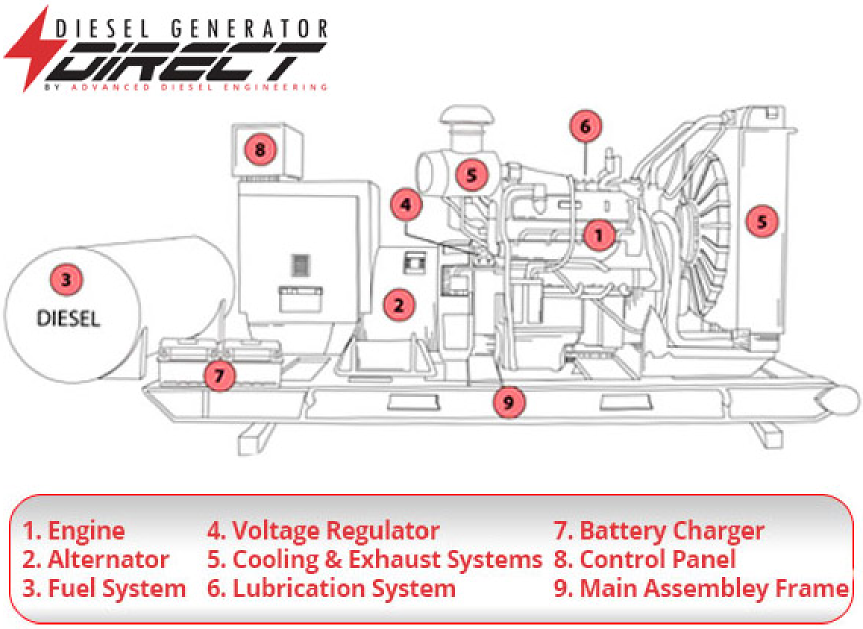


Figure 3.13: Component of Diesel Generator.[17]

3.4 Battery in Hybrid System

3.4.1 Battery

Batteries are an important element in any stand-alone PV system but can be optional depending upon the design. Batteries are used to store the solar-produced electricity for night time or emergency use during the day. Depending upon the solar array configuration, battery banks can be of 12V, 24V or 48V and many hundreds of amperes in total.[18]
There are certain specifications you should use when evaluating your solar battery options, such as how long the solar battery will last or how much power it can provide. Below, learn about all of the criteria that you should use to compare your home energy storage options, as well as the different types of solar batteries.[19]

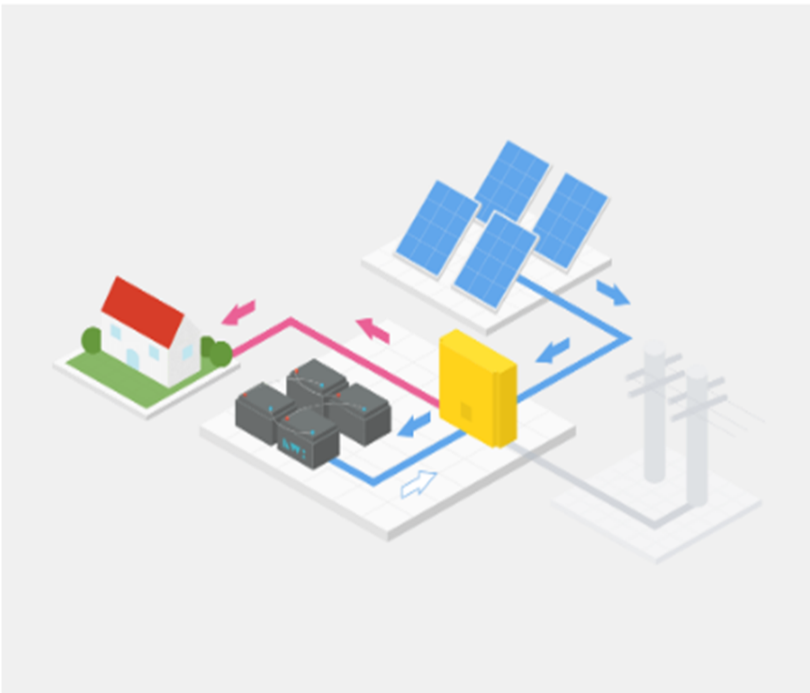


Figure 3.14: Battery in hybrid system.[19]

3.4.2 Basic battery parameters

A battery 'cycle' means a single sequence of battery charging and discharging. Lead-acid batteries can be divided into two types - 'deep-cycle' and 'shallow-cycle'.[20]

Deep-cycle: batteries are designed for deep discharges and are used in solar power systems, while shallow-cycle batteries are not designed for deep discharge and are intended for use in cars and vehicles. The advantage of a shallow-cycle battery is its ability to provide a high starting current which is not a primary requirement in a solar panel system. Instead, for solar panel system much more important is the battery's ability to be discharged at least down to 50% and be recharged many times over a couple of years. Therefore, you could use an automotive battery for your solar system but you should be careful not to discharge it deeply, which presents an obvious inconvenience.[20]

Capacity: is the amount of energy a battery can store.
Capacity is measured in amp-hours (Ah).It should be noted that the rate at which a battery is discharged affects its capacity.[20]

Charging current: is the current supplied by the solar panel to the battery and stored in it. Lower charging currents (about 5% of the capacity) are better for a battery. A rule of a thumb is that the maximum current during battery charging should not exceed one-tenth of its capacity.However, some solar batteries, i.e. Li-Ion solar batteries, can withstand charging currents higher than one-tenth of their capacity without the substantial decrease in their lifespan.
Another important battery parameter is 'state of charge'.The state of charge measures the energy remaining in the battery. A fully charged battery means a 100% state of charge, while a half-charged battery means a 50% state of charge. Alternatively, this can be denoted by 'depth of discharge' (DoD) indicating how much a battery is discharged before it is charged again. Therefore, a state of charge of 80% and a depth of discharge of 20% refer to the same battery state.[20]

Self-discharge: is a process where batteries lose charge as a result of being left uncharged for a long period. Such a process depends on the temperature but also on the type, condition, and age of the battery.[20]

Chapter 4

Methodology

This chapter will make a load analysis in different time periods and different seasons, collect the data of solar and wind speed, build the structure of the hybrid energy system, analyze the parameter and price of system component parts, form different schemes of the system, and identify the optimized model.

4.1 Load Calculation

In this project, a hybrid energy system will be designed to supply electricity for PPU university in hebron.The first step is to make the load calculation in different time periods and different seasons. The following table 4.1 display the monthly consumption for PPU campus in Wadi Al-Haruya .

Table 4.1: Monthly load for PPU

Month	Consumption(KWh)	Cost (bill)($)
January	61552	11,969
February	62388	12,131
March	58665	16,657
April	67912	13,205
May	73967	14,382
June	65287	12,694
July	50348	9,790
August	46752	9,090
September	68757	13,369
October	60998	11,860
November	74917	14,567
December	68624	13,343
Total	787167	153,057

From the load analysis,Average daily load is 2156.4 KWh ,the daily load estimation plots and the monthly load estimation plot can be represented as Figures 4.1 and 4.3 respectively. Appendix B presents the hourly load day for PPU Campus in Wadi al Haruya for four days in March during 24 hour. The load was calculated the main metering by VEGA78 at 5-March, 6-March, 7-March, and 9-March.

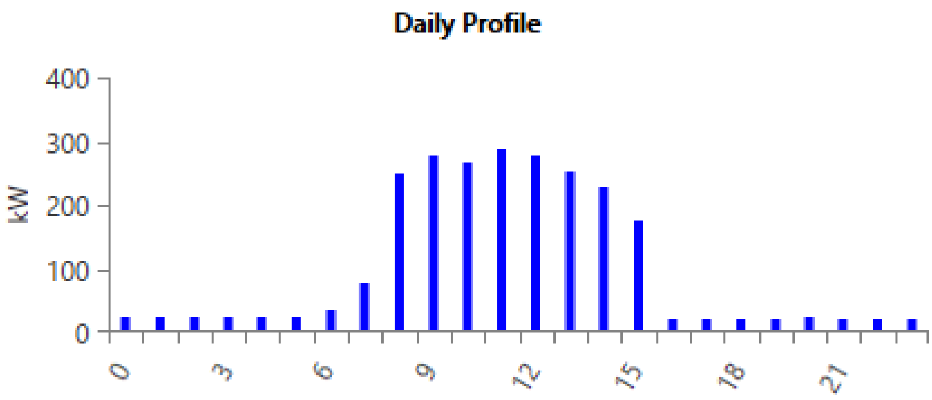


Figure 4.1: Daily load.

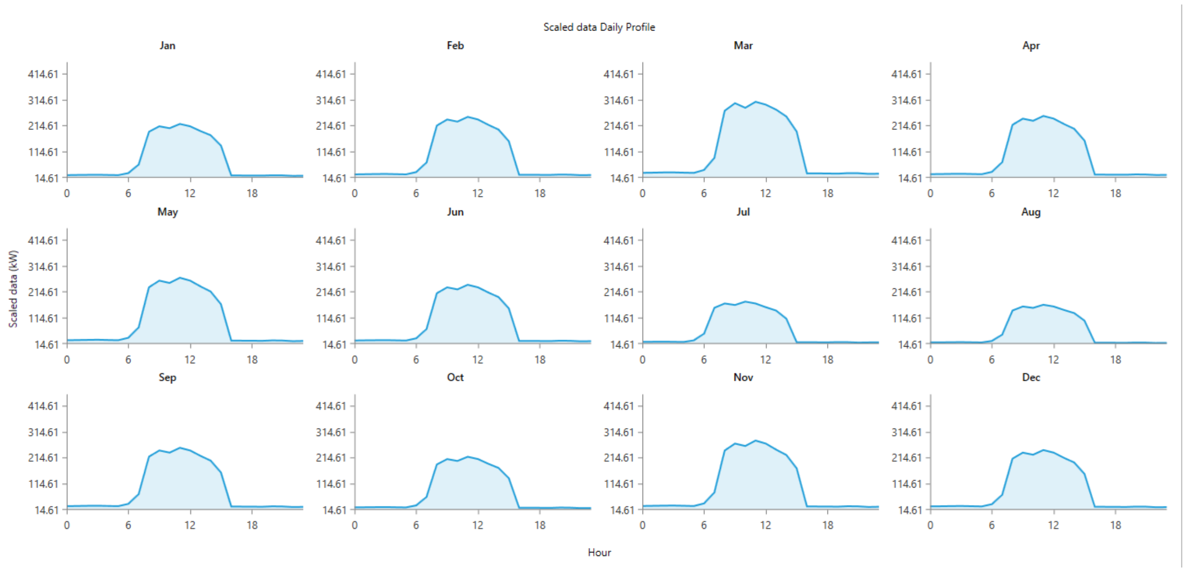


Figure 4.2: Daily load-profile

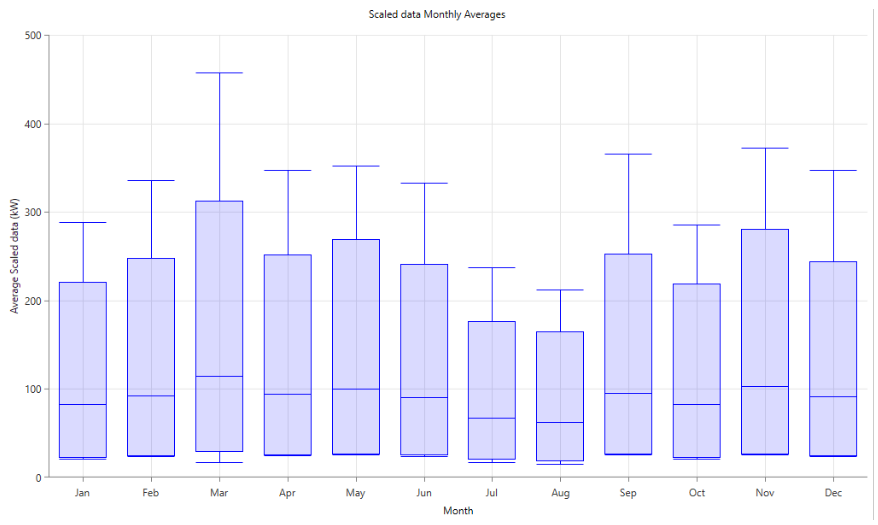


Figure 4.3: monthly-load

4.2 Location of PPU Campus

Palestine Polytechnic University is located in Hebron , where the site was studied for longitude and width as shown in the following aerial photograph. Location of each building:

- B and B+: latitude 31° 30' 31.664462" N
  Longitude 35° 5' 30.74690" E

- A : latitude 31° 30' 31.64464" N
  Longitude 35° 5' 30. 74690" E

- C : latitude 31° 30' 26.16378" N
  Longitude 35° 5' 27.40563" E

- A+ : latitude 31° 30' 31.64464" N
  Longitude 35° 5' 30. 74690" E

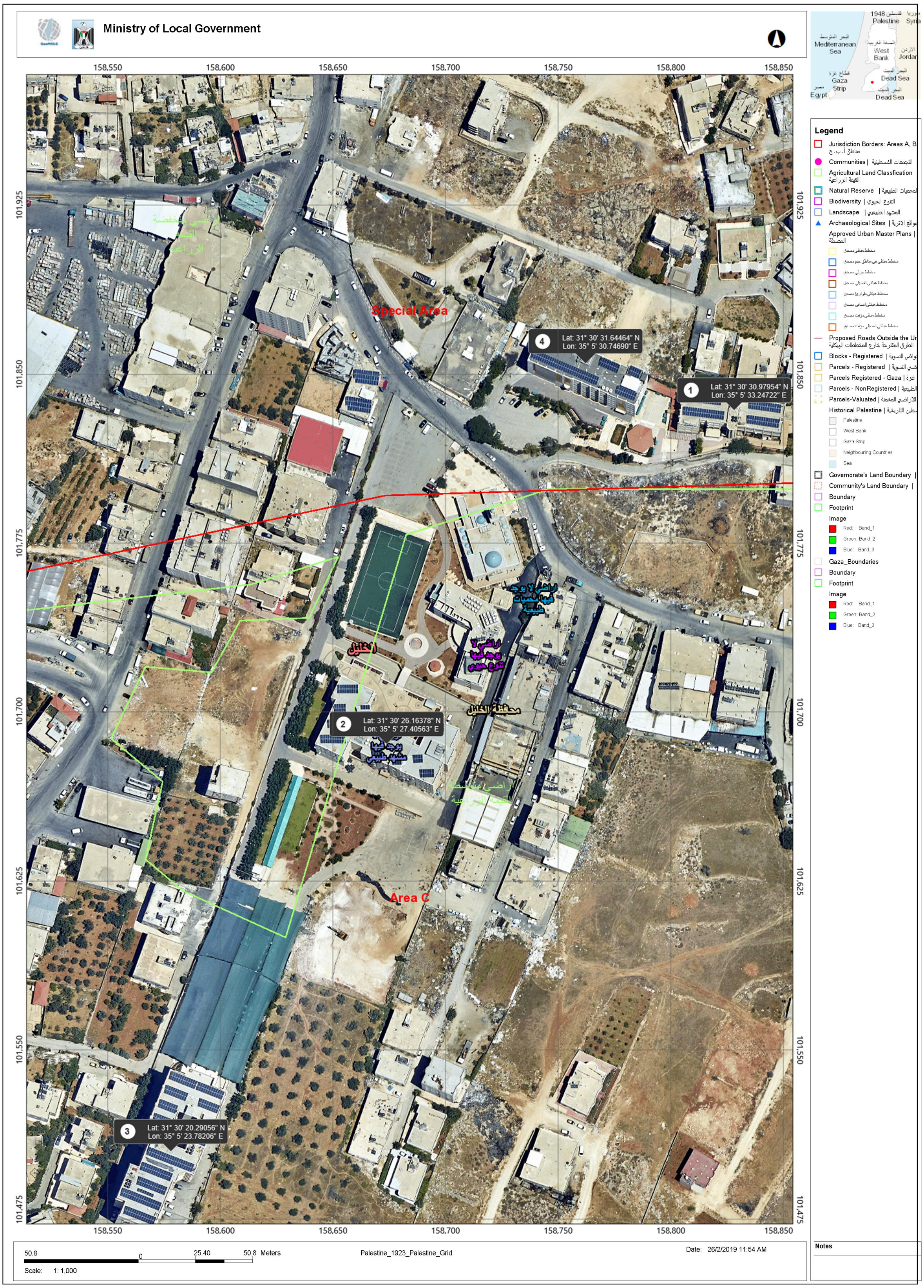


Figure 4.4: Aerial photograph of Palestine polytechnic university

4.3 Solar Radiation in Palestine

The National Aeronautics and Space Administration (NASA) provides the solar radiation data for PPU as in the follow table4.2. From the above data, the solar radiation plot can be

Table 4.2: Solar Radiation for PPU

Month	Clearaness Index	Daliy Radiation(KWh/m^2/day)
January	0.503	2.850
February	0.511	3.540
March	0.553	4.760
April	0.599	6.080
May	0.628	6.980
June	0.678	7.770
July	0.669	7.530
August	0.637	6.670
September	0.626	5.700
October	0.563	4.170
November	0.534	3.170
December	0.499	2.630

drawn as the Figure4.5. The annual average solar radiation is 5.15 $\frac{kWh}{m^2d}$

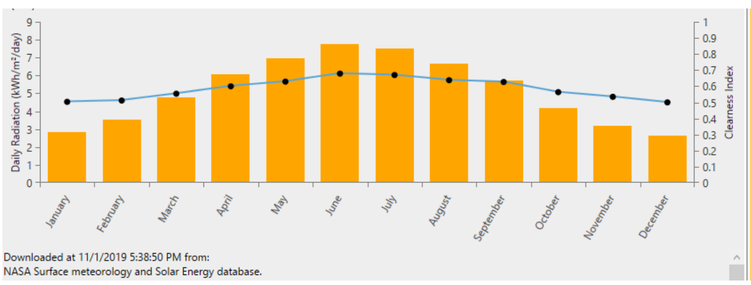


Figure 4.5: PPU monthly average solar radiation data.

4.4 Distribution PV in building

4.4.1 The Overall Structure Of The PV System

The main system components:

- 325 W photovoltaic modules poly crystalline total number 708.
- Transform less inverter 24 kwp total number 10.
- Anodized aluminum structure.

Plant Information		
Plant Power	Pitch	Location
DC 230.1 KWp/ AC 200 KVA	25°	PS-705 Hebron
Inverter		
Qty.	Manufacturer	Type
10	KACO	200L32
Modules		
Qty.	Manufacturer	Type
708	Hanwha Qcell	Q.Power L-G5-325W

Figure 4.6: Photovoltaic cell information.[21]

- The type of PV: Hanwha Q. power l-G 5 -325 W.

Figure 4.7: Hanwha Q cell[21].

4.4.2 Inverter Technical Data

- KACO new energy is a German manufacturer of solar PV inverters.
- one of the world's largest manufacturers in the PV business.
- The company developed the first transformer less inverter for feeding direct energy into the grid.
- KACO new energy has sold over half a million inverters resulting in a clean energy output of nearly 7 Gigawatts across the globe.

Figure 4.8: KACO Inverter.[21]

4.5 System capacity overview

4.5.1 Building B and B+

- The capacity of the system on the surface of B & B+ is equal to 94.9 KWp.
- The surface area of the building is $1465m^2$.
- The area is sufficient to install 292 solar panels .
- The capacity of the single solar panel is equal to 325 watts.
- 4 inverter with a capacity of 24 KWp are used for each inverter.
- The expected yearly yield = 150.4 Mwh/y.
- This system has been distributed to 16 string each 4 string located on each inverter and each MPPT have 2 string.

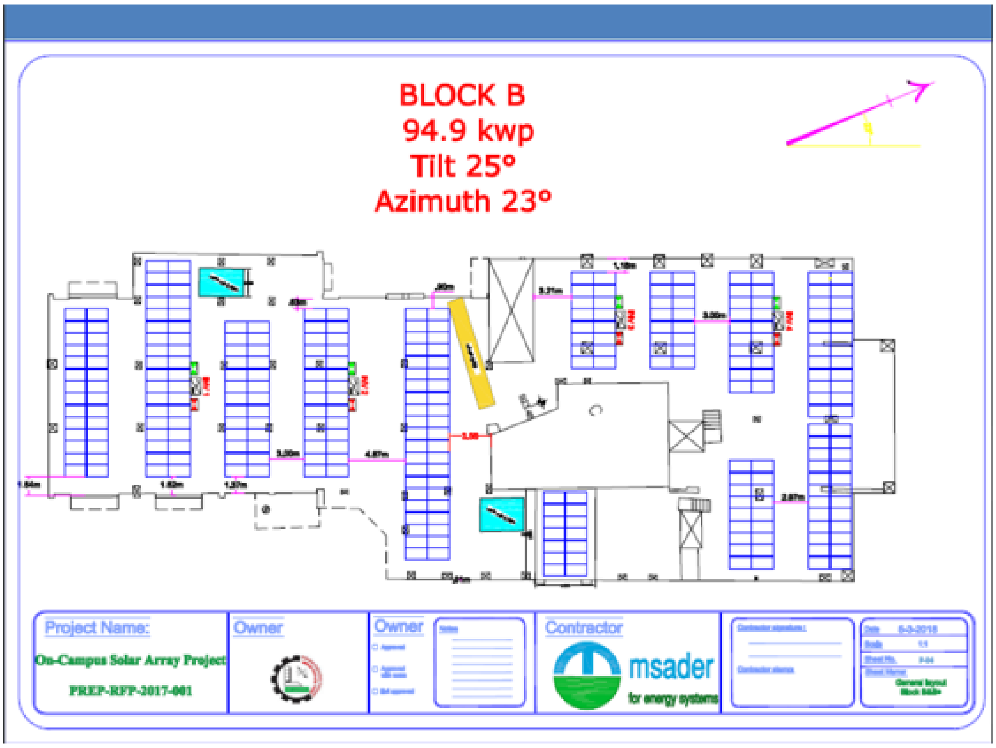


Figure 4.9: Solar cell distribution schemes on building B.[21]

4.5.2 Building A+

- The capacity of the system on the surface of A+ is equal to 46.8 KWp.
- The surface area of the building is $650m^2$.
- The area is sufficient to install 144 solar panels .
- The capacity of the single solar panel is equal to 325 watts.
- 2 inverter with a capacity of 24 KWp are used for each inverter.
- The expected yearly yield = 74 MWh/y.
- This system has been distributed to 8 string each 4 string located on each inverter and each MPPT have 2 string.

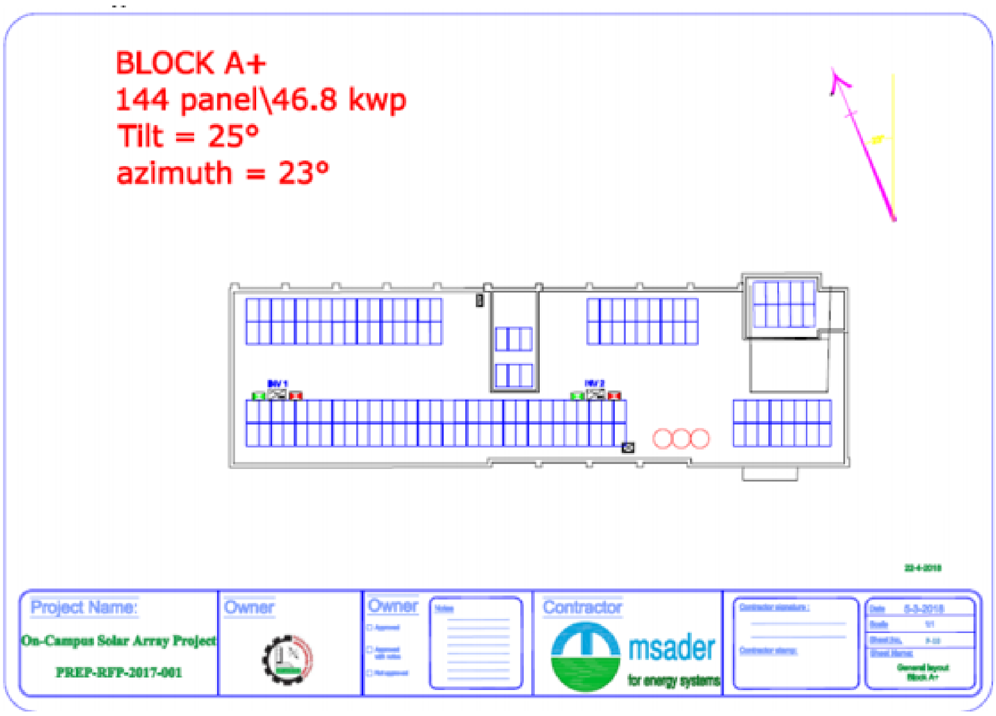


Figure 4.10: Solar cell distribution schemes on building A+.[21]

4.5.3 Building A

- The capacity of the system on the surface of A is equal to 40.95 KWp.
- The surface area of the building is 608 square meters.
- The area is sufficient to install the number solar panels 126.
- The capacity of the single solar panel is equal to 325 watts.
- 2 inverter with a capacity of 24 KWp are used for each inverter.
- The expected yearly yield = 67.56 MWh.
- This system has been distributed to 8 string each 4 string located on each inverter and each MPPT have 2 string.

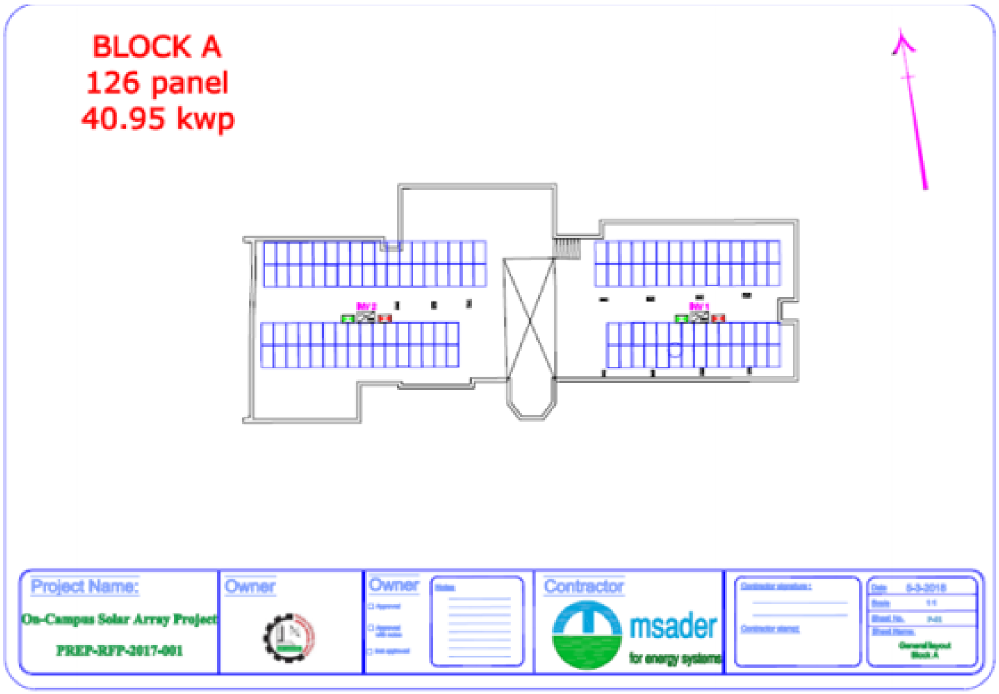


Figure 4.11: Solar cell distribution schemes on building A.[21]

4.5.4 Building C

- The capacity of the system on the surface of C is equal to 47.45 KWp.
- The surface area of the building is 1200 square meters.
- The area is sufficient to install the number solar panels 146.
- The capacity of the single solar panel is equal to 325 watts.
- 2 inverter with a capacity of 24 KWp are used for each inverter.
- The expected yearly yield = 77 MWh.
- This system has been distributed to 8 string each 4 string located on each inverter and each MPPT have 2 string.

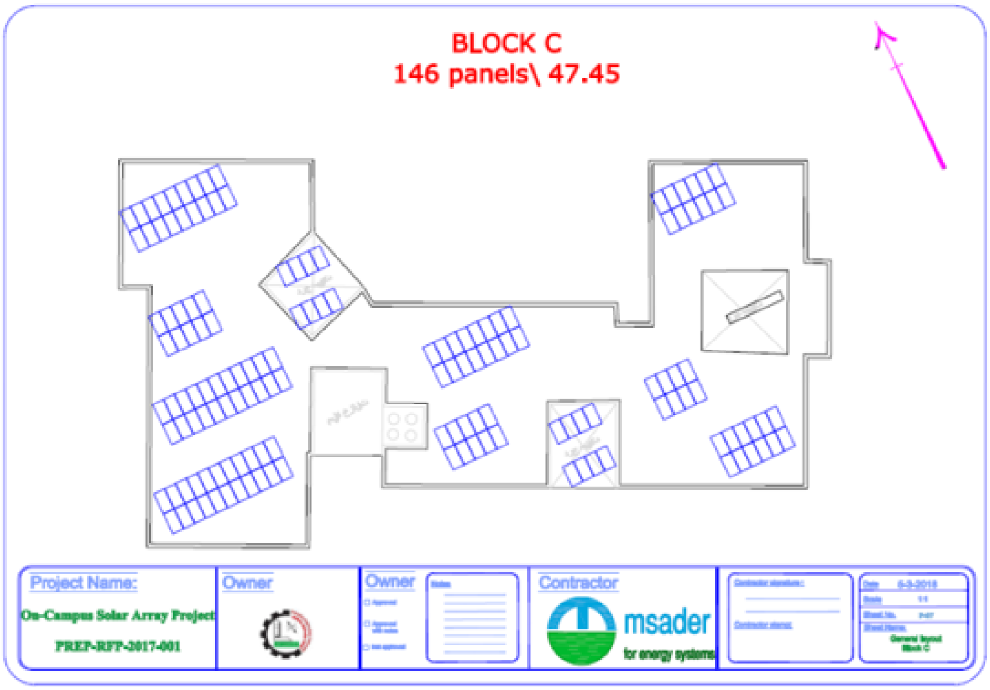


Figure 4.12: Solar cell distribution schemes on building C.[21]

4.6 The Collection of Wind Speed Data

The National Aeronautics and Space Administration (NASA) provides the wind speed data for PPU as Table4.3.

Table 4.3: Wind speed data for PPU

Month	Avarge (m/s)
January	5.630
February	5.810
March	5.980
April	5.520
May	5.190
June	5.230
July	5.230
August	4.960
September	4.610
October	4.620
November	4.620
December	5.230

From the above data, the wind speed plot can be drawn as the Figure4.13 The annual average wind speed is 5.22m/s.

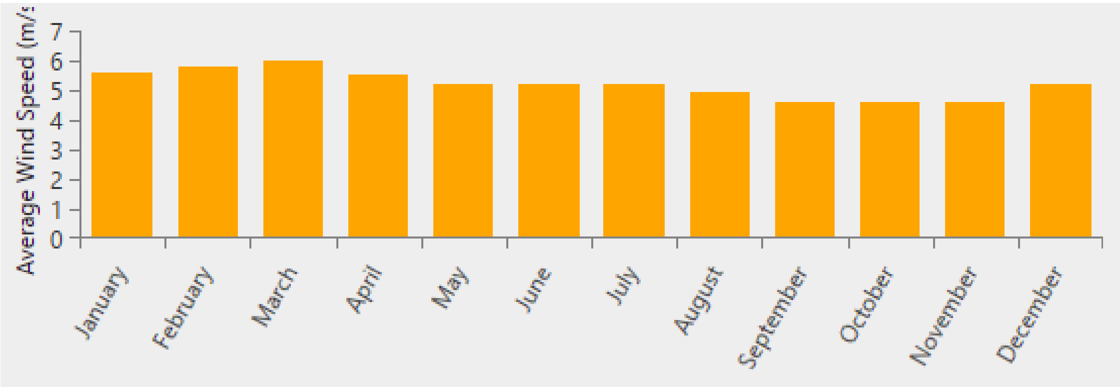


Figure 4.13: Monthly wind speed plot.

4.6.1 Wind Turbine

In this project, the 6-kW wind turbine made by Bergey Excel will be used to build the hybrid renewable system. The technical specification for WT of 6kW from Bergey Excel adopted in this work is illustrated in the table4.4.

Table 4.4: Technical parameters of Wind Turbine Specification.[22]

Parameter	Specification
Power (W)	6000
Diameter (m)	6.2
Cut in wind speed m/s	2.5
Rated wind speed Vr(m/s)	9

The total energy delivered from each turbine about 9,920 kWh/year at 5m/s.[22]
Based on the above data, the Bergey Excel 6 kW wind turbine characteristic curve is shown as the Figure 4.14.

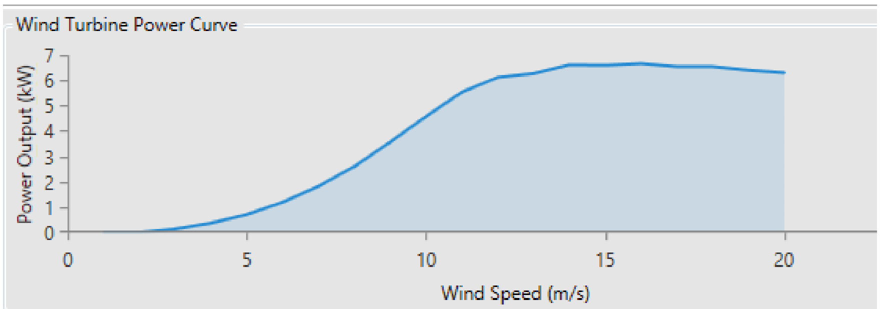


Figure 4.14: The characteristic curve of 6kW turbine.

4.6.2 Distribution of Wind Turbines

Distribution of wind turbines depends on rough rules of tower spacing of such rectangular arrays. Recommended spacing is 3-5 rotor diameters separating towers within a row and 5-9 diameters between rows, the offsetting, or staggering on one row behind another, the distribution WT on top roof of four main buildings [23]. The maximum capacity of Wadi El Hariya PPU rooftops for the WT system is about 70 kW. Figure 4.15 shows the distribution of WT on the top roof of buildings A, A+, C, B and B+ respectively. Every wind turbine needs an area about 46 m^2 for fixing tower[24].

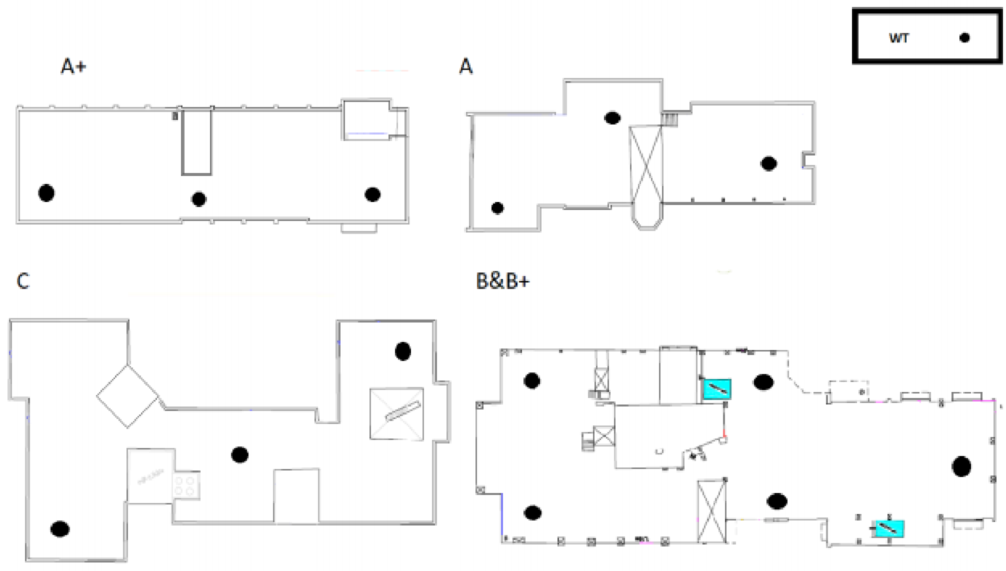


Figure 4.15: wind turbine distribution.

4.7 Battery Bank

A battery bank, composed from several identical batteries connected in series and/or parallel, must be sized correctly in order to obtain the desired capacity taking into account the load and the excess energy provided by PV-wind power system. Considering the profile of the energy consumption and the power curve generated by the wind, it was deduced that the maximum difference between these two profiles is about 172kW. The preliminary design must provide the installation of a battery bank able to absorb this maximum power.

After reviewing excess energy profile , it was found that this value is repeated only eight times a year, so this value was ignored when designing the size of the battery system and taking another value which is more frequent in the year which is 150 kW.
In this project battery (BAE PVS Block 6V 420) made by (BAE Batterien GmbH (BAE)) will be used to build the hybrid power system the technical specification for BAE battery adopted in this project is illustrated in table 4.5.

Table 4.5: Technical parameters of Battery Specification.

Parameter	Specification
Nominal voltage	6 V
Nominal capacity	2.61 KWh
Maximum Capacity	434Ah
Roundtrip efficiency	85%
Max Charge current	66.8 A
Max Discharge current	610 A

4.7.1 State of charge and discharge of Battery

The power conversion efficiencies in charging and discharging processes are represented by the mathematical model.[25]

$$P_{bb} = (P_{ren} - P_D)\eta_{chg} \quad (P_{ren} >= P_D) \tag{4.1}$$

$$P_{bb} = \frac{P_{ren} - P_D}{\eta_{dsg}} \quad (P_{ren} < P_D) \tag{4.2}$$

Where:

P_{bb} :excess power

P_{ren} :Power form PV and Wind turbine.

P_D : Power Demand.

η_{chg}:The charging efficiency.

η_{dsg}:The discharging efficiency.

When both the renewable source (solar and wind) power, is higher than the load demand over a definite period of time, then the surplus power is utilized as charging the battery and the battery bank discharge, if the generated renewable power is higher than the load demand.[25]

The capacity of battery bank (C_{bb}):

$$C_{bb} = \frac{Max \quad P_{bb}(t)}{MDOD} \tag{4.3}$$

where,

C_{bb}:Capacity of battery bank.

$MDOD$:Maximum Depth of discharge of battery.

4.7.2 Battery bank sizing

A battery bank system must able to capable of absorbing the maximum value of surplus power.

$$Usable \quad storage \quad capacity \quad (Ah) = \frac{Max \quad P_{bb}}{V_{sys} \times \eta} \times Days \quad of \quad storage \tag{4.4}$$

$$Total \quad storage \quad capacity = \frac{Usable \quad storage \quad capacity \quad (Ah)}{MDOD} \tag{4.5}$$

$$Num \quad of \quad string = \frac{Total \quad storage \quad capacity}{Capacity \quad of \quad a \quad single \quad battery \quad (Ah)} \tag{4.6}$$

$$Number \quad of \quad batteries \quad in \quad series = \frac{System \quad voltage}{Nominal \quad battery \quad voltage} \tag{4.7}$$

where :

η :Over all efficiency.

V_{sys} :DC voltage system .

The number of sting is 25 ,every string has 8 batteries.

4.8 Diesel Generator

In this project the load following strategy will be use to build hybrid system where it is a dispatch strategy whereby whenever a generator operates, it produces only enough power to meet the primary load. Lower-priority objectives such as charging the storage bank or serving the deferrable load are left to the renewable power sources. The generator can still ramp up and sell power to the grid if it is economically advantageous.

In this project the size of generator is 500KW.The size of the generator was determined through load Profile and the Renewable power Profile.

$$P_G = MAX(P_D - (P_{ren} + P_b)) \tag{4.8}$$

Where the max difference is 423.5kW,And to be more reliable a 500 kW generator was selected.

In this project one or more generators with a total capacity of 500 kW will be developed and the results of each case will be studied. The type of generator that will be used in this project is from Generic. HOMER has the data for generic diesel generators built in.and its specifications are shown in the following table 4.6.

Table 4.6: Technical parameters of Battery Specification

Parameter	Specification
Power	500KW
Fuel carve Intercept	L/h
Fuel carve slope	L/h/kw
Density	830kg/m3
Lifetime	150000h

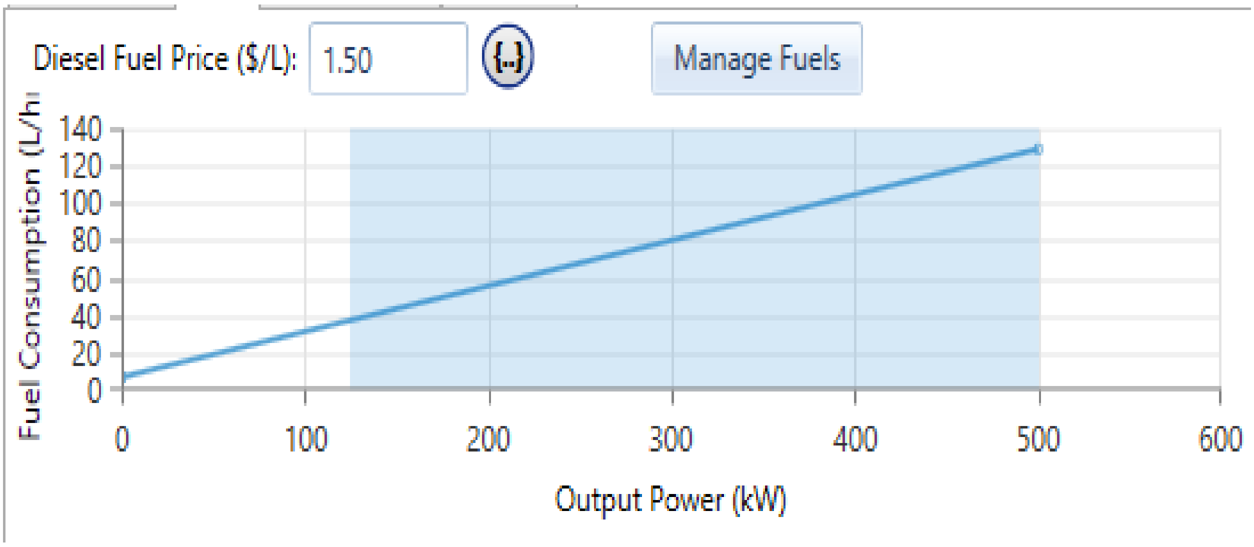


Figure 4.16: Fuel consumption curve of the Diesel Generator.

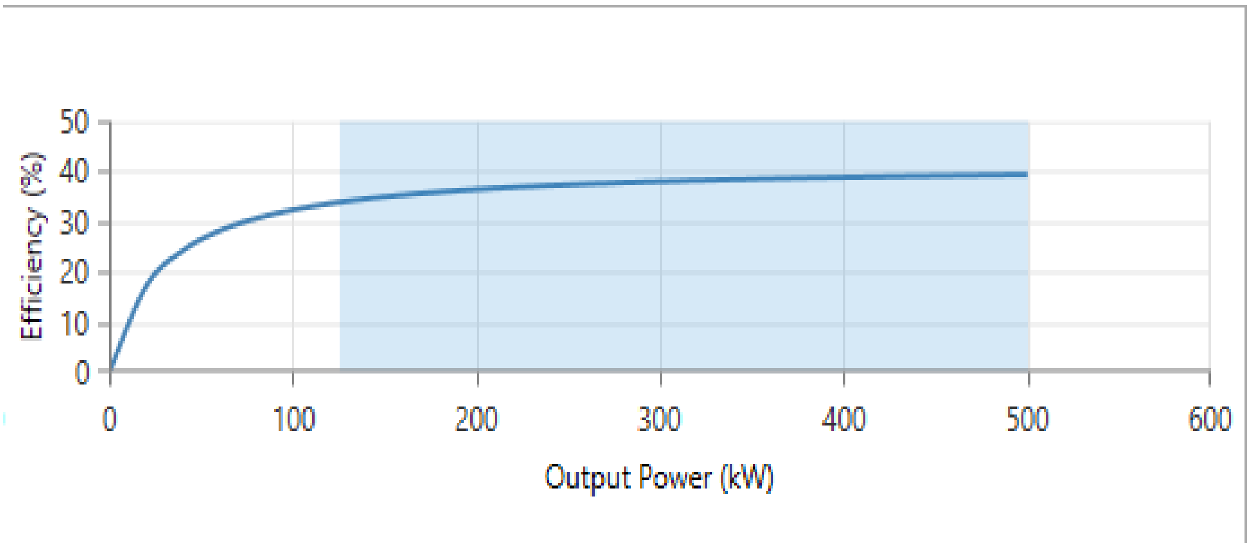


Figure 4.17: The typical efficiency curve of the Diesel Generator.

4.9 Modeling of Energy Cost

4.9.1 Levelized cost of energy

HOMER defines the levelized cost of energy (COE) as the average cost per kWh of useful electrical energy produced by the system.

Units: \$/kWh.

Symbol: COE.

To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served, using the following equation:

$$COE = \frac{(C_{ann,tot} - C_{bolier} H_s erved)}{E_s erved} \tag{4.9}$$

Where:

$C_{ann,tot}$: Total annualized cost of the system [$/yr].

C_{boiler} : Boiler marginal cost [$/kWh].

H_{served} : Total thermal load served [kWh/yr].

E_{served} : Total electrical load served [kWh/yr].

4.9.2 Total annualized cost

The total annualized cost is the annualized value of the total net present cost. HOMER calculates the total annualized cost using the following equation:

$$C_{ann,tot} = CRF(i, R) \times C_{NPC,tot} \tag{4.10}$$

Units: $/year.
Symbol: $C_{ann,tot}$.
where:

$C_{NPC,tot}$: The total net present cost [$].

i : The annual real discount rate [%].

R_{proj} : The project lifetime [yr].

CRF : A function returning the capital recovery factor.

HOMER uses the total annualized cost to calculate the levelized cost of energy.

4.9.3 Total electrical load served

The total electrical load served is the total amount of energy that went towards serving the primary and deferrable loads during the year, plus the amount of energy sold to the grid. HOMER calculates the total electrical load served using the following equation:

$$E_{served} = E_{served,ac} + E_{served,ds} \tag{4.11}$$

Units: kWh/yr.
Symbol: Eserved.
where:
$E_{served,primAC}$: AC primary load served [kWh/yr].

$E_{served,primDC}$: DC primary load served [kWh/yr].

- DC primary load served :The DC primary load served is the total amount of energy that served the DC primary load(s) during the year.

- AC primary load served :The AC primary load served is the total amount of energy that went towards serving the AC primary load(s) during the year.

- Deferrable load served :The deferrable load served is the total amount of energy that served the deferrable load during the year.

4.9.4 Total Net Present Cost

The total Net Present Cost (NPC) of a system is the present value of all the costs the system incurs over its lifetime, minus the present value of all the revenue it earns over its lifetime. Costs include capital costs, replacement costs,operating and maintenance(O&M) costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue. HOMER calculates the total NPC by summing the total discounted cash flows in each year of the project lifetime.
The total NPC is HOMER main economic output, the value by which it ranks all system configurations in the optimization results, and the basis from which it calculates the total annualized cost and the levelized cost of energy.

Units: $.

Symbol: C_{NPC} .

4.9.5 Real discount rate

The real discount rate is used to convert between one-time costs and annualized costs. HOMER calculates the annual real discount rate (also called the real interest rate or interest rate) from the "Nominal discount rate" and "Expected inflation rate" inputs. HOMER uses the real discount rate to calculate discount factors and annualized costs from net present costs.

Users can enter the nominal discount rate and the expected inflation rate in the Economics page under the Projects tab. HOMER uses the following equation to calculate the real discount rate:

$$i = \frac{(i' - f)}{(1 + f)} \tag{4.12}$$

Where:

i: Real discount rate.

i' : Nominal discount rate (the rate at which you could borrow money).

f : Expected inflation rate.

Units: %.

Symbol: i.

4.9.6 Replacement Cost

The replacement cost is the cost of replacing a component at the end of its lifetime, as specified by Lifetime parameter in the component model. This cost can be different than the initial capital cost for several reasons.

4.9.7 Project lifetime

The Project lifetime is the length of time over which the costs of the system occur. HOMER uses the project lifetime to calculate annualized costs from net present costs. HOMER assumes that salvage values occur at the end of the project lifetime. You enter the project lifetime on the Economics page under the Projects tab.

Units: yr.

Symbol:R_{proj}.

4.9.8 Capital Recovery Factor

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is:

$$CRF(i,N) = \frac{i(1+N)^N}{(1+i)^N - 1} \tag{4.13}$$

Where:

i = Real discount rate.

N = Number of years.

Chapter 5

Simulation

The hybrid power system has been analyzed With HOMER. Homer optimization results indicate that the hybrid system capable of producing lowest cost electricity from several scenarios that consist (PV ,Wind Turbine ,Diesel Generator,Battery bank and Main Grid).

5.1 Photovoltaic System and Main Grid Results

From Homer Pro analysis PV system able to generate 363,883 kWh/y,which able to cover 47% from load of PPU, PV have a mean output 997 KWh per day.
Table 5.1 summarize the PV run statistics.

Table 5.1: PV run statistics.

Quantity	Value	Units
Total production	363,883	kWh/year
Mean output power	41.5	kW
Mean output work	997	kWh/day
Minimum output	0	kW
Maximum output	212	kW
Hours of operation	4,390	hour/year

The following figure5.1 show PV output during a year.

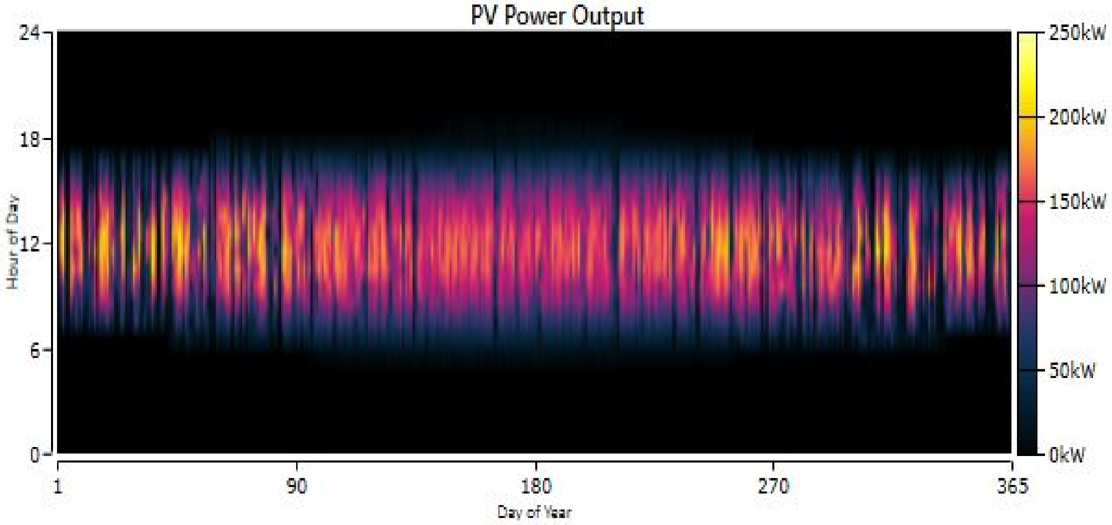


Figure 5.1: PV output during a year.

The following figure 5.2 presents relation between PV system ,Grid and load.As shown in this figure, the relationship between the components of the system is complementary, for example when there is sufficient energy to meet the load from PV system, the energy coming from the grid is zero, and at the same time when there is excess energy from the PV goes to the Grid and reverse true.

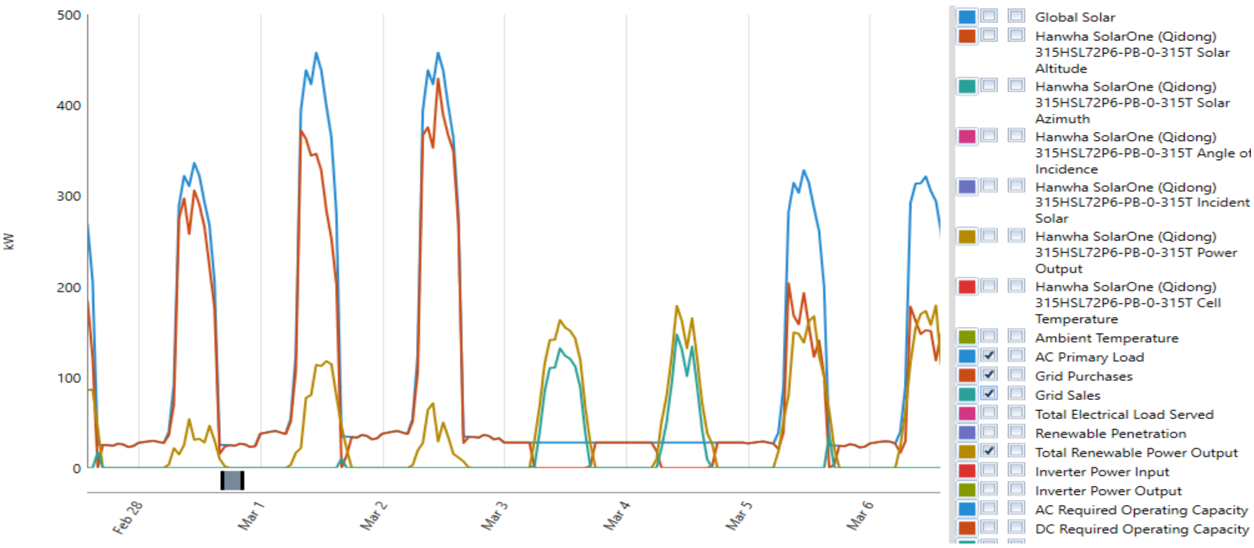


Figure 5.2: relation between PV system ,Grid and load.

Table 5.2: Solar energy system with Grid .

Type of generator	Product	Capacity KW	output KWh per year	NPC$	%
PV	Q cell	230	363,883	1,399,929	47
Grid	From company	999999	509,804	2,035,068	53

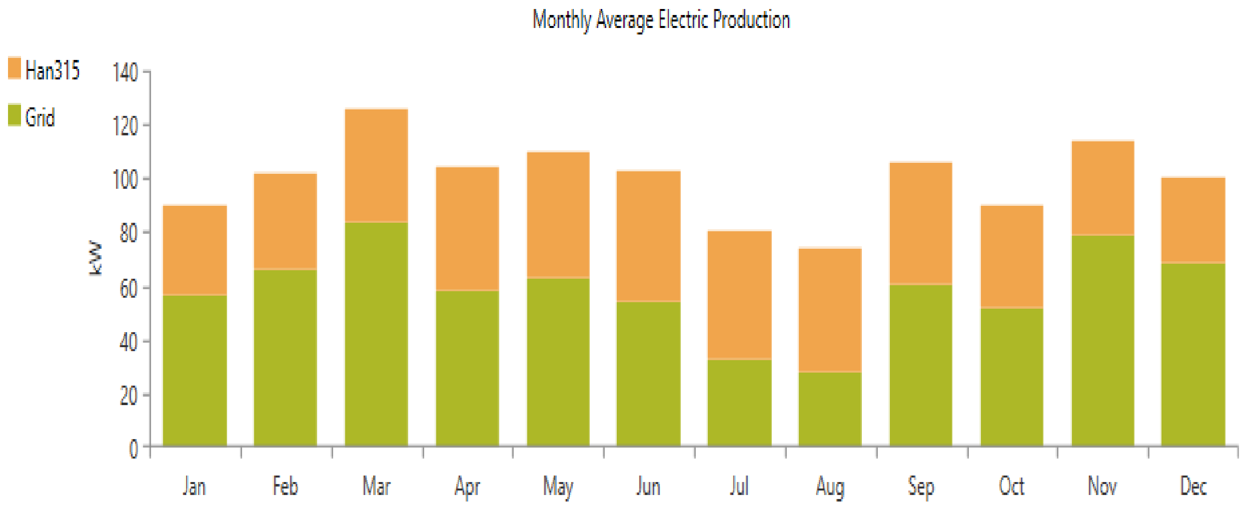


Figure 5.3: Monthly Average Electric Production.

The total cost of the PV system is 331,049$ which includes capital cost and operating and management in the case study of PPU.[24] The following table summarizes economic data for PV system .

Table 5.3: Cost summary of PV generation system.

Generator Type	Capital Cost ($)	OMC ($)	RC ($)	Total cost ($)	Energy cost($/kWh)
PV	239,890	57,574	57,574	331,049	0.0452

The Levelized COE for all this system 0.1234 $\$/KWh$.

The Discounted payback period of investment starts after 4 years & The Simple payback period of investment starts after 3 years and 4 months .

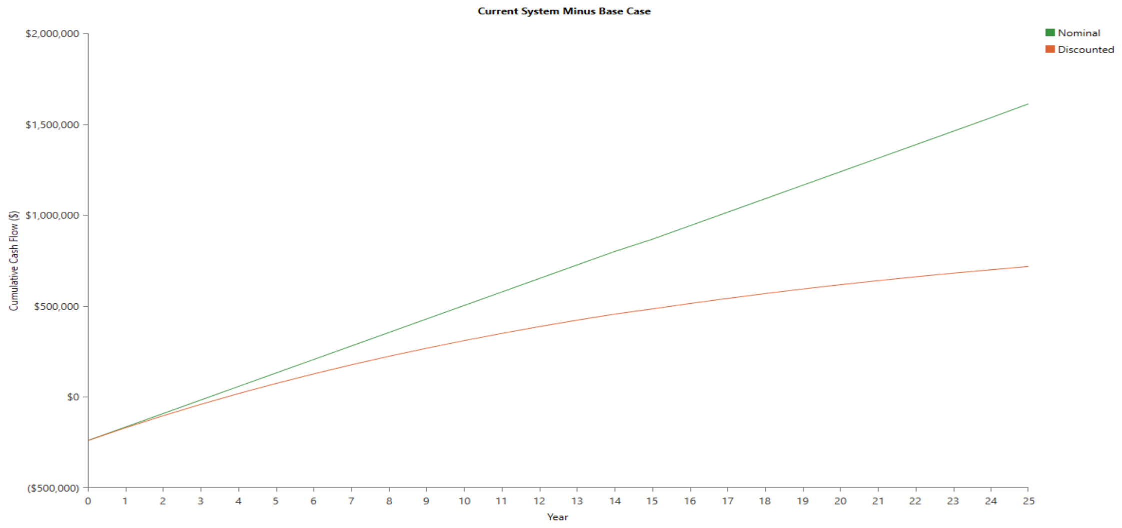


Figure 5.4: Cash flow of PV system.

The following table summarizes the energy purchased from the network in each month during the year and also summarizes the energy sold to the network and the load per month, where the highest purchased power from the network in March and the highest value of the power sold to the network in July and on a load in March .

Grid rate: All

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Demand (kW)	Energy Charge
January	42,131	4,630	37,500	287	$7,500
February	44,172	5,433	38,738	324	$7,748
March	62,022	7,346	54,676	429	$10,935
April	41,706	6,467	35,239	285	$7,048
May	46,754	7,022	39,731	321	$7,946
June	38,691	7,817	30,874	254	$6,175
July	24,079	9,019	15,061	182	$3,012
August	20,491	7,601	12,890	178	$2,578
September	43,605	6,910	36,695	329	$7,339
October	38,391	5,508	32,882	269	$6,576
November	56,590	6,252	50,337	366	$10,067
December	51,173	5,296	45,877	330	$9,175
Annual	509,804	79,302	430,502	429	$86,100

Figure 5.5: Summarizes the energy purchased and sold.

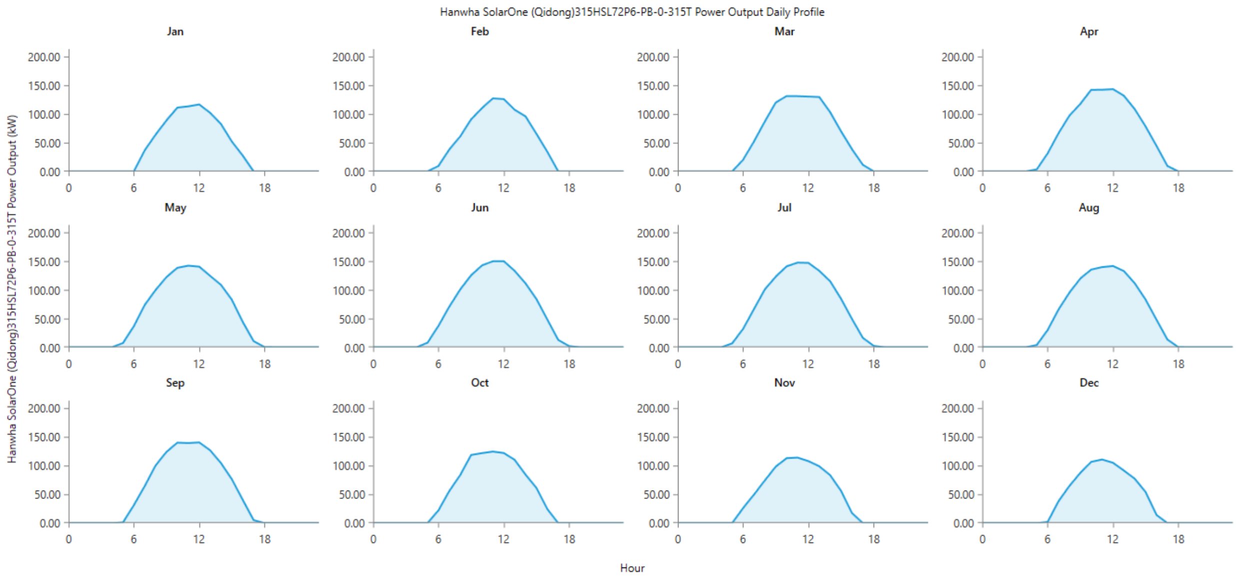


Figure 5.6: PV generation output for average in month.

5.2 Photovoltaic System, Wind Turbine and Main Grid Results

In this case, work has been done to reduce the size of the PV system as a result of the impact of the shade generated by the wind generator on the cells.

The Figure 5.7 shows the results of optimization for each day along the year (365 day). The Figure presents the output of PV-wind energy generation for all days during the year. Wind generation which is highly erratic peaks in the winter while solar generation which is far smoother peaks in the summer.

Table 5.4 illustrates results of hybrid PV-Wind energy system. The capacity of PV 158

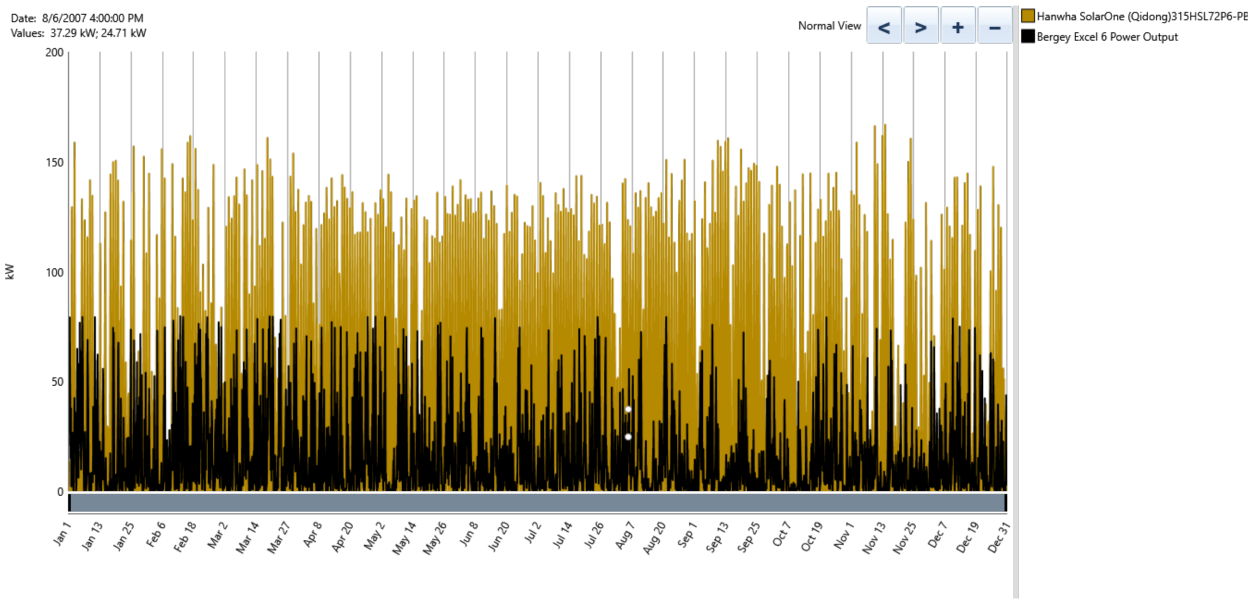


Figure 5.7: Yearly output of hybrid system.

kW and wind turbine 72 kW. The total energy generation of the PV and WT was about 365,146 kWh/y. The production of renewable energy covers 46.3 % of demand .

Table 5.4: PV-wind hybrid energy system with Grid

Type generator	Product	Capacity (kW)	Output (kWh per y)	%
PV	Q cell	158	249,972	31.7
WT	Bergey Excel 6	72	115,174	14.6
PV-Wind	Q cell& Bergey Excel 6	228	365,146	46.3
Grid	From company	999999	426,960	53.7

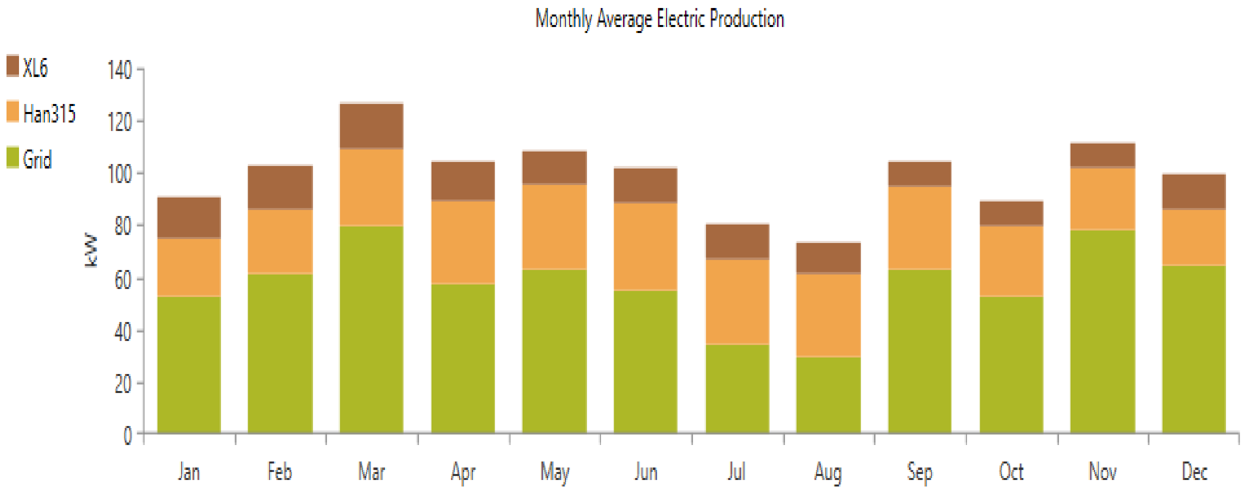


Figure 5.8: Monthly Average Electric Production for PV-Wind turbine-Grid system .

Table 5.5 shows a cost summary of the PV-wind system . The table presents the capital cost and the total O&C cost along 25 year. Salvage value and the total cost of the system after 25 year will cost US $ 409,259 which includes: the capital cost, O&C and Replacement cost in the case study of PPU along 25 years[24]. The cost of energy of PV 0.0578 $/KWh and for wind system equals 0.11 $/kWh. The following table summarize the economic data for all system

Table 5.5: Cost summary the PV-wind system.[24]

Type generation	Capital Cost($)	O&M($)	RC($)	Total cost($)	Avg COE($/kWh)
WT&PV	245,994	97,992	97,992	1,415,842.54	0.086

The COE for all this system 0.1341 $/KWh$.

The Discounted payback period of investment starts after 4 years and 4 months & The Simple payback period of investment starts after 3 years and 8 months .

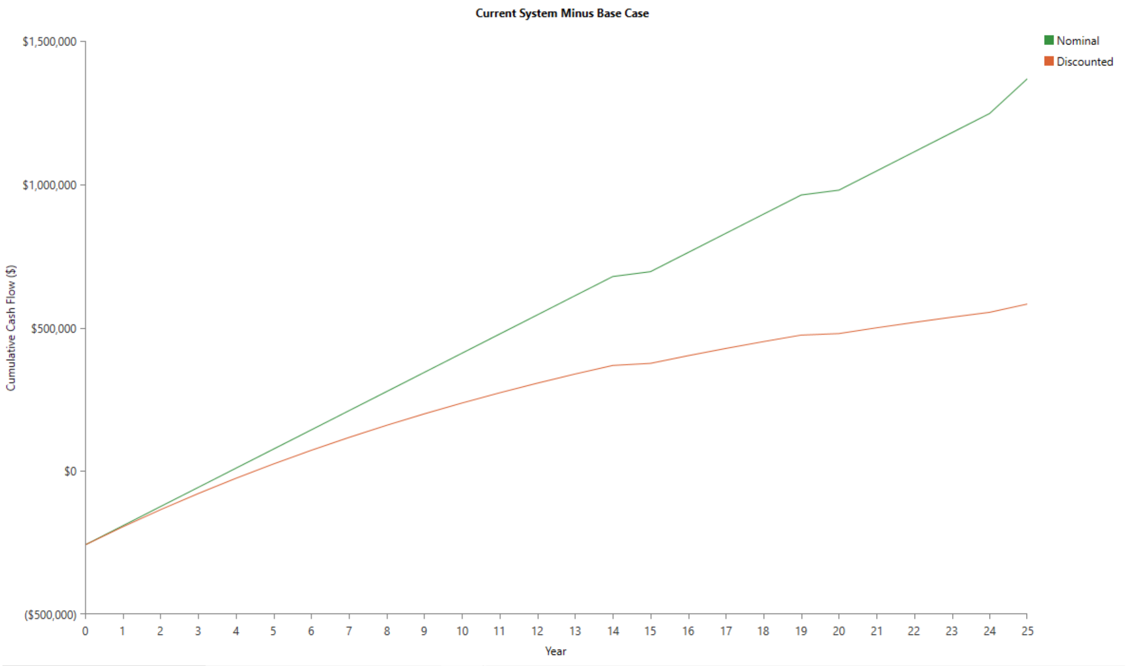


Figure 5.9: Cash flow of PV and Wind.

The following table summarizes the energy purchased from the network in each month during the year and also summarizes the energy sold to the network and the load per month.

Table 5.6: Energy purchased from the network and sold to network

Month	Energy Purchased(KWh)	Energy Sold(KWh)	Net Energy	Peak Demand(kW)
January	38700.7	5736.93	32963.77	260.55
February	40910.4	6533.47	34376.98	318.5
March	58530.54	8429.18	50101.35	424.30
April	39978.48	6766.16	33212.32	294.20
May	45448.76	6566.91	38881.85	320.96
June	38139.15	8241.33	29897.82	259.16
July	23503.2	9767.53	13735.68	192.04
August	20256.501	7907.60	12348.9	167.63
September	43812.40	6383.51	37428.8	324.08
October	38241.62	5174.92	33066.70	269.27
November	55641.5	5485.50	50156.09	359.38
December	47781.18	5000.46	42780.71	329.89
Annual	490,944.63	81,993.56	408,951.06	424.302797

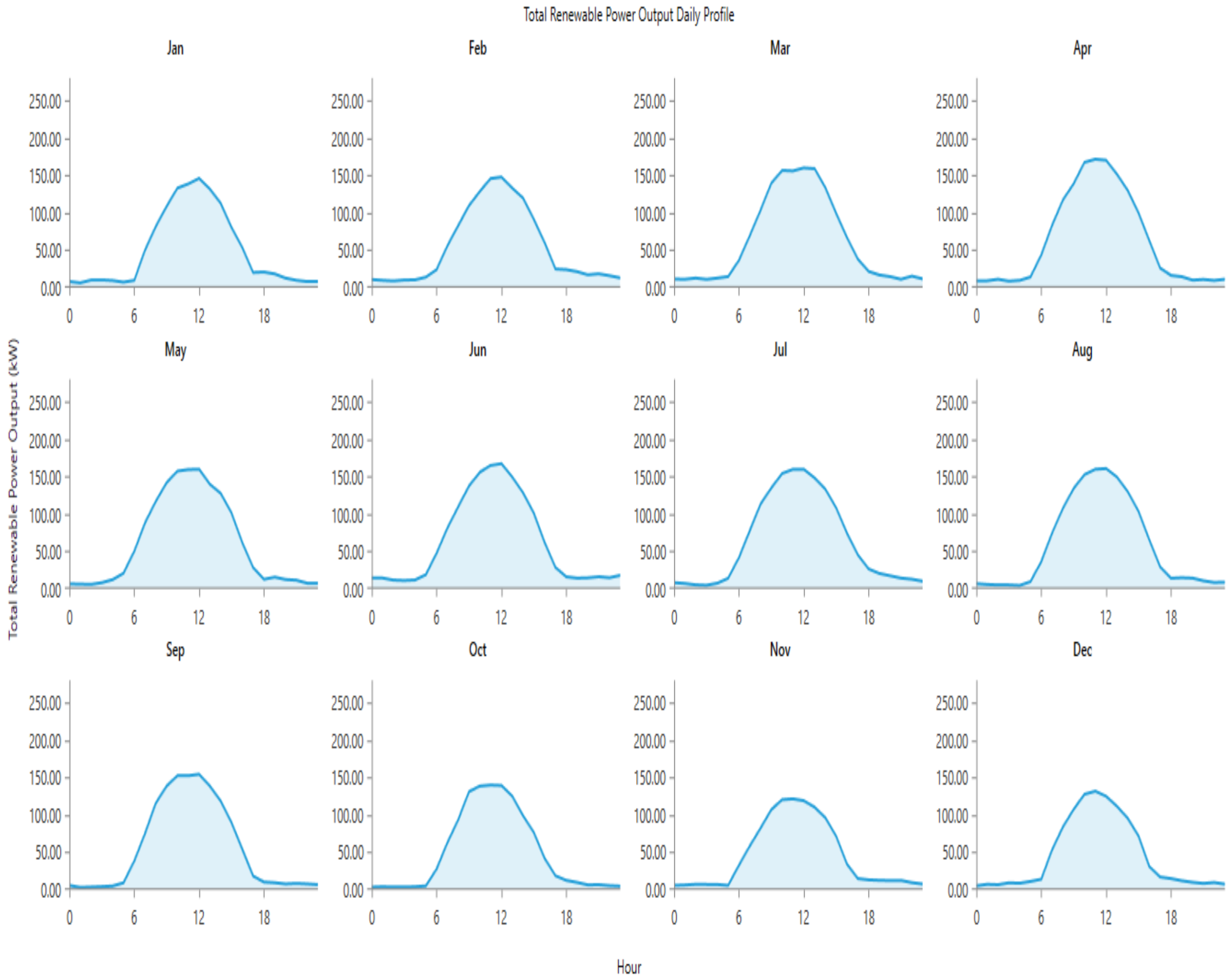


Figure 5.10: Total Pv wind turbine output daily Profile.

5.3 Photovoltaic System, Wind Turbine,Diesel Generator and Battery bank Hybrid Power System Results

The Figure 5.11 presents the output of Diesel Generator-PV-Wind Turbine and Battery in the peak demand day in march. This figure presents the output for every component in

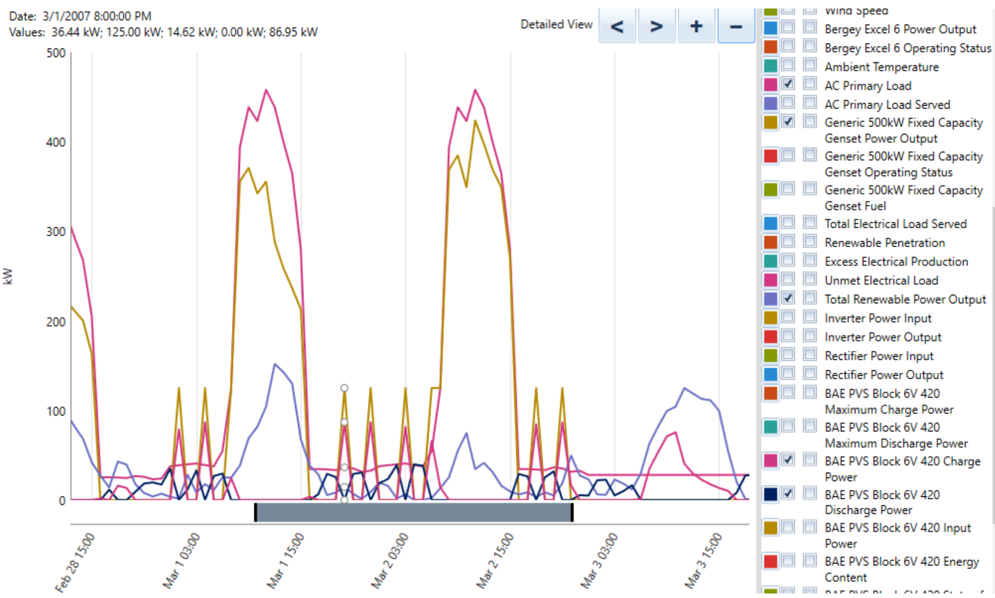


Figure 5.11: Output of PV-Wind Turbine-Diesel Generator and Battery bank

this system to cover load.For Example at this peak demand ,Output for DG 355.9 KW and Renewable 104.4 kW which cover this demand in this hour.

Table 5.7 shows the production proportion calculated by the Homer for each component. The proportion of renewable power is 46%.

Table 5.7: The production for each component in off grid system.

Type generator	Capacity KW	output (KWh/y)
PV-Wind	230	365,146
DG	500	492,099
Total	730	857,245

The monthly average electric production shown as the Figure 5.12.

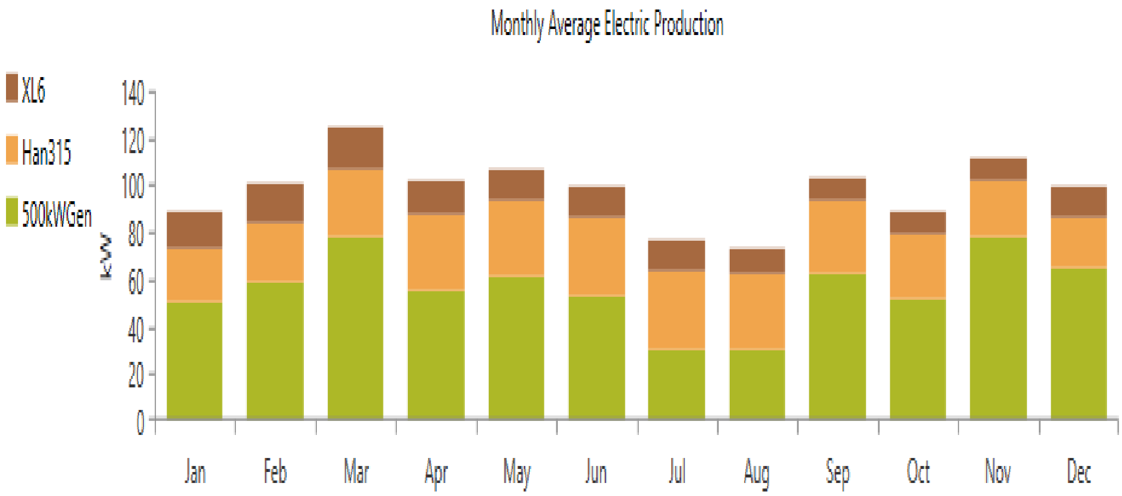


Figure 5.12: Monthly Average Electric Production for off Grid system.

Table 5.8 shows the power supply quality of this system, which is calculated by the Homer. The unmet electric load and capacity shortage proportion are 0.0%, which means the power supply quality is really good. But the system have excess electricity 5.20% because of the instability of solar and wind and the Minimum Electrical Output of DG is 125 KW.

Table 5.8: Power supply quality for off grid system

Quantity	KWh/y	%
Excess Electricity	44,614	21.9
Unmet Electric Load	0.0	0.0
Capacity Shortage	0.0	0.0

Table 5.9 shows a cost summary of the Off grid system . The table presents the capital cost ,replacment cost and the total O&M cost along 25 year.

Table 5.9: Cost summary for off grid system.

Type Generation	Capital cost($)	O&M($)	RC($)	Salvage($)	Fuel($)
PV-wind	245,994	97,992	97,992	1600	0.0
Battery	262000	359,752.56	12,927.52	24,406	0.0
DG	150000	198,114.19	150000	19,751	2,695,119

The COE for all this system 0.389 $/KWh,where the total NPC $3,964,995. Figure 5.13 shows the cost summary plot with types, figure 5.14 shows the cost summary plot with components.

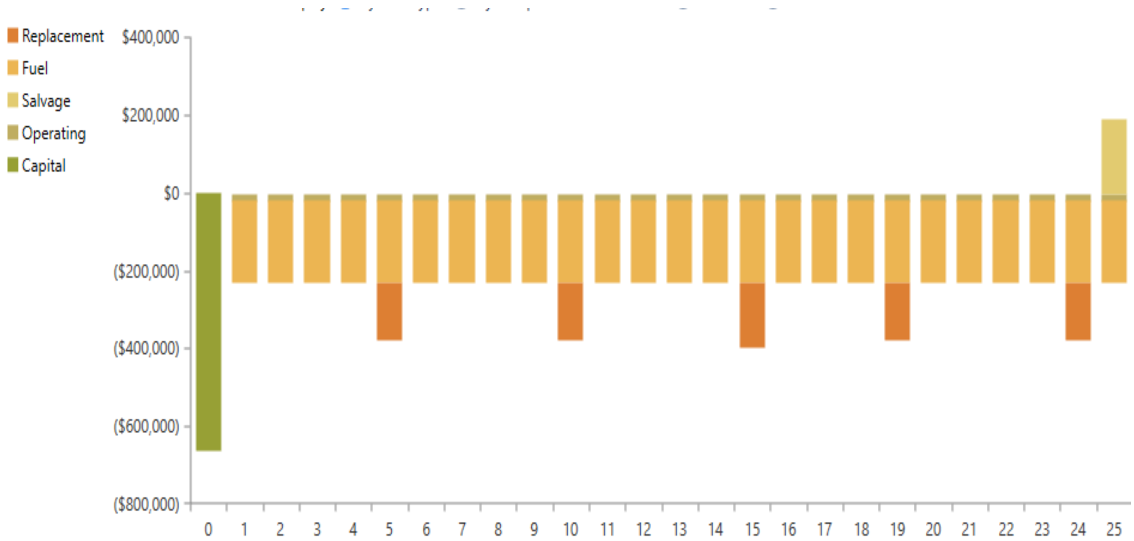


Figure 5.13: Cash flow summery with cost type

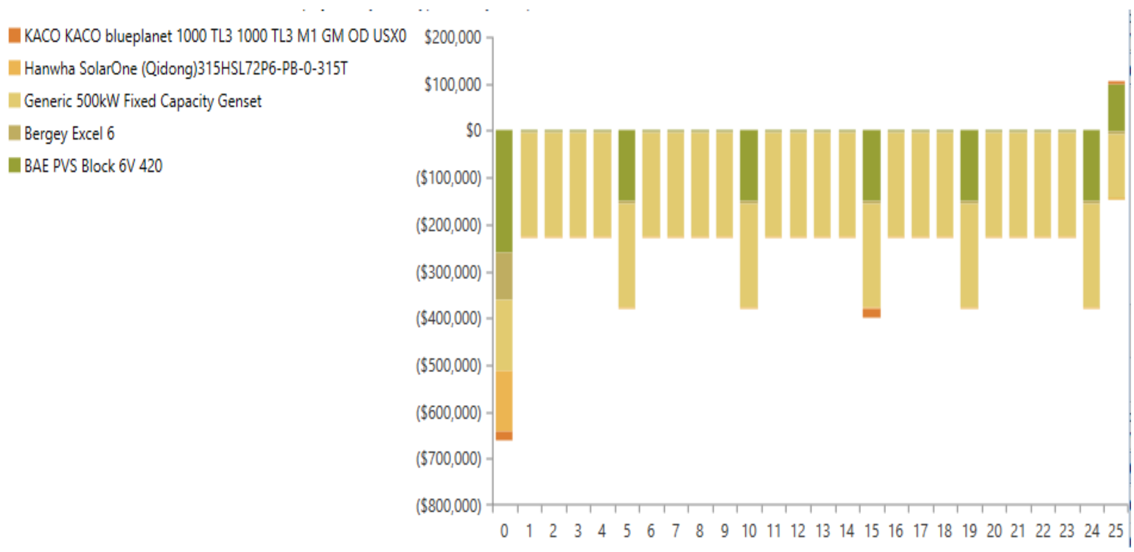


Figure 5.14: Cash flow summery with cost component

5.3.1 Comparing between scenarios

Three scenarios were compared with several factors resulting from simulation, which were represented by (Capital cost , Replacement cost , O&M , Selvage ,NPC , COE) Where the values of these factors were in the first scenario (Photovoltaic System and Main Grid) capital cost = 239,890 $, Replacement cost= 57500 $, O&M=57500 $, Selvage = 4711 $, NPC = 1,339,929.82 $, COE = 0.125 $. the values of these factors were in the second scenario (Photovoltaic System, Wind Turbine and Main Grid) Capital cost =245,994 , Replacement cost= 97990 $, O&M=97990 $, Selvage = 9183.05 $, NPC = 1,415,842.54 $, COE = 0.126$. the values of these factors were in the second scenario (Photovoltaic System, Wind Turbine,Diesel Generator and Batteries). Capital cost =657,000 $, Replacement cost= 383,111.70 $, O&M=251,310.92 $, Selvage = 53,341.45 $, NPC = 3,933,200.17 $, COE = 0.380$. In view of all the factors, it was better to use the first scenario, as it covers almost half of the university's load, and the COE was 0.125 $, which is the lowest cost of Energy in terms of the scenarios presented. Furthermore O&M, Replacement cost is less than other scenarios.

Table 5.10: Comparing between scenarios through different parameter

scenario	Grid&PV	Grid,PV&WT	DG,PV,WT&Batt
Capital cost($)	239,890	245,994	657,000
Replacment cost($)	57500	97990	383,111.70
O&M($)	57500	97990	251,310.92
Salvge($)	4,711	9,183.05	53,341.45
NPC($)	1,399,929.82	1,415,842.54	3,933,200.17
COE($)	0.125	0.126	0.380

Chapter 6

Summary

6.1 Summary

In this project, a hybrid renewable power system is designed to supply electricity for Palestine Polytechnic University. Firstly, the load analysis was maded in different time periods and different seasons. Secondly, the solar and wind speed data was collected . Thirdly, the structure of hybrid renewable power system was built and the parameter and price of component parts are discussed. Fourthly, different sizes or quantity of component parts form different schemes of the system. Then, the optimization method is introduced, the first step is to filter the qualified schemes that meet the requirements of system operation, the second step is to rank these qualified schemes with the net present cost.

Through the simulation process, installation of 230 kW on-grid PV system the result showed the output covered 47 % of demand with the simple payback of investment during 3 years and 6 months. And installation of 72 kW on-grid WT system with 158 KW PV the result showed the output covered 48 % of demand with the payback of investment during 4 years and 3 months. The result of the installation of the PV-Wind Hybrid energy system contains of 72 kW wind turbines and 158 kW solar PV was identified as economically most feasible design to supply average 48 % of load connected to the grid where payback period of the design is 4 years and 3 months. The results prove After performing the simulation, the Grid & PV system was the optimum system by comparing it with other systems with several factors, which are represented by NPC and levelized cost . As the levelized cost reached 0.0125

$ / Kw , as this value is the lowest price we obtained through research and applying the scenario to the program. The project not only compares the scenario evenly and the NPC level, but also includes other factors, such as replacement cost, operation and maintenance during life time of project 25 years.

6.2 Recommendation

1. In this project, the load analysis is the predicted value. If the administration of power supply can offer the real load data, the project will be more accuracy.
2. In the simulation section, the statistical solar and wind speed data is used. If the real time weather data is used to make the simulation, the results will have better persuasion.
3. In this project, alternative schemes are analyzed and compared on the aspects of power supply quality and economical efficiency. Besides, the factors of noise pollution, ecological influence and occupied area should also be considered in the future research.
4. Different places have different solar and wind situations. The project should be done for more places in different resource situations.

Bibliography

[1] P. Sabharwal, "Wind Hybrid Power System", steamgreen!, 2019. [Online]. Available: https://steamgreen.wordpress.com/2015/09/02/wind-hybrid-power-system/. [Accessed: 24- Apr- 2019].

[2] Abdel Aleem, Shady & Mohd Rozlan, Mohd & Zobaa, Ahmed. (2011). The Optimisation of Stand-Alone Hybrid Renewable Energy Systems Using HOMER. International Review of Electrical Engineering. 6.

[3] A. Rohani, K. Mazlumi and H. Kord, "Modeling of a hybrid power system for economic analysis and environmental impact in HOMER," 2010 18th Iranian Conference on Electrical Engineering, Isfahan, 2010, pp. 819-823.

[4] Lal, Deepak Kumar, Bharatee Bhusana Dash and A. K. Akella. "Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER for the Study Area." (2011).

[5] Homerenergy.com, 2019. [Online]. Available: https://www.homerenergy.com/pdf/HOMERHelpMan [Accessed: 18- Apr- 2019].

[6] Open jicareport.jica.go.jp, 2019. [Online]. Available: http://open jicareport.jica.go.jp/pdf/12265039 03.pdf. [Accessed: 18- Apr- 2019].

[7] Asee.org, 2019. [Online]. Available: https://www.asee.org/file server/papers/attachment/file/0004/5010/ASEE-2014-Teaching Renewable Energy System Design with HOMER.pdf. [Accessed: 18- Apr- 2019].

[8] M. Ross and J. Royer. Photovoltaic in Cold Climates, James & James (Science Publishers) Ltd., London, 1999.

[9] CLEAN ENERGY REVIEWS. (2019). Solar Panel Construction. [online] Available at: https://www.cleanenergyreviews.info/blog/solar-panel-components-construction [Accessed 9 Apr. 2019].

[10] A.J. WILEY and SONS,Renewable and Efficient Electric Power System Stanford University Copyright 2004 by John Wiley & Sons, Inc., Hoboken, New Jersey.

[11] Y. S. Allen ,Design and Implementation of MPPT Methods for Photovoltaic Systems Under, 2010.

[12] M.P.D. Tomas Skocil, "Mathematical modeling and simulation a photovoltaic array " University of West Bohemia,Pilsen,University OF Vigo,Spain.

[13] M. C. D.Piazza, G. Vitale,Photovoltaic Sources: Modeling and Emulation , Springer Science & Business Media,2012.

[14] F. L. Luo, Hong Ye ,Advanced DC/AC Inverters: Applications in Renewable Energy,2013.

[15] "Wind Energy Basics", Windeis.anl.gov, 2019. [Online]. Available: http://windeis.anl.gov/guide/basics/. [Accessed: 18- Apr- 2019].

[16] "Ammonit Systems for Wind and Solar Measurement (Data Loggers, Anemometers, Wind Vanes, Pyranometers, SoDAR, LiDAR, . . .)", Ammonit.com, 2019. [Online]. Available: https://www.ammonit.com/en/. [Accessed: 18- Apr- 2019].

[17] "How Diesel Generators Work, their parts and function", Dieselgeneratordirect.uk, 2019. [Online]. Available: https://dieselgeneratordirect.uk/how-does-a-diesel-generator-work.html. [Accessed: 23- Apr- 2019].

[18] "Stand Alone PV System for Off-grid PV Solar Power", Alternative Energy Tutorials, 2019. [Online]. Available: http://www.alternative-energy-tutorials.com/solar-power/stand-alone-pv-system [Accessed: 23- Apr- 2019].

[19] "What is the Best Battery for Solar Storage in 2019?EnergySage",Energysage.com, 2019. [Online]. Available: https://www.energysage.com/solar/solar-energy-storage/what-are-the-best-batteries-for-solar-panels-L-1O9U8. [Accessed: 23- Apr- 2019].

[20] S. Products et al., "Solar Batteries:The Definitive Guide . SOLAR PANEL SECRETS EXPOSED", SOLAR PANEL SECRETS EXPOSED, 2019. [Online]. Available: https://solarpanelsvenue.com/solar-batteries [Accessed: 23- Apr- 2019].

[21] "MSADER", Msader.ps, 2019. [Online]. Available: http://www.msader.ps/. [Accessed: May- 2019].

[22] Earthenergy.us.com. (2019). Bergey Excel 6 Grid-Tie Turbine + Option: 60to80ft Tower. [online] Available at: https://earthenergy.us.com/index.php/bergey-excel-6kw-grid-tie-turbine-option-60-80ft-tower.html product tabs description tabbed [Accessed 25 Nov. 2019].

[23] Masters, G.M., 2013. Renewable and efficient electric power systems. John Wiley & Sons.

[24] Alnatsha, Woroud. "Techno-Economic Feasibility Analysis of Solar-Wind Energy Conversion System Utilizing Genetic Algorithm." Palestine Polytechnic University.

[25] Pradhan, A.K. & Kar, S.K. & Mohanty, M.K.. (2016). Off-grid renewable hybrid power generation system for a public health centre in rural village. 6. 282-288.

Appendix A

PV data Sheet and Plan of The Building

- PV modules component.
- Datasheet of Hanwha Q power
- Inverter technical data:KACO blue plant20.0TI3

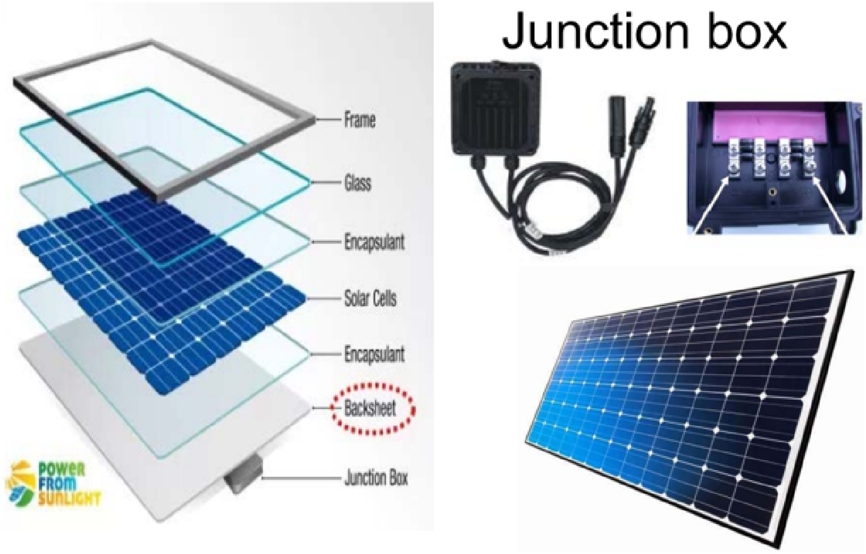


Figure A.1: PV modules component

Q.POWER L-G5 315-335

POLYCRYSTALLINE SOLAR MODULE

The new Q.POWER L-G5 is the result of the continued evolution of our polycrystalline solar modules. Thanks to improved power yield, excellent reliability, and high-level operational safety, the new Q.POWER L-G5 generates electricity at a low cost (LCOE) and is suitable for a wide range of applications.

LOW LEVELIZED COST OF ELECTRICITY
Higher yield per surface area and lower BOS costs and higher power classes and an efficiency rate of up to 17.5 %.

INNOVATIVE ALL-WEATHER TECHNOLOGY
Optimal yields, whatever the weather with excellent low-light and temperature behaviour.

EXTREME WEATHER RATING
High-tech aluminium alloy frame, certified for high snow (5400 Pa) and wind loads (2400 Pa).

MAXIMUM COST REDUCTIONS
Lower logistics costs due to higher module capacity per box.

A RELIABLE INVESTMENT
Inclusive 12-year product warranty and 25-year linear performance warranty[1].

EUPD RESEARCH
TOP BRAND PV
MODULES
EUROPE
2016

Photon
YIELD MEASUREMENT
Q CELLS
Best polycrystalline solar module 2014
Q.PRO-G2 235
174 modules tested

[1] See data sheet on rear for further information.

THE IDEAL SOLUTION FOR:

Ground-mounted solar power plants

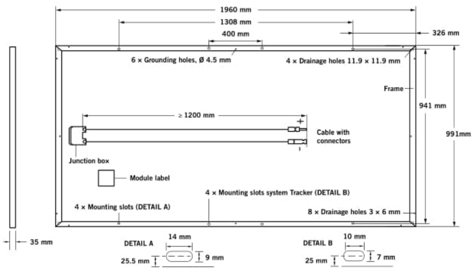
Engineered in **Germany**

Q CELLS

Figure A.2: Photovoltaic cell type

MECHANICAL SPECIFICATION

Format	1960 mm × 991 mm × 35 mm (including frame)
Weight	22.5 kg ± 5 %
Front Cover	3.2 mm thermally pre-stressed glass with anti-reflection technology
Back Cover	Multi-layer composite sheet
Frame	Anodised aluminium
Cell	6 × 12 polycrystalline solar cells
Junction box	Protection class IP67, with bypass diodes
Cable	4 mm² Solar cable; (+) ≥ 1200 mm, (-) ≥ 1200 mm
Connector	Intermateable connector with H4, MC4

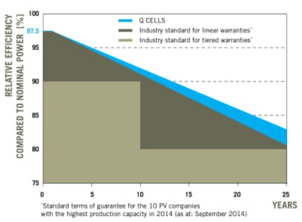


ELECTRICAL CHARACTERISTICS

POWER CLASS				315	320	325	330	335
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5 W / -0 W)								
Minimum	Power at MPP[2]	P_{MPP}	[W]	315	320	325	330	335
	Short Circuit Current*	I_{SC}	[A]	9.11	9.15	9.20	9.30	9.40
	Open Circuit Voltage*	V_{OC}	[V]	45.7	45.8	46.0	46.1	46.3
	Current at MPP*	I_{MPP}	[A]	8.50	8.61	8.67	8.76	8.87
	Voltage at MPP*	V_{MPP}	[V]	37.1	37.2	37.5	37.7	37.8
	Efficiency[2]	η	[%]	≥ 15.3	≥ 15.6	≥ 15.8	≥ 16.1	≥ 16.3
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NOC[3]								
Minimum	Power at MPP[2]	P_{MPP}	[W]	232	235	239	243	247
	Short Circuit Current*	I_{SC}	[A]	7.37	7.40	7.44	7.52	7.60
	Open Circuit Voltage*	V_{OC}	[V]	42.9	43.0	43.1	43.2	43.4
	Current at MPP*	I_{MPP}	[A]	6.79	6.88	6.93	7.00	7.09
	Voltage at MPP*	V_{MPP}	[V]	34.1	34.2	34.5	34.7	34.8

[1] 1000 W/m², 25 °C, spectrum AM 1.5 G [2] Measurement tolerances STC ± 3 %; NOC ± 5 % [3] 800 W/m², NOCT, spectrum AM 1.5 G * typical values, actual values may differ

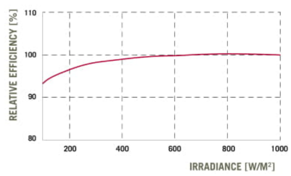
Q CELLS PERFORMANCE WARRANTY



At least 97.5 % of nominal power during first year. Thereafter max. 0.7 % degradation per year.
At least 90.5 % of nominal power up to 10 years.
At least 82 % of nominal power up to 25 years.

All data within measurement tolerances.
Full warranties in accordance with the warranty terms of the Q CELLS sales organisation of your respective country.

PERFORMANCE AT LOW IRRADIANCE



Typical module performance under low irradiance conditions in comparison to STC conditions (25 °C, 1000 W/m²).

TEMPERATURE COEFFICIENTS

Temperature Coefficient of I_{SC}	α	[%/K]	+0.05	Temperature Coefficient of V_{OC}	β	[%/K]	-0.31
Temperature Coefficient of P_{MPP}	γ	[%/K]	-0.40	Normal Operating Cell Temperature	NOCT	[°C]	45

PROPERTIES FOR SYSTEM DESIGN

Maximum System Voltage	V_{SYS}	[V]	1000	Safety Class	II
Maximum Reverse Current	I_R	[A]	20	Fire Rating	C
Wind/Snow Load (Test-load in accordance with IEC 61215)		[Pa]	2400/5400	Permitted Module Temperature On Continuous Duty	-40 °C up to +85 °C

QUALIFICATIONS AND CERTIFICATES

IEC 61215, IEC 61730, Conformity to CE, Application Class A

PARTNER

NOTE: Installation instructions must be followed. See the installation and operating manual or contact our technical service department for further information on approved installation and use of this product.

Hanwha Q CELLS GmbH
Sonnenallee 17-21, 06766 Bitterfeld-Wolfen, Germany | TEL +49 (0)3494 66 99-23444 | FAX +49 (0)3494 66 99-23000 | EMAIL sales@q-cells.com | WEB www.q-cells.com

Engineered in **Germany**

Figure A.3: Photovoltaic cell datasheet

Figure A.4: Inverter type

EN 5001046-01-180608

Technical Data

DC input data	15.0 TL3	20.0 TL3
Max. recommended PV generator	18 000 W	24 000 W
MPP range	420 – 800 V	515 – 800 V
Operating range	200 – 950 V	200 – 950 V
Rated DC voltage / start voltage	673 / 250 V	673 / 250 V
Max. no-load voltage	1 000 V	1 000 V
Max. input current	2 x 20 A	2 x 20 A
Max. short circuit current $I_{sc\ max}$	2 x 32 A	2 x 32 A
Number of MPP tracker	2	2
Connection per tracker	2	2
Max.input power per tracker	15 000 W	15 000 W
AC output data		
Rated output	15 000 VA	20 000 VA
Max. power	15 600 VA	20 800 VA
Line voltage	240 V / 415 V (3 / N / PE) 230 V / 400 V (3 / N / PE) 220 V / 380 V (3 / N / PE)	277 V / 480 V (3 / N / PE) 240 V / 415 V (3 / N / PE) 230 V / 400 V (3 / N / PE) 220 V / 380 V (3 / N / PE)
Voltage range (Ph-Ph)	305 – 480 V	305 – 480 V
Rated frequency (range)	50 Hz / 60 Hz (42 – 68 Hz)	50 Hz / 60 Hz (42 – 68 Hz)
Rated current	3 x 20.9 A @ 415 V 3 x 21.7 A @ 400 V 3 x 22.8 A @ 380 V	3 x 24.1 A @ 480 V 3 x 27.9 A @ 415 V 3 x 28.9 A @ 400 V 3 x 30.4 A @ 380 V
Max. current	3 x 23.0 A	3 x 31.0 A
Reactive power / cos phi	0 – 100 % Snom / 0.30 ind. – 0.30 cap.	0 – 100 % Snom / 0.30 ind. – 0.30 cap.
Max. total harmonic distortion (THD)	0.7 %	0.5 %
Number of grid phases	3	3
General data		
Max. efficiency	98.0 %	98.4 %
Europ. efficiency	97.6 %	98.1 %
CEC efficiency	97.6 %	98.1 %
Standby consumption	1.5 W	1.5 W
Circuitry topology	transformerless	transformerless
Mechanical data		
Display	graphical display + LEDs	graphical display + LEDs
Control units	4-way navigation + 2 buttons	4-way navigation + 2 buttons
Interfaces	Ethernet, USB, RS485, optional: 4-DI	Ethernet, USB, RS485, optional: 4-DI
Fault signalling relay	potential-free NOC max. 30 V / 1 A	potential-free NOC max. 30 V / 1 A
DC connection	DC plugs (MC4)	DC plugs (MC4)
AC connection	spring-loaded terminal, max. 16 mm²	spring-loaded terminal, max. 16 mm²
Ambient temperature	-25 °C – +60 °C [1)]	-25 °C – +60 °C [1)]
Humidity	0 – 95 %	0 – 95 %
Max. installation elevation (above MSL)	2 000 m	2 000 m
Min. distance from coast	2 000 m / 500 m (OD+ version)	2 000 m / 500 m (OD+ version)
Cooling	temperature controlled fan	temperature controlled fan
Protection class	IP65	IP65
Noise emission	< 52 db (A)	< 53 db (A)
H x W x D	690 x 420 x 200 mm	690 x 420 x 200 mm
Weight	48 kg	48 kg
Certifications		
Safety	EN 62109-1 / -2, EN 61000-6-1 / -2 / -3, EN 61000-3-2 / -3 / -11 / -12	
Grid connection rule	overview see homepage / download area	

[1)] Power derating at high ambient temperatures

Versions	15.0 TL3	20.0 TL3
DC switch	✓	✓
DC surge protection	○	○
OD+	★	★

standard = ✓ upgradeable = ○ optional = ★

The text and figures reflect the current technical state at the time of printing. Subject to technical changes. Errors and omissions excepted. This current version replaces all older versions. Download the most current version at: www.kaco-newenergy.com

KACO new energy GmbH | Carl-Zeiss-Str. 1 | 74172 Neckarsulm | Germany

Figure A.5: Inverter data sheet

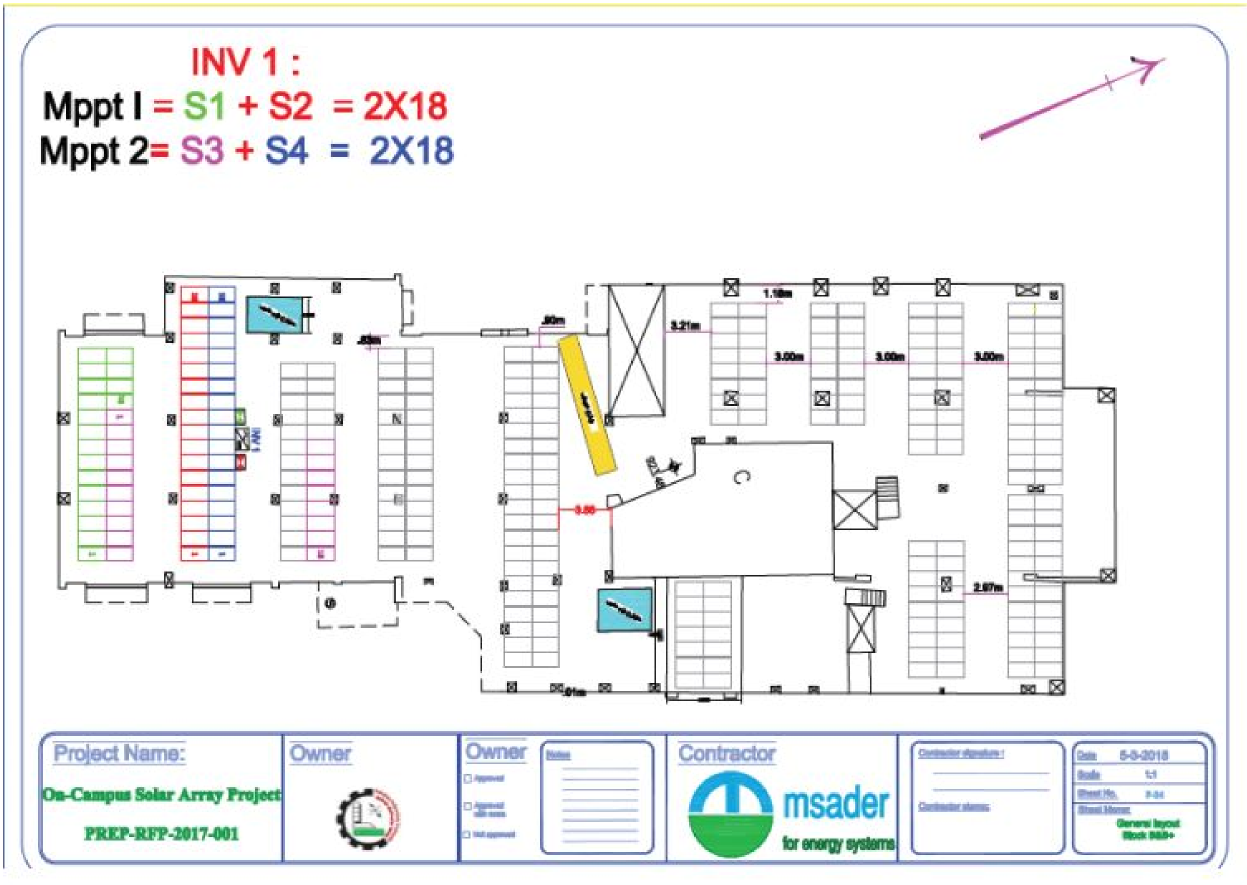
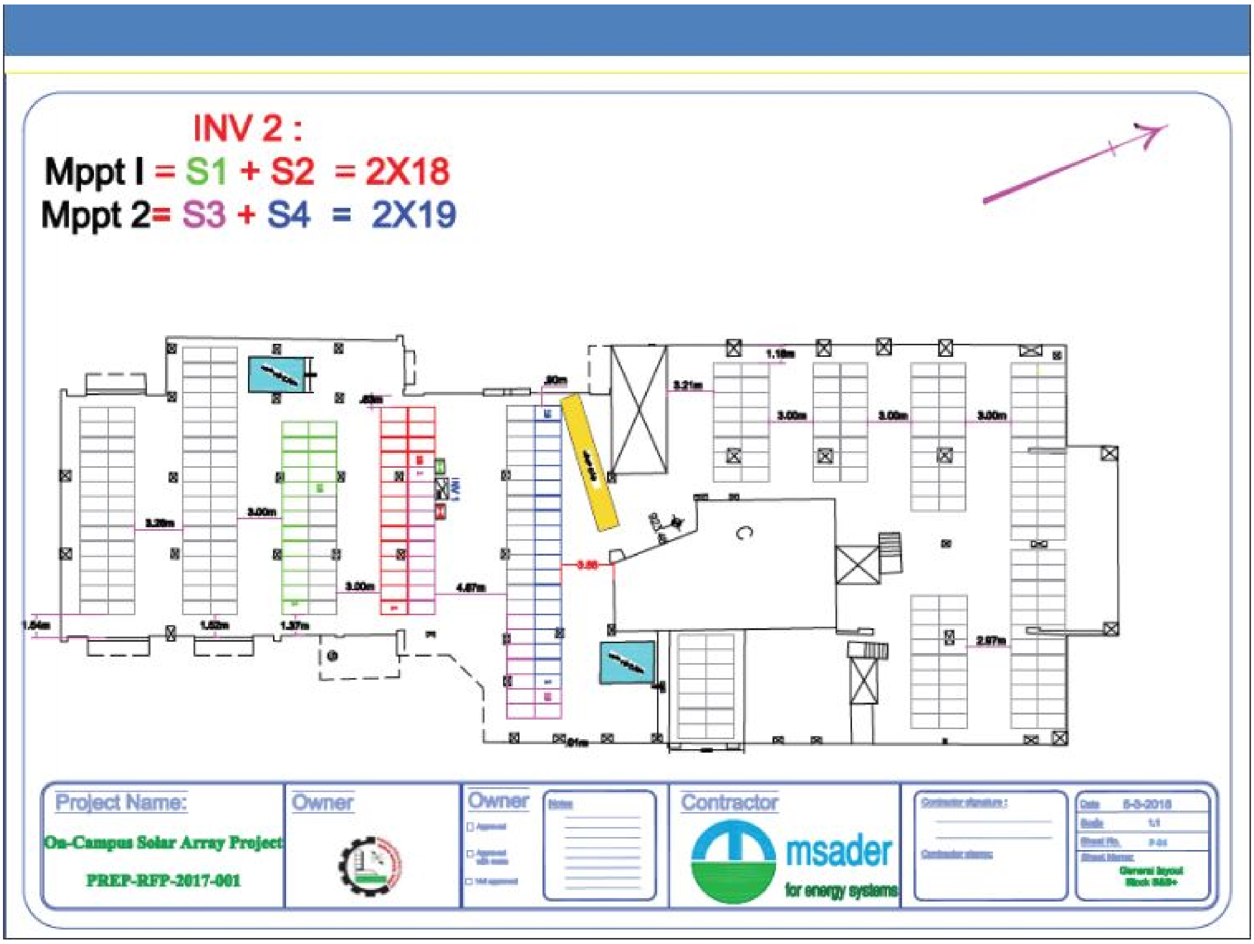
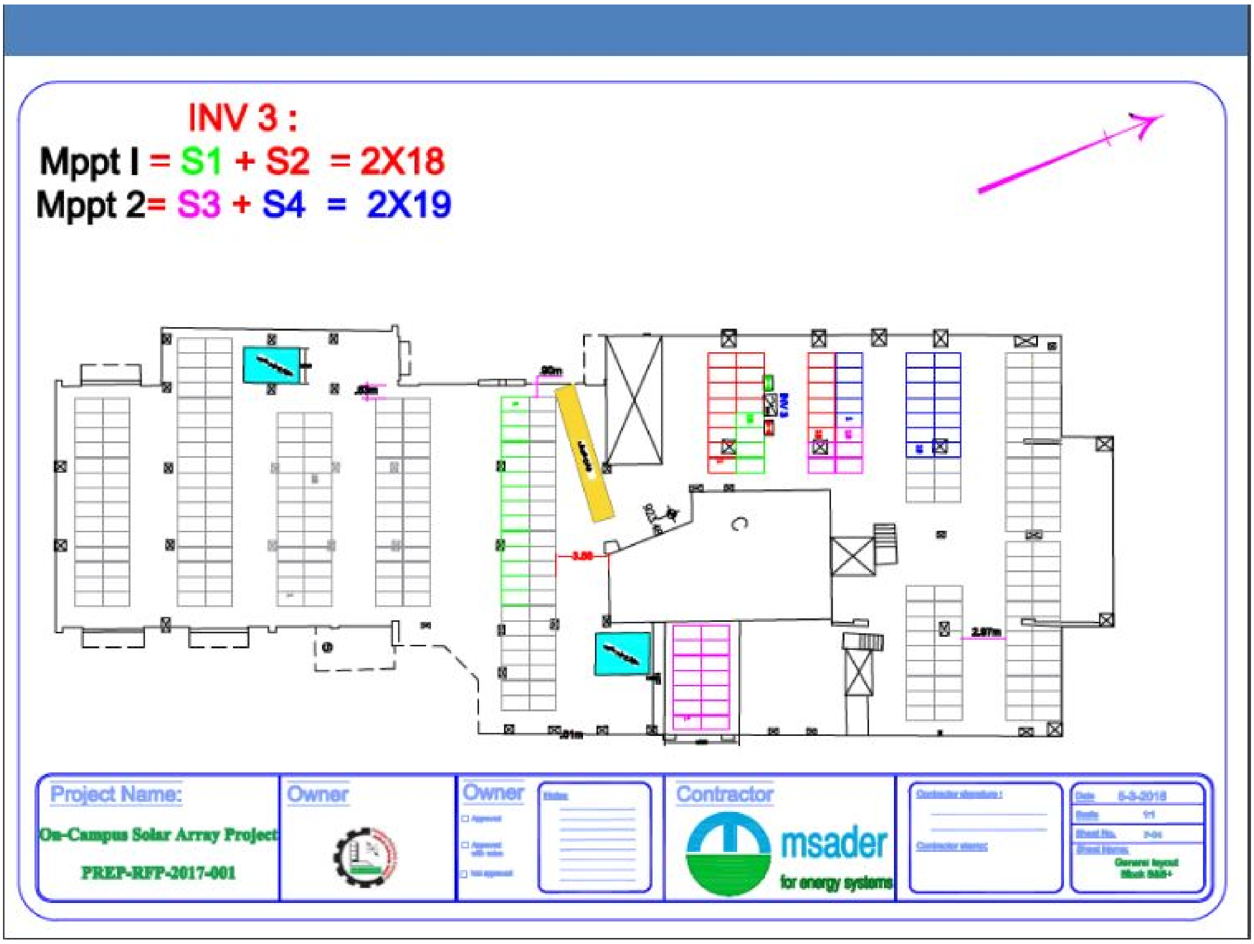
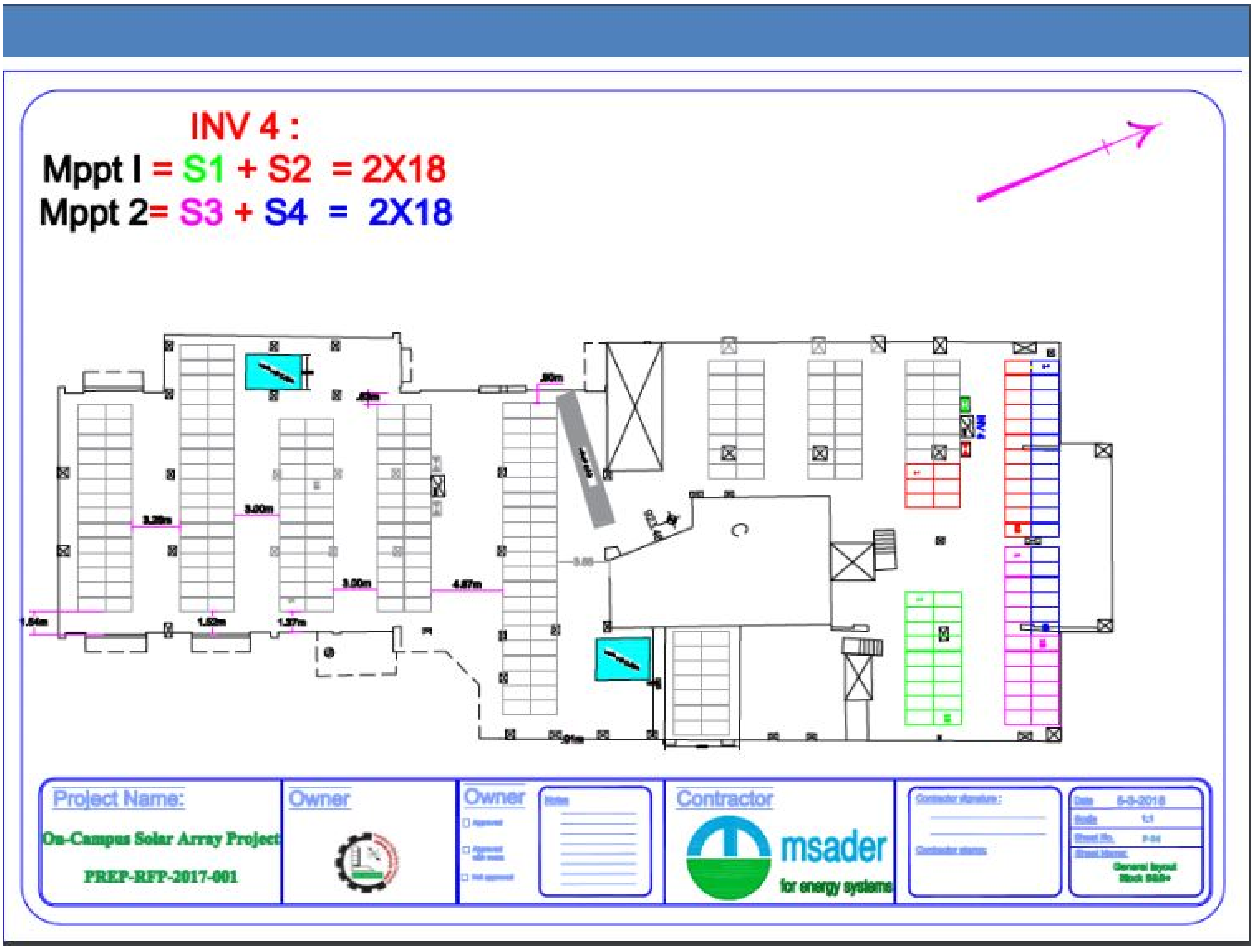
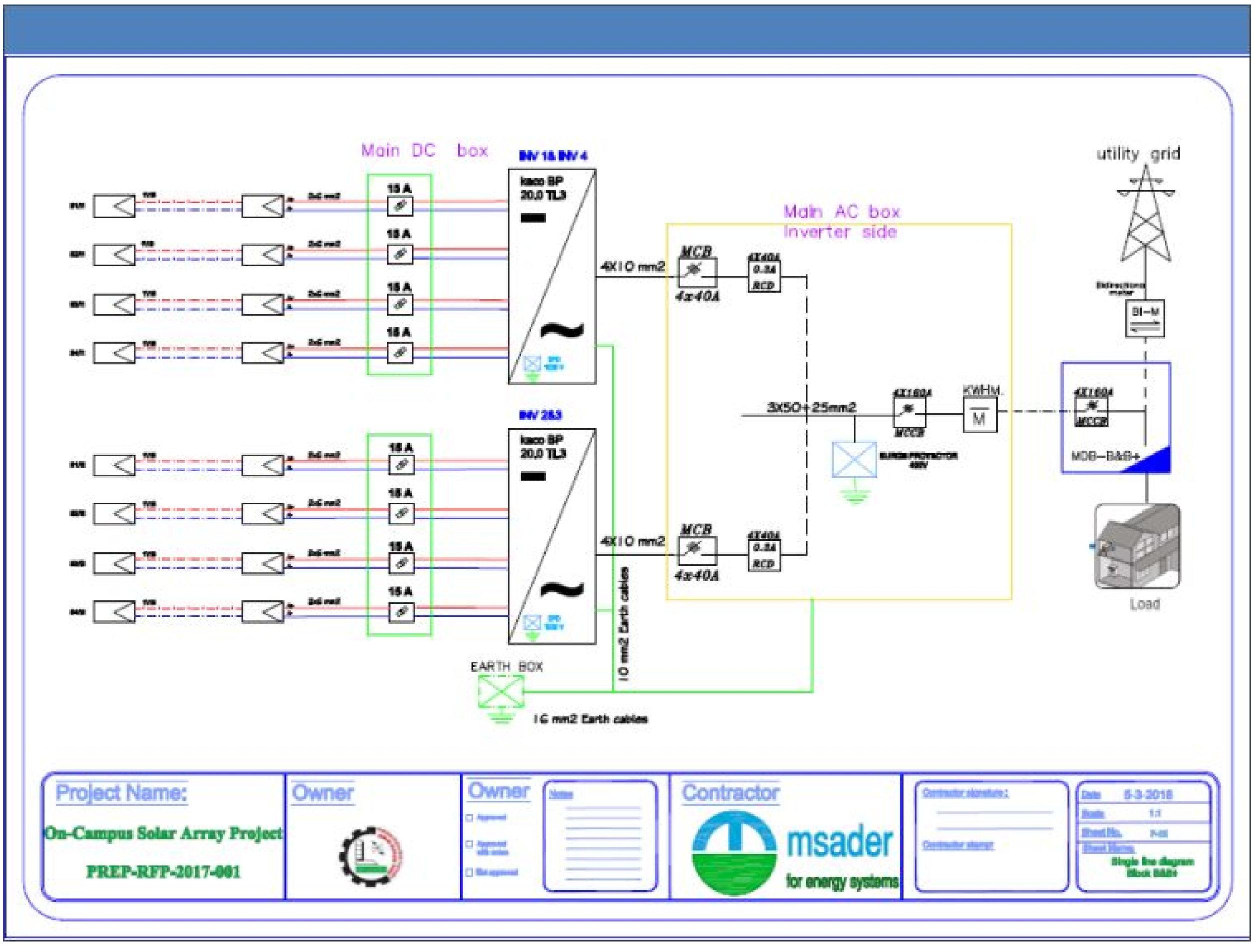


Figure A.6: Distribution of photovoltaic cells on the Inverters for a building B&B+


INV 2 :
Mppt I = S1 + S2 = 2X18
Mppt 2= S3 + S4 = 2X19
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Contractor
msader
for energy systems


INV 3 :
Mppt I = S1 + S2 = 2X18
Mppt 2= S3 + S4 = 2X19
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Contractor
msader
for energy systems


INV 4 :
Mppt I = S1 + S2 = 2X18
Mppt 2= S3 + S4 = 2X18
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Contractor
msader
for energy systems


Main DC box
INV 1& INV 4
kaco BP 20,0 TL3
15 A
4X10 mm2
MCB
4x40A
RCD
Main AC box
Inverter side
3X50+25mm2
KWHM
M
utility grid
BI-M
MDB-B&B+
Load
INV 2&3
EARTH BOX
10 mm2 Earth cables
16 mm2 Earth cables
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Contractor
msader
for energy systems

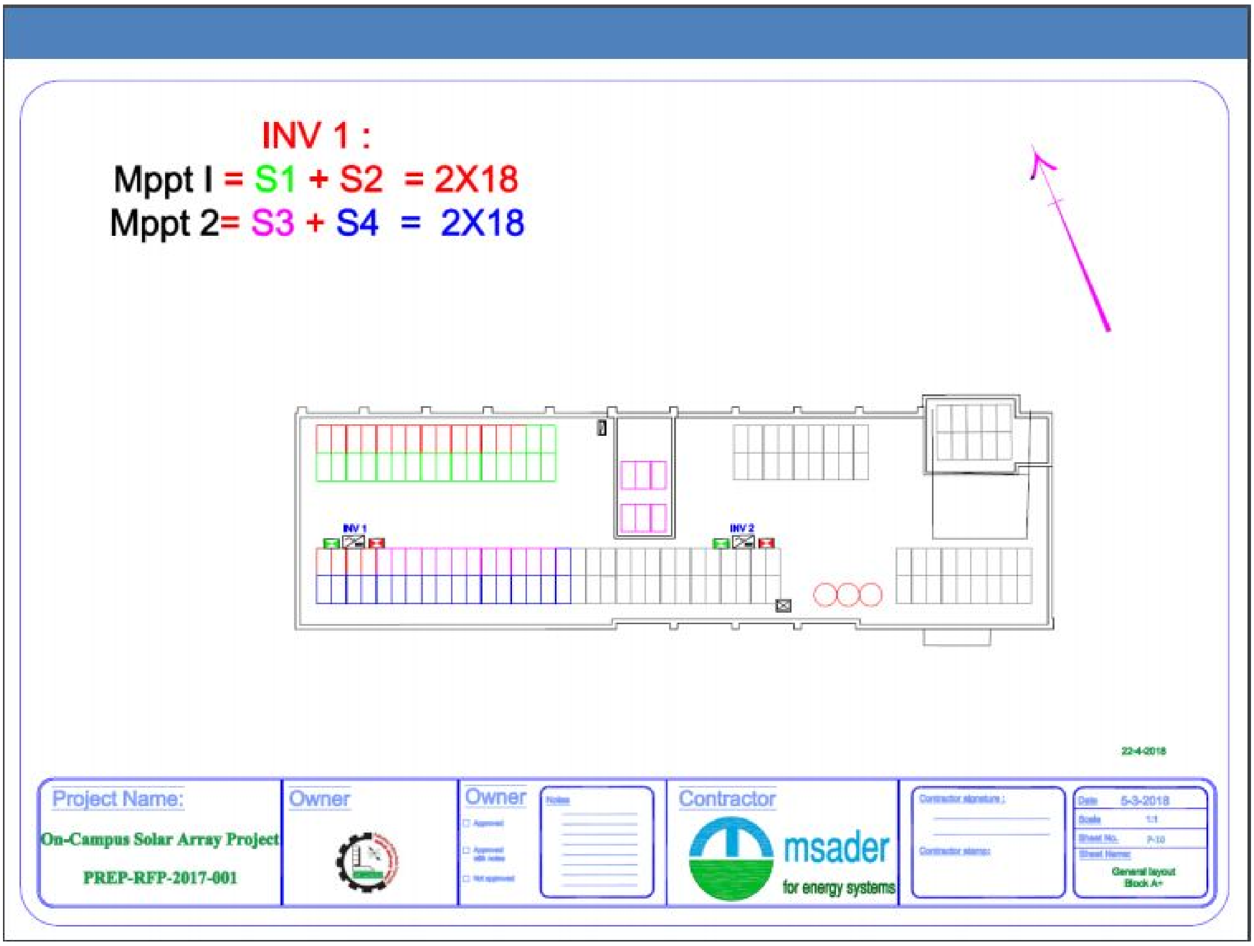
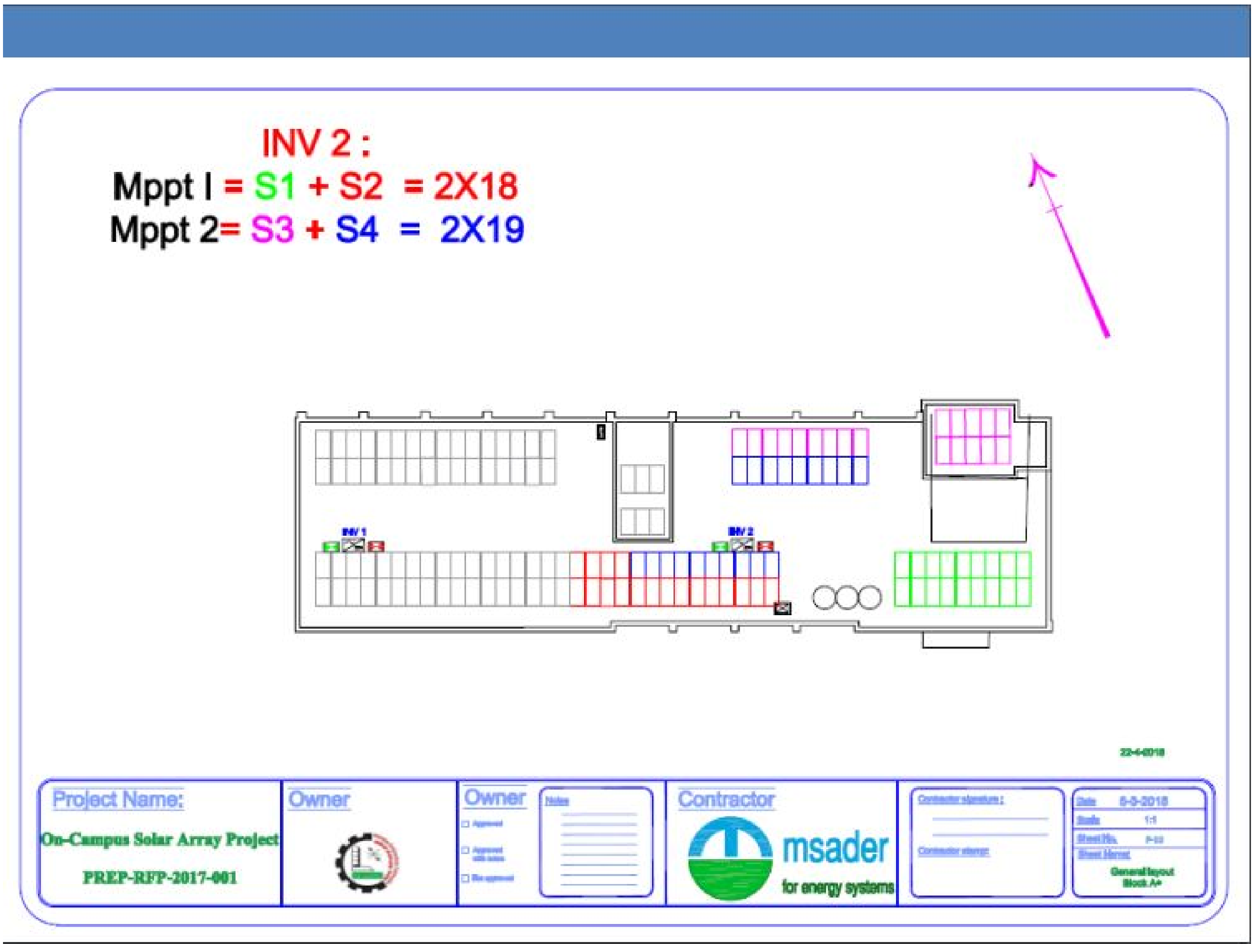
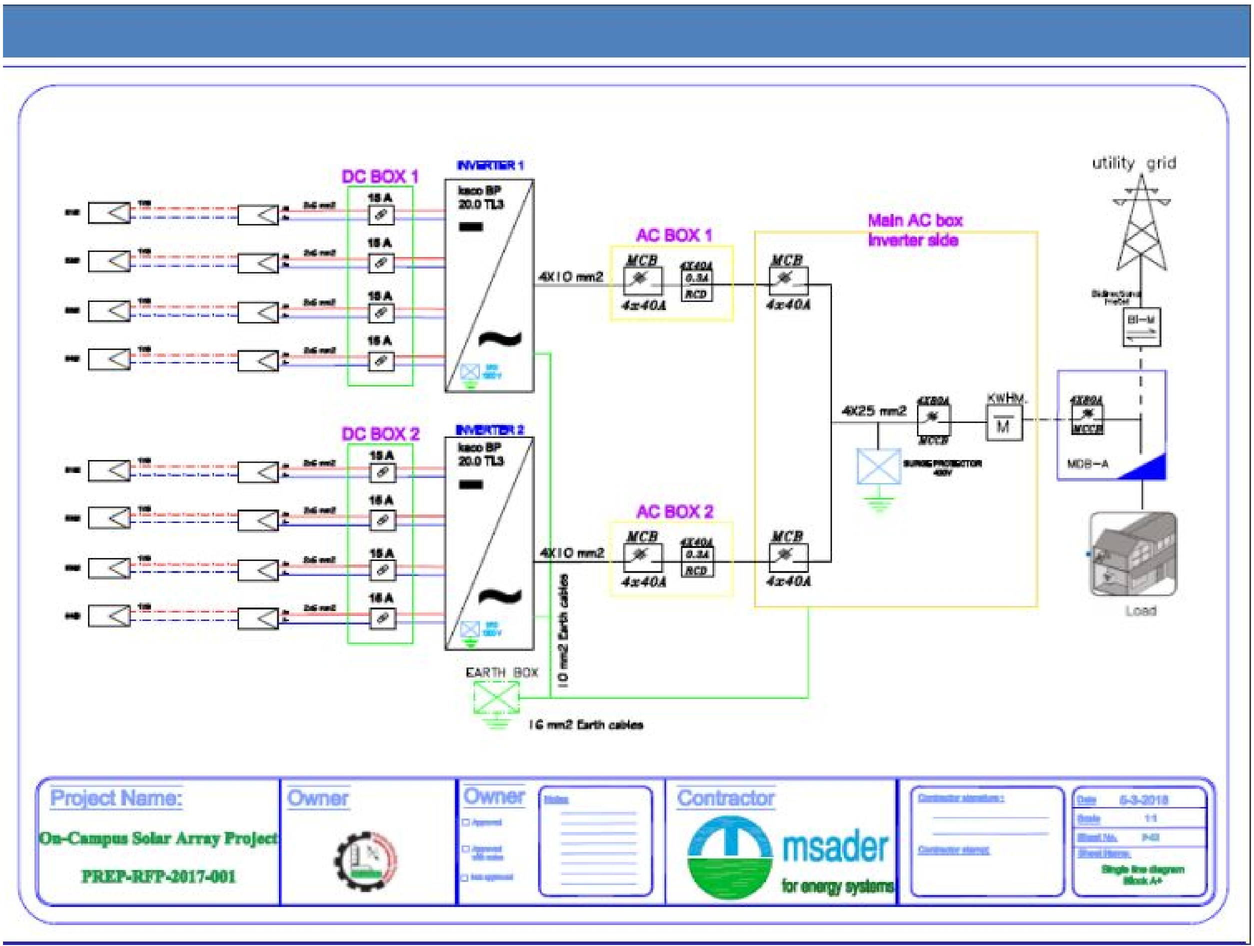


Figure A.7: Distribution of photovoltaic cells on the Inverters for a building A



INV 2 :
Mppt I = S1 + S2 = 2X18
Mppt 2= S3 + S4 = 2X19
INV 1
INV 2
22-4-2018
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Notes
Contractor
msader
for energy systems
Date 5-3-2018
Scale 1:1
General layout
Block A+



DC BOX 1
INVERTER 1
kaco BP 20.0 TL3
AC BOX 1
MCB
4x40A
RCD
4X10 mm2
Main AC box
Inverter side
utility grid
DC BOX 2
INVERTER 2
kaco BP 20.0 TL3
AC BOX 2
4X25 mm2
KWHM.
M
MCCB
SURGE PROTECTOR
MDB-A
Load
EARTH BOX
10 mm2 Earth cables
16 mm2 Earth cables
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Contractor
msader
for energy systems
Date 5-3-2018
Single line diagram
Block A+

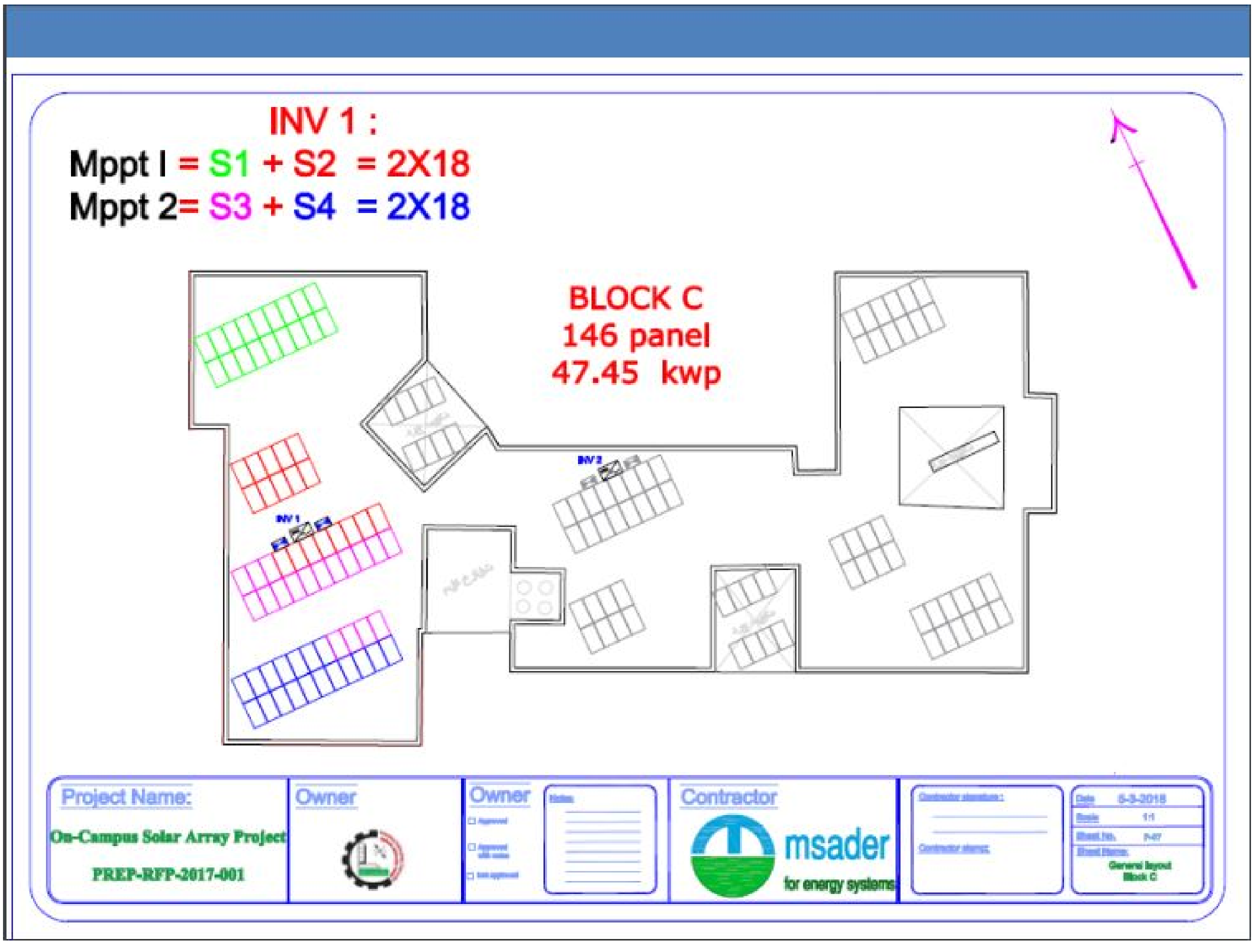
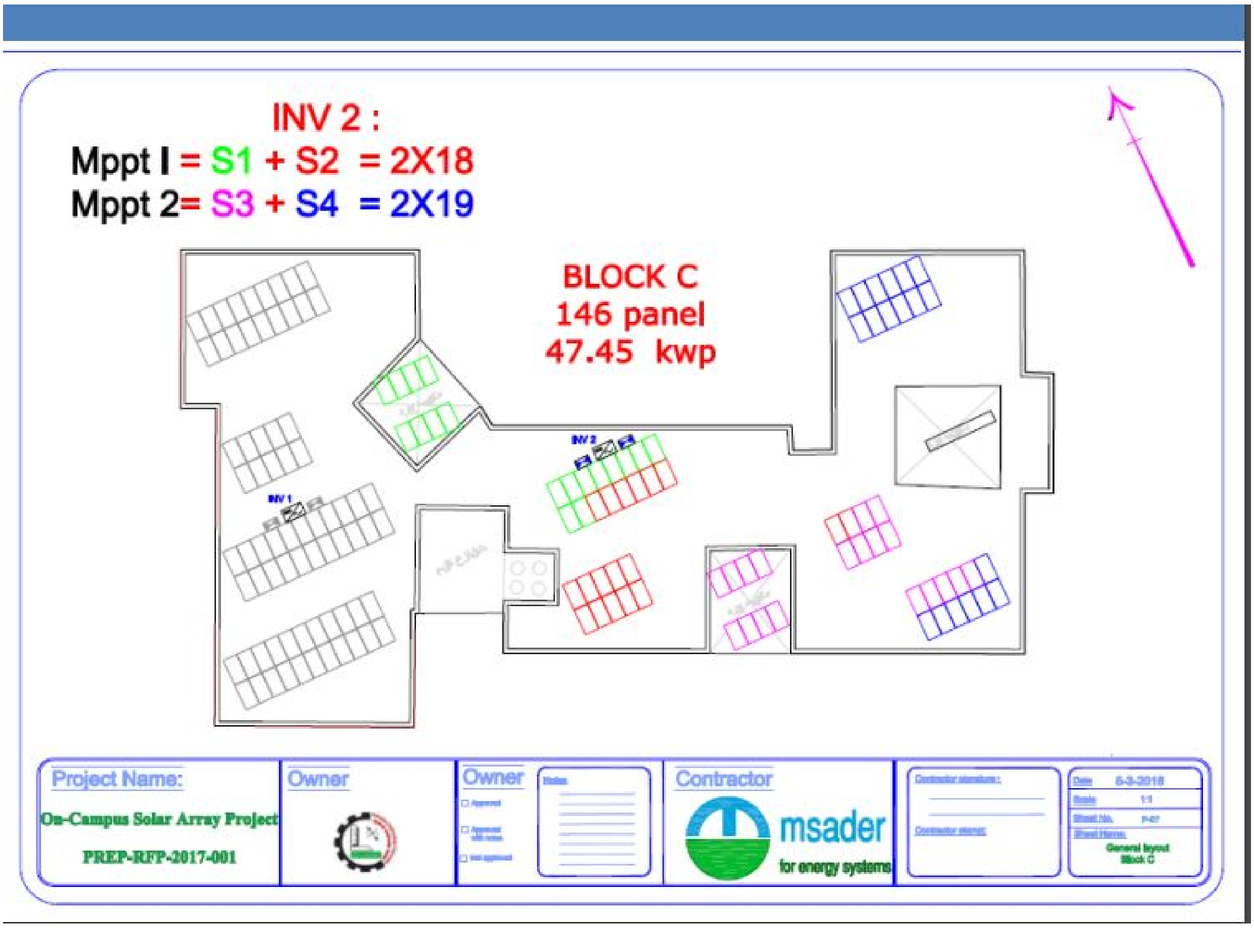
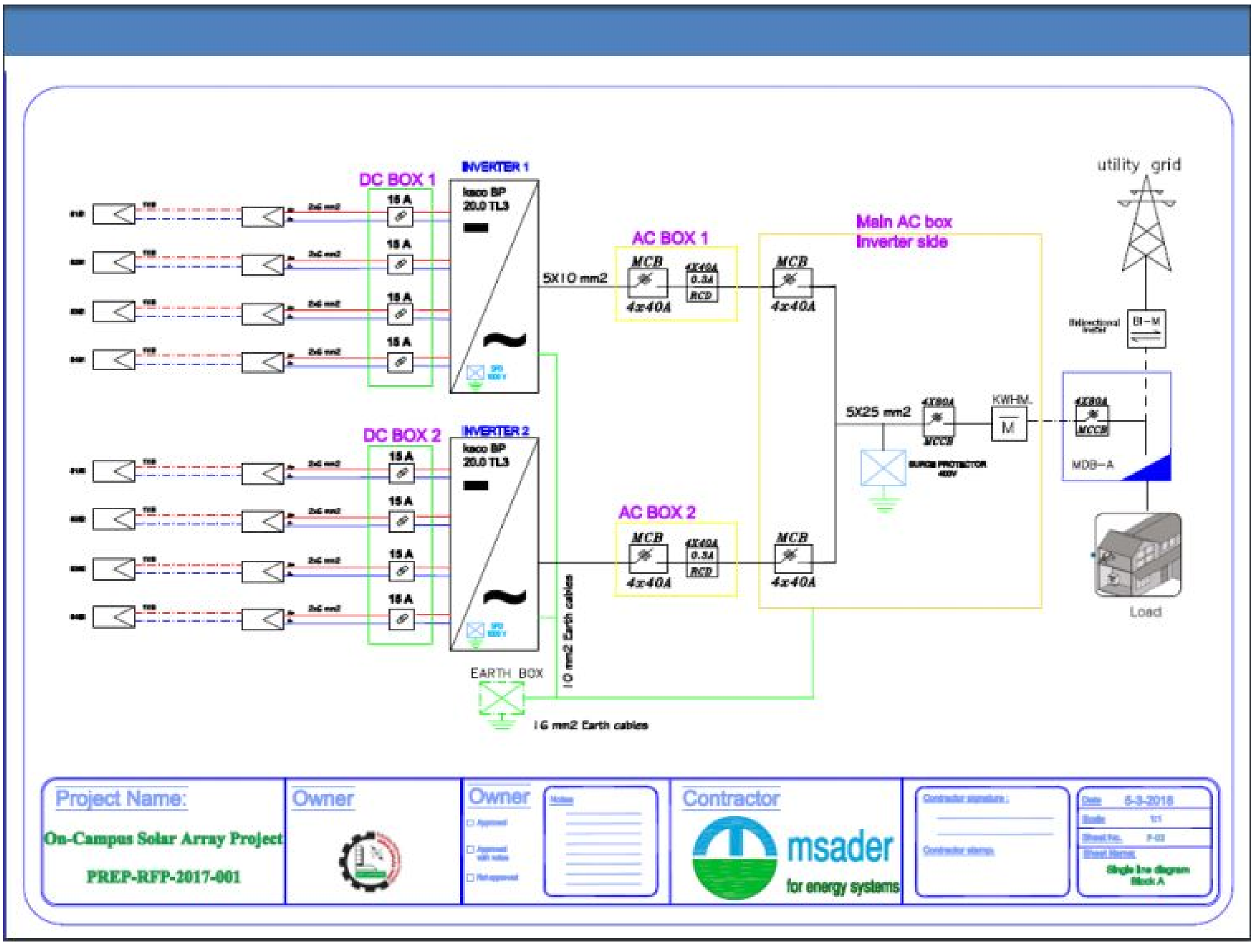


Figure A.8: Distribution of photovoltaic cells on the Inverters for a building C.


INV 2 :
Mppt I = S1 + S2 = 2X18
Mppt 2= S3 + S4 = 2X19
BLOCK C
146 panel
47.45 kwp
INV 1
INV 2
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Contractor
msader
for energy systems


DC BOX 1
INVERTER 1
kaco BP 20.0 TL3
AC BOX 1
MCB
4x40A
4X40A 0.3A RCD
5X10 mm2
Main AC box Inverter side
utility grid
BI-M
5X25 mm2
4X80A MCCB
KWHM
M
MDB-A
SURGE PROTECTOR 400V
DC BOX 2
INVERTER 2
kaco BP 20.0 TL3
AC BOX 2
15 A
10 mm2 Earth cables
EARTH BOX
16 mm2 Earth cables
Load
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Contractor
msader
for energy systems
Date 5-3-2018
Single line diagram Block A

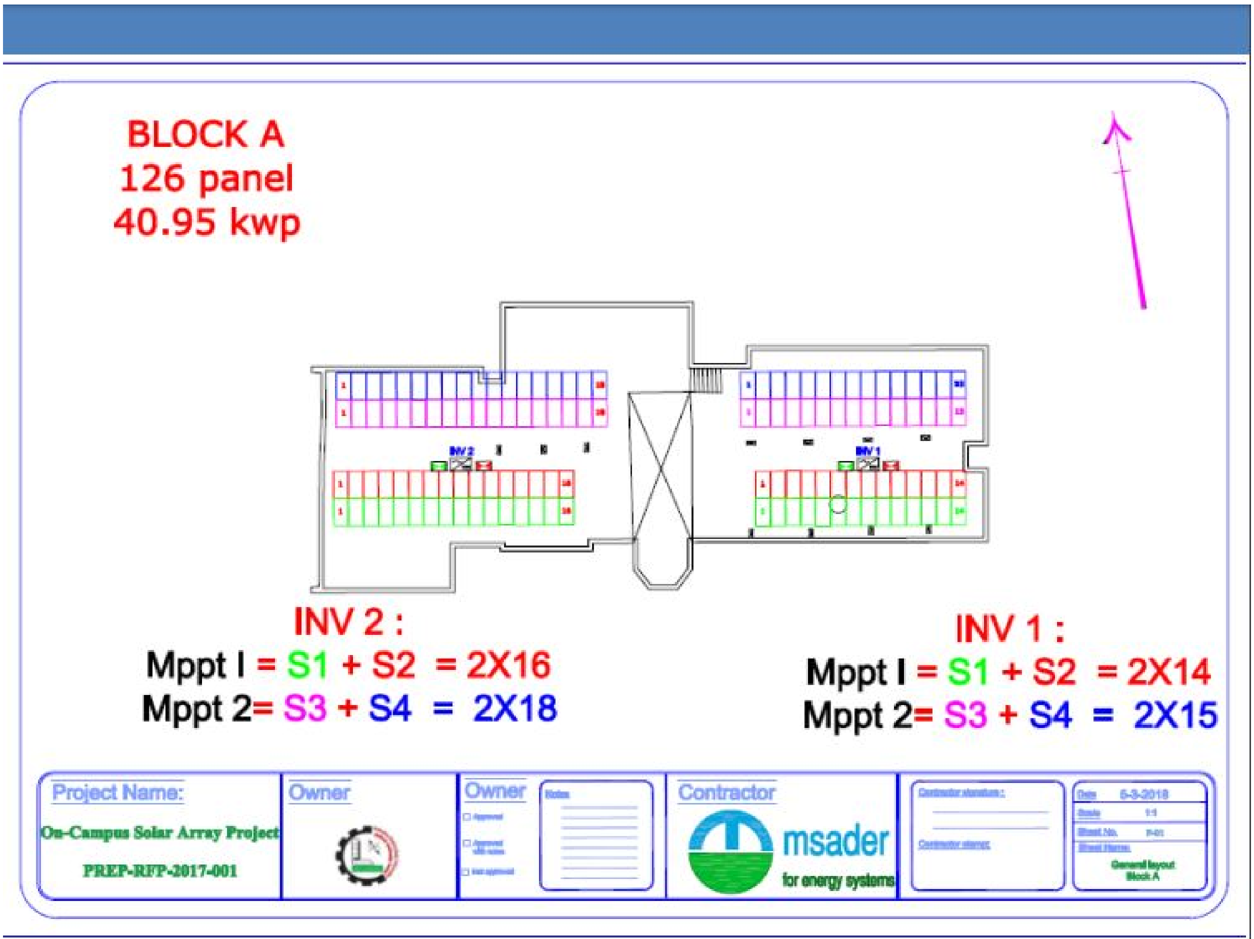
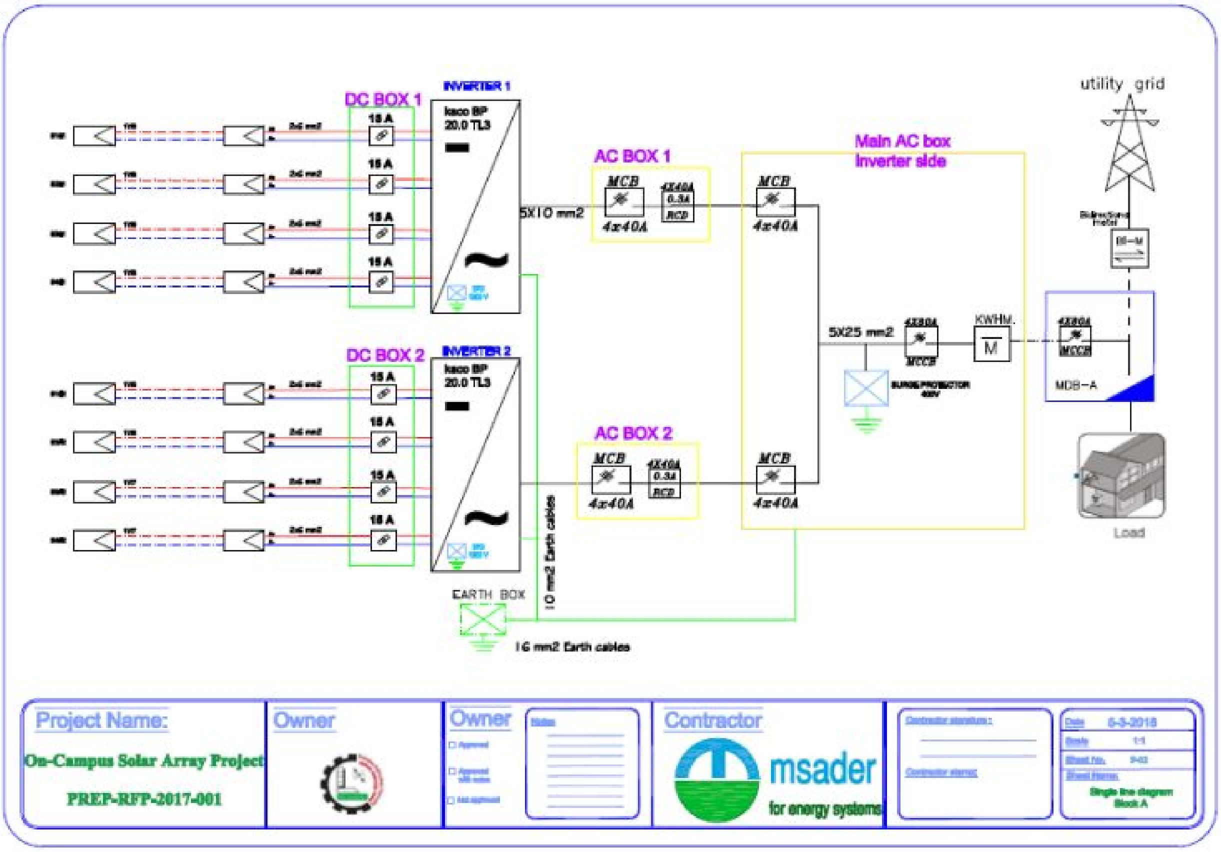


Figure A.9: Distribution of photovoltaic cells on the Inverters for a building A+



DC BOX 1
INVERTER 1
kaco BP
20.0 TL3
15 A
2x6 mm2
5X10 mm2
AC BOX 1
MCB
4x40A
4X40A
0.3A
RCD
Main AC box
Inverter side
utility grid
DC BOX 2
INVERTER 2
AC BOX 2
5X25 mm2
4X80A
MCCB
KWHM.
M
SURGE PROTECTOR
MDB-A
Load
EARTH BOX
10 mm2 Earth cables
16 mm2 Earth cables
Project Name:
On-Campus Solar Array Project
PREP-RFP-2017-001
Owner
Owner
Contractor
msader
for energy systems
Single line diagram
Block A

Appendix B

Results report

B.1 Photovoltaic System and Main Grid

B.2 Photovoltaic System, Wind Turbine and Main Grid

B.3 Photovoltaic System, Wind Turbine,Diesel Generator and Batteries

Table B.1: Daily load for 5,6,7,9 from March

Hour	5-March Load kWh	6-March Load kWh	7-March Load kWh	9-March Load kWh
0	27.0955	27.0955	27.0955	28.59
1	27.938	27.938	27.938	29
2	28.894	28.894	28.894	29
3	29.387	29.387	29.387	19
4	29.0185	29.0185	29.0185	17
5	26.8865	26.8865	26.8865	24.5
6	40	40	40	36.6
7	90	90	90	58.8
8	282.68	292.072	256.108	252.071
9	315	313.542	274.587	273.924
10	304.324	313.744	158.012	132.898
11	329.183	321.473	162.015	181.223
12	314.971	305.358	283.093	95.65
13	278.461	294.085	259.821	268.285
14	262.455	261.736	225.019	163.864
15	200.483	189.074	135.354	135.354
16	40	40	40	40
17	40	40	40	35
18	24.493	24.493	24.493	24.461
19	23.981	23.981	23.981	17.081
20	26.137	26.137	26.137	19.371
21	25.258	25.258	25.258	29.097
22	22.607	22.607	22.607	29.317
23	23.463	23.463	23.463	28.595
Total	2782.72	2786.24	2249.17	1948