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On Grid photovoltaic System in Palestine: A Case Study of techno-economic impact for Dar Salah School

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Dedication

With the help of God Almighty and the success of the Almighty, this research was accomplished.

I dedicate this work first to my parents... my role models in life, who have the first and last credit for achieving this achievement through their support and encouragement of my education.

My honorable professors, supervisors, and faculty members have never been stingy in giving any information or any valuable idea.

My colleagues and comrades have never been stingy in helping me.

Bassam saleem

Declaration

I certify that this thesis submitted for the degree of the master is the result of my research, except where otherwise acknowledged, and that this thesis, neither in whole nor in part, has been previously submitted for any degree to any other university or institution.

The work was done under the supervision of Dr. Husain Alsamamra from the physics department- Al-Quds University.

Signed:

Bassam Odeh Salameh Saleem

Date: 29 / 4 / 2023

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Praise be to God and thanks be to him as it should be for the majesty of his countenance and the greatness of his authority, the number of his creation, the pleasure of himself, and the weight of his Throne and ink his words that it is Ali to complete this study, and prayers and peace be upon the best of creation, our master Muhammad and his family and companions and peace be upon him abundantly.

I extend my thanks and appreciation to his excellency the supervisor, Dr. Husain Alsamamra, who was after God - the Almighty - the first helper for me to complete this study. He has all the appreciation and gratitude.

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Finally, I would like to extend my thanks and appreciation to my generous parents for their care and support throughout the study period, so may God reward them on my behalf.

Abstract

The increase in electric energy consumption and the immediate need for electricity in Palestine leads us to strengthen and develop the electric power system. In this work, the photovoltaic system at Dar Salah School for Boys was studied, which was installed on 1/1/2020. My work focused on the installation, features, determination of system performance and output, and analysis of economic feasibility and efficiency of this system using Ret screen & PV System.

Upon completion of the system performance evaluation study, it was found that the system outputs are lower than the expected for technical reasons and external factors that were not taken into account when installing the system. These problems facing the system were identified and the ways to address them were put forward to maintain the expected system productivity.

The system represents a good investment case for the Ministry of Education because it almost covers the school's energy needs according to the percentage agreed upon with the company and the price per kilowatt .hour with the Electricity Company. It represents a good investment case for many companies to exploit renewable energy sources if there are encouraging government laws and regulations.

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LIST OF ABBREVIATIONS

PV	photovoltaic
RE	Renewable energy
IEC	Israel Electrical Company
PA	Palestinian Authority
spD	surge protection Device
CoE	Cost of Energy
PSH	Peak Sun Hour
PV- syst	PV-syst software
MENA	Middle East and North Africa
KVA	kilo Volt Amperes.
STC	Standard Test Conditions
AC	Alternative Current
DC	Direct Current
MPPT	Maximum Power Point Tracking.
Vdc	Volts direct current
LCC	Life cycle cost
KWh	Kilo Watt-hour
Pc	package software computer

LIST OF SYMBOLS

I	Output Current
Imp	Current at Maximum power
Voc	Open Circuit Voltage
Isc	Short Circuit Current
Vmp	Voltage at Maximum power
ɳ Sys	total system efficiency
Wp	peak Watt
Mpp	Maximum power point
PR	performance ratio

Chapter One

Introduction and Literature Review

1.1 Introduction

Energy is very important in many sectors of the world and supports aspirations to the comfortability In our life, especially with increasing the population, which leads to growing energy demand. Burning fossil fuels provide us with traditional energy resources which pollute the environment, in addition, the cost was increased since 1970 though it's still available [1-2]. Natural energy such as wind, solar, and hydropower energy is part of renewable energy sources [3], the reduction of equipment cost drives us to start using it to generate electricity around the most region in the world in addition to that, the use of RE in electricity generation at 2020 is about 25% [4].

Rooftop PV systems and large grid PV systems have been installed over the past ten years with grid-tied systems in many countries that show great potential for solar energy in the Middle East and North Africa (MENA) and Europe such as Cyprus, Jordan, Tunisia, Palestine, Italy, Spain, Portugal, and France since MENA region have higher solar radiation, so the drop in the PV price in parallel with improving the efficiency of its cells, and the increase in fuel price [6], all of them get the PV system competitive with other electricity generation, thus PV's now is the most world popular electricity source [6].

MENA region has two accounting schemes that are active tools for running the PV market, this is the Net-Metering and Feed-in Tariff schemes [7], the rules of these differ from country to country, for example in Israel the Net-Metering scheme at end of the billing year allows the PV owner to credit the surplus generated PV energy for the following 24 months, and in Cyprus, is forced to pay a fixed credit based on the installed PV capacity, but in Palestine [7] will decrease the cost as consideration for using the electric grid to 25% of the monthly energy generated by PV [5].

The increase in electric energy consumption and the immediate need for electricity in Palestine leads us to strengthen and develop the electric power system. The use of renewable energy systems, especially solar energy, is one way to produce a system of sustainable and environmentally friendly electric energy in Palestine, where Palestine has great potential for solar radiation.

1.2 Energy Situation in Palestine.

Palestinian territories suffer from the scarcity of conventional energy sources, high population growth, and rising prices of energy [8]. Thus, this would lead Palestine to a developing energy crisis. In 2018, Palestine's total energy demand reached around 5800 GWh, in which the Israel Electric Company (IEC) covered around 92.6% of this demand. The rest of the energy supplies are from Jordan (1.5%), Egypt (0.6%), and Gaza Power Plant (4.4%) [9]. Meanwhile, renewable energy sources accounted for 10.2% respectively of the total demand in 2018 [9]. The high-energy imports from the IEC had left the Palestinian Authority (PA) with an estimated debt of 574 million USD [3]. On the other hand, the cost of energy (CoE) is relatively high in Palestine, where CoE is approximately 0.6215 ILS/kWh for the residential sector. Meanwhile, the CoE in Israel is approximately 0.4516 ILS/kWh [10]. It is expected that seasonal power shortages will be emerging in the West Bank following a demand growth of 3.5% per year until 2030**.**

1.3 Solar Energy in Palestine

Palestine has a high potential for solar energy. It has over 3000 sunshine hours/per year and a high annual average solar energy radiation [11, 12]. As shown in figure 1.1, the monthly average solar radiation in Dar Salah village was obtained from the RET screen Expert.

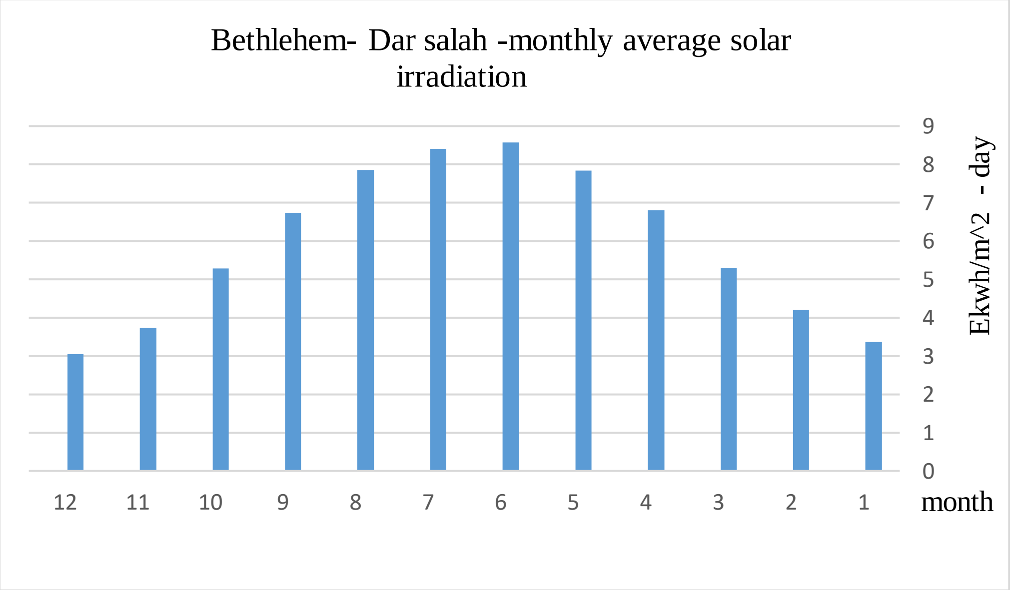

Figure 1.1 Histogram of Monthly Average Solar Potential in Dar Salah Area.

The figure shows that the average solar radiation varies with the season: it reaches a minimum value of 3.05 kWh/m^2 in December and a maximum value of 8.57 kWh/m^2 in June.

In conclusion, on average Bethlehem- Dar Salah has a solar global horizontal irradiation of 5.94 kwh/m$^{\wedge 2}$ which yearly stand for about 1960 kwh/m$^{\wedge 2}$.

Solar PV systems have several advantages and one of these is the cost and the installation, they are easier and faster in comparison to other types of renewable energy sources. Thus, it is cost savings, safe investment, increasing access to energy, government subsidies; reducing carbon emissions, and low maintenance costs [13].

1.4 Literature review

Previous research has reported an analysis of the long-term performance of grid-connected rooftop solar PV systems in different Mediterranean countries. Ghouri et. al. (2015) analyzed the performance of 1.6 kW of PV power at the University of Batna, Algeria. The average solar radiation was 5.21 kWh/m$^{\wedge 2}$ per day and the PV system was monitored for one year of operation to evaluate the performance of the on-grid PV system. The performance ratio ranged between 51% and 61% and the total connected energy of the network was 1705 kWh/year. The annual yield was 1065 kWh/kWp, and all the energy generated from this aforementioned PV system was delivered to the university's internal electrical grid. [14]

Ayadi et. al. (2018**)** conducted a study that aims to analyze the performance of connected networks of the photovoltaic system at the University of Jordan, the final output of the system ranged from 1600 -1715 kWh / kWp and the payback period was about 3 years[15].

Alsamamra and Shoqeir (2021) analyzed the solar photovoltaic systems in Public Schools buildings, their study aimed to exploit renewable energy sources and help independence in the field of energy. Their work was a comprehensive assessment of the potential of renewable energy to penetrate the electricity needs of Palestine. Al Dhaheriya Secondary School in the Directorate of Education, south of Hebron, was used as a case study, the results showed that the ceiling accommodates 144 panels with a power of 57.16 kilowatts. They found that the system would produce 92,866 kWh each year, which could represent an input of 5.12% of the total annual energy consumption in Palestine if this system is installed in every school in Palestine, which totals 3,074 schools. The calculations found that the payback period is 4.38 years, and the surplus income when installing this project in all schools in Palestine will reach about 43 million US dollars for the Palestinian treasury each year after the payback period [16].

Manoj and Kumar (2018) studied the on-grid solar photovoltaic system components, design, and considerations, this PV system consists of a 95 kWp PV array comprising 312 PV modules, and Four 25-kVA inverters. Results include the online monitored data on power generation in kWh/kWp, energy saved in MWh, and CO_2 emissions avoided. Along with this, the simulated energy performance of the PV system was also illustrated. They conclude that the promotion of solar PV plants in educational institutes would help in reducing their energy consumption bills and helpful in carrying out research activities [17]

The techno-Economic impact of grid-connected rooftop solar PV systems for schools in Palestine was studied by Ibrik (2019), the study provides a 12-month performance evaluation of the 7.68 kW grid-connected PV systems on the roof of each of the three schools that were taken as a case study: Al-Razi School for Boys, Al-Mouh school for boys, Khawla Bint Al-Azwar school for girls. The average performance ratio was found to be 78%, and the annual average energy produced by each system equals 10.930 MWh/year. Consequences economic analysis encourages intensification of the use of PV school systems because the payback period of such a system is less than 5 years, the cost of a produced kilowatt-hour is about 0.1 US dollars, and the internal rate of return is about 20%. Besides these results, his work also presented the effects of the systems on the electrical network represented in reducing losses, raising the level of voltage, and the impact of photovoltaic systems on the environment [18].

Al-Otaibi and his co-workers (2015) presented a study on the performance evaluation of photovoltaic systems on Kuwaiti schools' rooftops. The study was conducted on the performance of grid-connected PV systems, which were analyzed based on 12 months of field data, producing promising initial results. The results showed that the average PV performance ratio was no less than 0.70 Moreover; the minimum monthly energy yield of the PV systems was about 104 kW h/kWp. The annual average daily final yields of the PV systems in this study were 4.5 kW h/kWp/day. Due to the installation of an automated cleaning system set to run weekly [19].

Khatib and Bazyan (2021) studied the current energy policy model for photovoltaic power generation in Palestine and the challenges it faces. According to the results, the average production factor of photovoltaic systems in Palestine varies between 1368 and 1816 kWh/kWp per year with a payback period of 5.5 - 7.4 years but the evaluation campaign also showed that 47% of the selected systems are not working correctly and thus are categorized as failures. In this research, the authors concluded that this large proportion of the failure of the PV system is due to several behavioral and structural reasons; lack of awareness and lack of non-technical information was found to be the main behavioral reasons, while the network infrastructure, the lack of technical standards and personnel training as well as loose and discouraging policies are the most common structural causes [20].

1.5 Objectives of Thesis.

The main objective of this study is to analyze the components and installation of the solar system and determine the long-term performance of grid-connected photovoltaic systems in Palestine. To check the performance and the results of the system, study the problems that face the system, and find an appropriate solution.

Discuss and analyze the feasibility and efficiency of using economic indicators for grid-connected solar energy systems through a review of sustainable development.

Coming up with recommendations and results that the researcher can generalize on a larger scale in the long run.

1.6 Statement of the problem

The problem of this study represents the mysterious installation of the solar system at Dar-Salah School, in which the components of the system, its performance, outputs, saving quantity, and other issues are not reflected in the reports of the school. Therefore, this study will reflect all related issues of the on-grid solar system in Dar-Salah school, to be documented and controlled after analyzing the needed issues.

Most of these grid-connected systems have an energy yield of less than expected. Moreover, despite this huge amount of installed PV systems, a significant reduction in energy demand from Israel was not noticed in Palestine. Based on that, this research aims to discuss the current energy policy model for photovoltaic generation in Palestine. The model is reviewed and analyzed to show the current challenges that it faces. Moreover, this photovoltaic system was selected for technical and economical evaluation in this research to show first the typical performance of photovoltaic systems in Palestine. Second, the analysis is done to prove the failure of many systems due to many behavioral and structural barriers. These barriers are also discussed and analyzed in this research.

Chapter Two

On-Grid PV system

2.1 Introduction

The grid-connected PV system is one of the PV technology where electricity-producing by solar panels then joined to the utility grid [21, 22], because of reducing the PV cost from one side and creating governmental regulations in Palestine on the other side, all of them with benefits of RE help to encourage the usage of RE such as using of grid-connected PV systems whether, on the ground or the rooftop of buildings, all of these was a help to begin to expand since 5 years in Palestine [18, 21], such as the Palestinian government announced in 2015 the legislation of Net- Metering to control the on-grid PV system [5, 23].

The School's rooftop PV systems will give many advantages to the Palestinian economy, as those will produce significant savings for the price of electricity bills to schools and a coat portion of its expenses, In addition to bringing Palestine closer to energy independence and encouraging its commitment to RE. It will also create knowledge of green energy in schools and make sustainable energy practices in the educational environment in Palestine, and therefore the installation of photovoltaic energy systems on the roofs of schools has two-way benefits, and the first direction is to contribute to and strengthen the plans and strategies of the authority to reduce dependence on the Israeli occupation in purchasing energy to support Electricity distribution and Palestinian municipalities in easing pressures and debts on them by reducing dependence on purchases and minimizing losses, as well as lowering the prices of electricity purchased from the Israeli occupation. The second trend is related to education for students, motivating them, setting a practical model for them to improve energy technologies, and helping students in schools also learn and study how electricity works, the benefits of RE, and energy efficiency. Likewise, it is important to note the encouraging nature of school consumption so that you work there for five days from seven in the morning until three in the evening mostly, as well as the winter vacation and the summer vacation are a great encouragement to invest in schools, especially when talking about the feed-in tariff scheme.

The Higher Education and Palestinian Ministry of Education emerged a national program to deploy solar PV systems on the rooftops of 500 public schools in Palestine having a total generation capacity of 35 MW, this program is based on a net metering scheme, and the aim of this program shown in figure 2.1 [24,18].

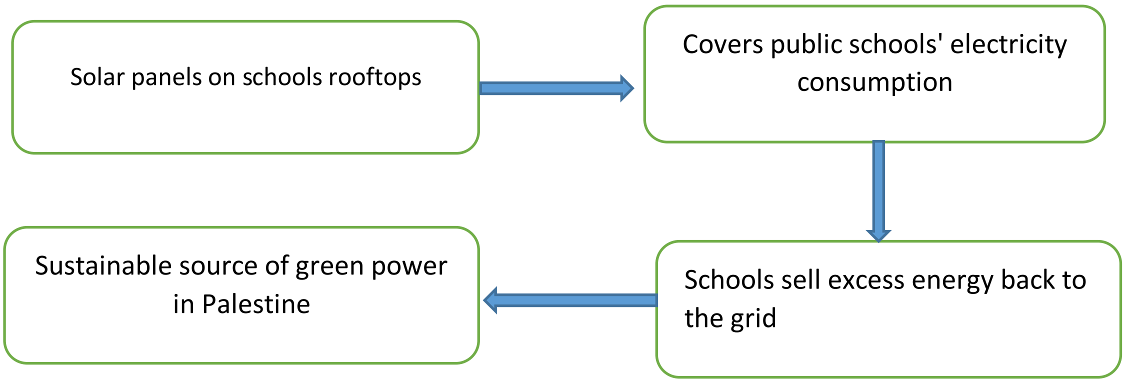

Figure 2.1 Schematic chart solar photovoltaic system public school program in Palestine

2.2 On Grid System Configuration.

An on-grid solar photovoltaic system generates electrical power with the help of solar photovoltaic harvesters and delivers the power to an electric utility. The schematic view and working flow of the system are clearly shown in Fig. 2.2 Various components involved in the system are discussed in sub-section-A, and the brief operation of the system is dealt with in sub-section-B.

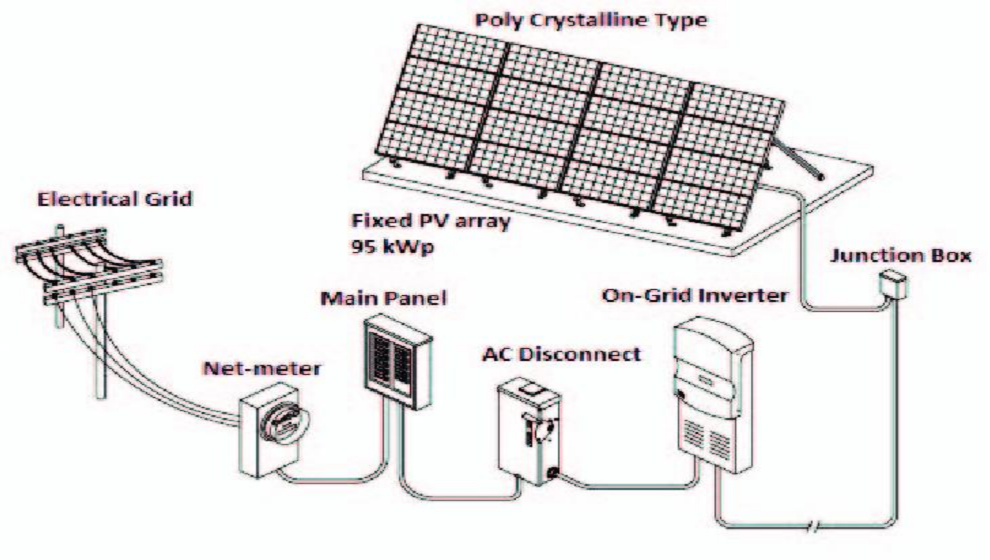

Fig 2.2 Schematic view of the on-grid photovoltaic system reprint [25]

A. Components.

The various components involved in the grid-connected photovoltaic system are as follows [25-27].

1) **Photovoltaic Modules**:

Mono-crystalline solar cells are referred to as Si-mono. Si-mono photovoltaic modules or cells are made from a single cylindrical crystal ingot having high purity. From the single crystal, wafers can be sliced and cut into octagonal shapes. At Standard Test Conditions i.e. STC 1000 W/Sq. m, Si-mono cells show the best performance but the same cell shows poor performance when temperature levels rise [28].

Poly-crystalline solar cells are referred to as Si-poly. Si-poly modules or cells consist of small crystals which make the cell or module look like a "crystal grain known as crystallites". Si-poly cells are "produced by sawing a square cast block of silicon first into bars and then into wafers". These cells perform better at STC and the performance reduces as the temperature rises. Si-poly modules are configured by series and parallel combinations to form Si-poly PV generators as per the requirement [28].

Amorphous silicon solar cells are simply referred to as Siamorph. The Si-a morph PV generator is configured with sets of Si-a morph PV modules. These modules are thin films and made by sandwiching one-μm thick Si-a morph materials between two sheets of glass. Si-a morphs photovoltaics perform better than those of Si-mono and Si-poly crystalline under elevated temperature conditions when compared to crystalline silicon cells [28].

2) **Junction Box:** Junction boxes have mainly been used in two different places in photovoltaic systems, one of which is at the interconnection of the power transformer. Here all the photovoltaic chains are linked together. Another place in the solar PV enclosure where this junction is used includes bypass diodes that allow power to flow in one direction only, i.e. from the solar panels to the utility system.

3) **On-Grid Inverter:** An on-grid inverter converts DC power into AC power. This is an essential component of photovoltaic systems to communicate with the existing energy sector. We have various types of transformers available in the market that are rated from small kVA to larger kVA. The inverter currently available comes with MPPT enabled and a wider input Vdc range.

4) **AC disconnect and main panel:** In photovoltaic systems, AC disconnect and DC are the two boxes where the role of the AC disconnect is to disconnect the on-grid power transformer, i.e., the

DC-AC inverter from the electrical utility network. The output currents of the inverters must be taken into account while sizing the AC disconnect which is simply a circuit breaker. This is generally placed on the main board. The main panel is shown in the picture before the electrical system can be integrated into the electric power grid. This generally consists of electromechanical devices that are used to disconnect the photovoltaic system from the electrical grid**.**

5) **Net Meter**: A net meter is a device that is used to monitor the inflow and outflow of electricity between the electrical power generating system and the electric utility grid. In photovoltaic systems, if excess energy is generated that can be sold to the utility using this.

6) **Electrical Grid**: It is an electrical power grid that connects load centers and energy providers. It is one of the main parts of the electrical power system network that acts as an interface between the power generation plant, power transmission line, and distribution lines. It transmits the electrical energy that is generated using any source (renewable or non-renewable) anywhere and distributes it finally to consumers according to requirements.

B. Operation

A photovoltaic system operates to generate electricity and the process is similar for both off-grid and on-grid photovoltaic systems. When the energy of the light falling on the photovoltaic module is sufficient to produce electrons, DC power is generated at the output terminals of the photovoltaic array and then fed to the transducers, which in turn help in converting the direct current to the alternating current. AC power can be used directly for electrical loads, or it can be supplied to the utility grid using net metering. If the generated power is used for different load applications at the same generation level, it is said to be an independent photovoltaic system, if the generated power is fed continuously to the utility grid, it can be called an on-grid photovoltaic system [25-26]

2.2.1 **Module Efficiency.**

The efficiency of each PV product is specified by the manufacturer. Efficiencies range from as low as 5% to as high as 15%–19%. A technology's conversion efficiency rate determines the amount of electricity that a commercial PV product can produce. For example, although thin film amorphous silicon PV modules require less semiconductor material and can be less expensive to manufacture than crystalline silicon modules, they also have lower conversion efficiency rates. These will need close to twice the space of a crystalline silicon PV array because its module efficiency is halved, for the same nominal capacity under Standard Test Conditions (STC)

The conversion efficiency of different PV cell technologies is summarized in Table 2.1.

Table 2.1 Conversion efficiencies of various PV module technologies.

PV type	**Module Efficiency**
Mon crystalline (m-si)	14-19%
Polycrystalline (p-Si)	12-15%
Thin film Amorphous silicon (a-si)	6-8%
Thin film CIGS/ CIS	9-12%
Thin film CdTe	7-10%

2.2.2 **Solar PV panel**.

The solar cell consists of a layer of silicon to which some impurities are added to give it some electrical properties. The upper layer opposite the sun is added to the element phosphorous, to give it the property of pumping electrons when light hits it, and this layer is called (N-Type). While boron is added to the lower layer and gives it the property of absorbing electrons and this layer is called (p- Type). The working principle for the silicon solar cells is shown in Figure 2.3.

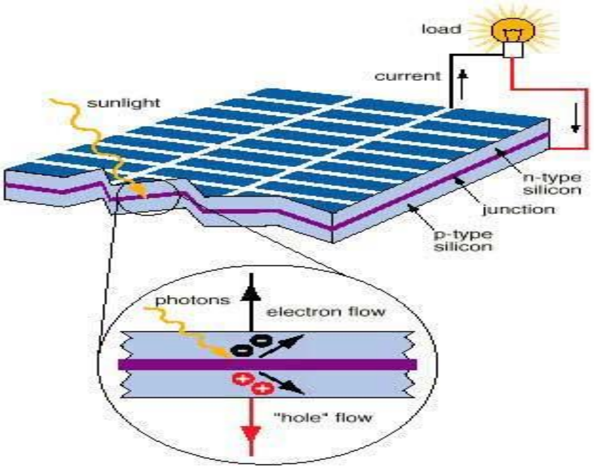

Figure 2.3: Schematic of the basic structure of a silicon solar cell reprint [29].

In a silicon crystal, each atom is bonded to another atom by a covalent bond and thus contains no free electrons. For this reason, it resorts to the grafting process, in which the silicon atom is replaced by a pentavalent atom such as phosphorous, and this provides free-moving electrons capable of conducting. This type of flake (N-type) is called the negative layer,

the silicon atom is replaced by a trivalent boron atom, so there is a shortage of electrons, and this lack of electrons generates positive holes resulting in positive flakes (P-type) .fig 2.4 This is the basic difference between n-type and p-type semiconductors

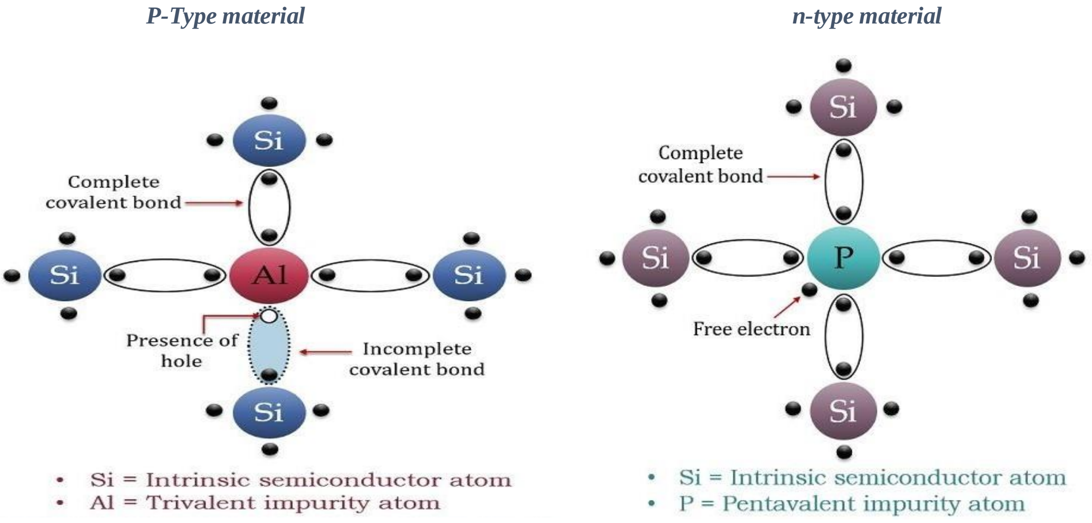

Figure 2.4 basic difference between n-type and p-type semiconductors [30].

Each solar cell consists of several layers, the most important of which is the transit layer, which is responsible for the direction of electron movement. When light is absorbed from the upper layer, the free electrons gain kinetic energy that depends on the intensity of the radiation. It is transmitted to the positive holes through the jumper layer, which creates an electric field between the two layers, which causes a potential difference, and creates an electric current [29, 30].

2.2.3 **Photovoltaic power**

The type of solar power produced by a photovoltaic solar cell is called direct current or DC the same as from a battery. Most photovoltaic solar cells produce a "no load" open circuit voltage of about 0.5 to 0.6 volts when there is no external circuit connected. This output voltage (VOUT) depends very much on the load current (I) demands of the PV cell. For example, on a very cloudy day, the current demand would be low and so the cell could provide the full output voltage, VOUT but at a reduced output current. But as the current demand of the load increases a brighter light (solar radiation) is needed at the junction to maintain a full output voltage, VOUT. However, there is a physical limit to the maximum current that a single photovoltaic solar cell can provide no matter how intense or bright the sun's radiation is. This is called the maximum deliverable current and is symbolized as IMAX. The IMAX value of a single photovoltaic solar cell depends upon the size or surface area of the cell, the amount of direct sunlight hitting the cell, its efficiency of converting this solar power into a current, and of course the type of semiconductor material that the cell is manufactured from either silicon, gallium arsenide, cadmium sulfide, cadmium telluride, etc. Most commercially available photovoltaic solar cells have solar power ratings, which indicate the maximum deliverable solar power, PMAX that the cell can provide in watts and is equal to the product of the cell voltage V multiplied by the maximum cell current I and is given as:

$P_{MAX} = V_{OUT} \times I_{MAX}$

Where: P is in Watts, V is in Volts, and I is in Amperes.

Various manufacturers refer to a PV cell's output power at the full sun as its: "maximum output power", "peak power", "rated power", "maximum power point" or other such terms but they all mean the same

2.2.4 **Photovoltaic I-V Characteristics Curves**

Manufacturers of photovoltaic solar cells produce current-voltage (I-V) curves, which give the current and voltage at which the photovoltaic cell generates the maximum power output and are based on the cell being under standard conditions of sunlight and temperature with no shading.

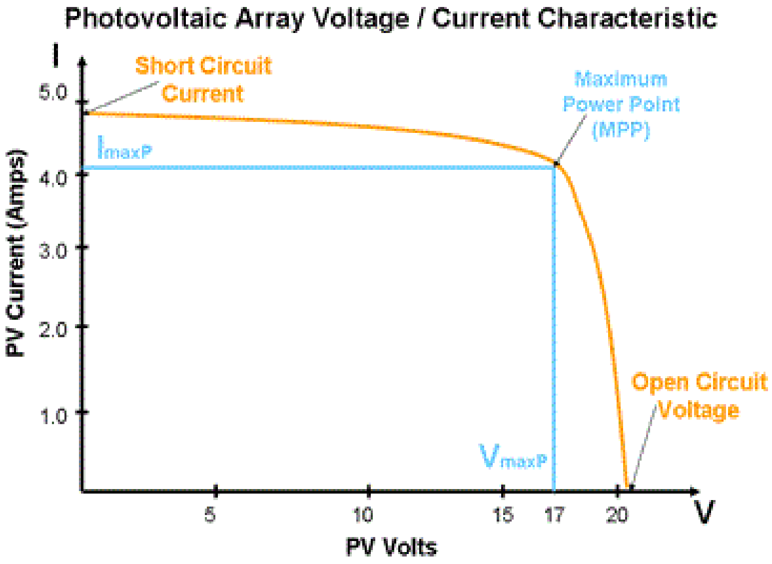

Figure 2.5. Typical current-voltage curve of a photovoltaic module

Voltage (V) is plotted along the horizontal axis while Current (I) is plotted along the vertical axis. The available power (W) from the PV, at any point of the curve, is the product of current and voltage at that point.

2.2.5 **Short Circuit Current (ISC)**

A photovoltaic module will produce its maximum current when there is essentially no resistance in the circuit. This would be a short circuit between its positive and negative terminals. This maximum current is called the short circuit current (Isc). This value is higher than Imax which relates to the normal operating circuit current. Under this condition, the resistance is zero and the voltage in the circuit is zero.

2.2.6 **Open Circuit Voltage (VOC)**

Open circuit voltage (Voc) means that the PV cell is not connected to any external load and is therefore not producing any current flow (an open circuit condition). This value depends upon the number of PV panels connected in series. Under this condition, the resistance is infinitely high and there is no current

2.2.7 **Maximum Power (PMAX or MPP)**

This relates to the point where the power supplied by the array that is connected to the load (batteries, inverters) is at its maximum value, where Pmax = Imax x Vmax. The maximum power point of a photovoltaic array is measured in Watts (W) or peak Watts (Wp). Imax and Vmax value occurs at the “knee” of the I-V curve

2.2.8 **PV Panel Energy Output**

You have learned previously that the power output of a photovoltaic solar cell is given in watts and is equal to the product of voltage times the current (V x I). The optimum operating voltage of a PV cell under load is about 0.46 volts at normal operating temperatures, generating a current in the full sunlight of about 3 amperes. Then the power output of a typical photovoltaic solar cell can be calculated as: P = V x I = 0.46 x 3 = 1.38 watts. Now, this may be okay to power a calculator, small solar charger, or garden light, but this 1.38 watts is not enough power to do any usable work. However, when the PV cells are connected in series (daisy chained), the voltage is added and when connected in parallel (side-by-side) the current is added. Suitable combination PV modules in series and parallel give you the desired voltage, current, and power output

2.3 PV Array Sizing

The equation that may be used to size a stand-alone PV system is:

$$W_{PV} = E / P_{SH} \times \eta_{sys}$$

- W_{PV} = peak wattage of the array, Wp
- E = daily energy requirement, Wh
- PSH: the average daily number of Peak Sun Hours in the design month for the inclination and orientation of the PV array
- η Sys = total system efficiency

The month that the system is designed is the month with the lowest average daily solar radiation during the operational period of the system. The number of peak hours is for the inclination and orientation of the PV array. If the only information available is for solar radiation in a horizontal plane, then a tilt and orientation correction factor should be applied.

2.3.1 **Wiring Solar Panels in a Series Circuit**.

Connect the positive terminal of the first solar panel to the negative terminal of the next one. Example: If you had 3 solar panels in a series and each was rated at 6 volts and 3 amps, the entire array would be 18 volts at 3 amps

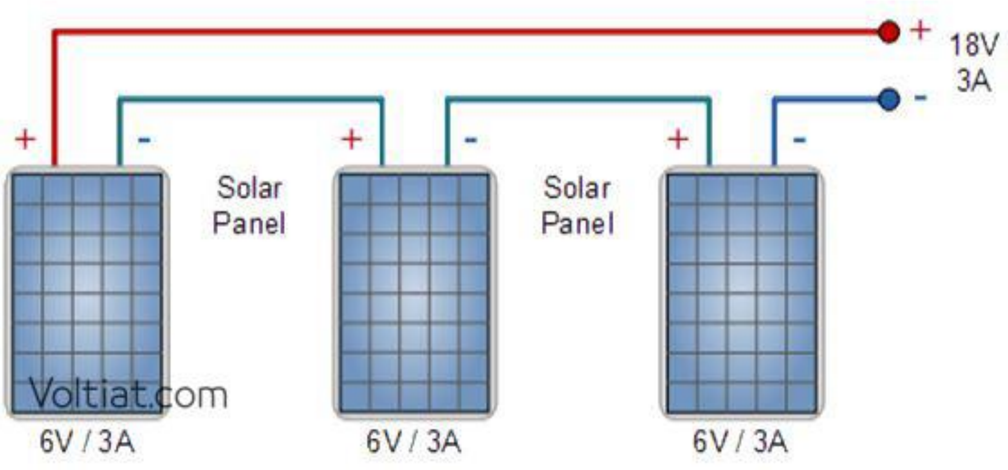

Figure 2.6. Three panels wired in Series

2.3.2 **Wiring Solar Panels in a Parallel Circuit**

Connect all the positive terminals of all the solar panels and all the negative terminals of all the panels. Example: If you had 3 solar panels in parallel and each was rated at 6 volts and 3 amps, the entire array would be 6 volts at 9 amps.

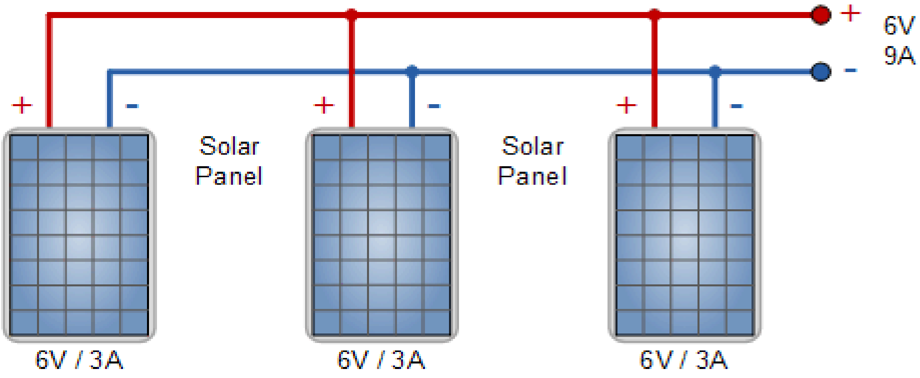

Figure 2.7. Three panels wired in parallel

Chapter Three

Economic Viability of PV System

3.1 Introduction

Palestinian industry of Grid solar pv systems is reflected in the operations of Massader Company, which offers to install solar panels on the rooftops of 500 schools in the West Bank. Schools will get clean electricity for free, while the excess electricity supply will flow into the West Bank electricity grid [31]. The Ministry of Education will get 18% of the generated energy and the rest for Massader [32]. The International Finance Corporation provides projects with a budget of 32$ million to support Palestine in the field of renewable energy. The solar panels will provide a sufficient amount of electricity to about 16,000 homes. The project is a major support for "Noor Palestine", an ambitious program by Massader that aims to produce 200 megawatts of solar energy [33]**.**

The implementation of rooftop solar PV systems in schools is set to bring a host of benefits to the Palestinian economy. For one, the projects will result in significant savings on electricity bills for the schools, which can be allocated to other expenses. Moreover, the initiative will raise awareness about green power and encourage sustainable energy practices in public schools. Additionally, electricity distribution companies and municipalities in Palestine stand to benefit from the availability of power at lower costs than what is currently offered through occupation, and technical losses will be reduced. At a national level, the systems will move Palestine closer to energy independence and reinforce the country's commitment to renewable energy. [34].

An economic evaluation of residential grid-connected PV systems based on net-metering and feed-in tariff schemes in Palestine was studied by Omar (2018). In his study, the net metering and feed-in tariff schemes used to calculate the energy of systems connected to photovoltaic networks in Palestine were evaluated. The net-metering scheme includes two main components that hurt the economics of the PV system. The first component is represented in the monthly subtraction of 25% of the excess PV, as compensation for the use of the electric grid and the second is the disposal of the excess PV energy at the end of each year instead of transferring it to the following year. The economic analysis of the grid-connected PV system attests that net-metering reduces the income of the PV system and thus discourages the expansion of the use of PV systems. Given net metering, a 5 kW PV system with an annual yield of 8686 kWh installed on a house with an annual consumption of 6984 kWh, 19% of the total annual PV generated would not be added resulting in a 5126 $, an internal rate of return of 17.3% The payback period was found to be 7.6 years. On the other hand, the same analysis was used to evaluate the same system with the feed-in tariff, where the total annual PV will be calculated, and the results were found to be 7991$, 22%, and 5.7 years, respectively [34].

3.2 Life cycle cost analysis.

The economic analysis used in this work is based on the use of life cycle cost, annual premium cost (NIS/kWh), and the economic impact of the network Connection PV system.

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

A) Initial Cost of Grid-Tied PV System.

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

Initial cost = Σ Components cost + installation cost

- **Initial Cost of Photovoltaic Modules**

PV modules are available in different sizes and types, and the PV size is characterized by its maximum watts under standard test conditions (rated power). The price of a peak watt is the same for mono or polycrystalline, but the cost of installation or structure will vary depending on the installed PV area. (NIS/Wp) will decrease as unit size increases [35]

- **Initial Cost of Grid-Tied PV Inverter**

The grid inverter is available in different sizes and types. The price of a grid-tied inverter depends on its capacity, efficiency, whether or not it has an MPPT controller, protection, and other parameters [35]

- **Other Initial Costs**

Shipping costs and accessories needed for installation and protection of the system, wiring, and rooms must also be considered. These costs depend on the size of the system and vary by project type; If it is for public use (the land may be freely available), or for private use.

B) Operation and Maintenance Cost of Grid-Tied PV system

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

C) Salvage value

Salvage value is the value of project components after the end of the life of the system. Figure 3.1 shows the cash flow representing primary revenue, maintenance, cost, and salvage revenue.

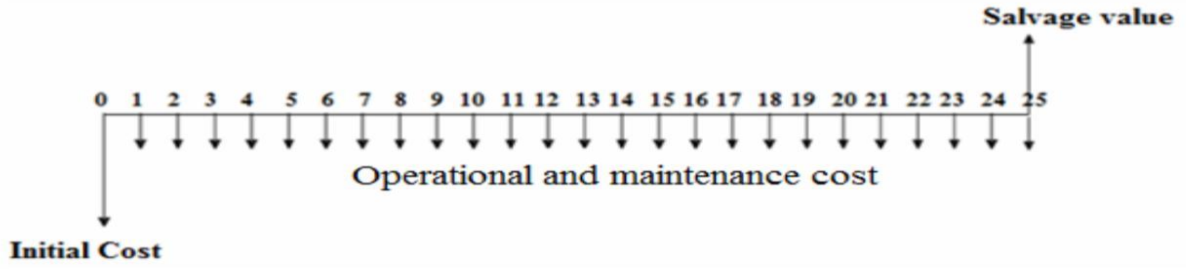

Figure 3.1. The cash flow, which represents the initial, operational cost and salvage revenue

3.3 Economic Factors

To calculate the equivalent uniform annual series (Aw) of cash flow in figure 3.1 the most important fact to remember is to first convert everything to present worth.

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

To convert maintenance and salvage cost to present worth, we multiply with factors (p/A, i ,n) and (p/F, i, n) respectively

The life cycle cost of a grid-tied system= initial cost of the system + Operation and maintenance

X (P / A, i ,n) – salvage value X (P / F, i,n).

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

This expression determines the present worth P of an equivalent uniform annual series A which begins at the end of year 1 and extends for n years at an interest rate i, and (P/A) can be found by equation 3.1:

$$\boldsymbol{P = A\left[\frac{(1+i)^{n} - 1}{i(1+i)^{n}}\right] i \neq o \qquad (3.1)}$$

The term F (P/ F,i, n) is known as the single-payment present worth factor, or the P/F factor. This expression determines the present worth P of a given future amount F after n years at interest rate i, and (P/F) can be found by equation 3.2:

$$\boldsymbol{P = F\left[\frac{1}{(1+i)^n}\right]} \qquad (3.2)$$

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

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

Then the energy unit price calculated from equation 3.3:

$$\boldsymbol{(Nis/kwh) = \frac{AW}{Total\ yearly\ kwh\ produced}} \qquad (3.3)$$

3.4 Cost of producing one kWh from Grid-Tied PV System for Dar Salah School

PV system price and installation are important factors in the economics of grid-tied PV systems. These include the prices of PV modules, Inverters, and all other auxiliary devices as shown in Table 3.1. The cost of installation must be taken into account.

Table 3.1 Cost of elements and installation of grid-tie PV system [36].

Component material or work	**Quantity**	**Price(NIS)**	**Live time year**
PV –module	80.94kwp	105000	25
Inverter	2	24500	25
Mechanical part, installation Material and various accessories		122500	
Total		252000	

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

1- The lifecycle of the system components will be considered 25 years.
2- The interest rate is about 10%.

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

The initial cost of the PV system = 105000+24500+122500 = 252000NIS.

The annual maintenance and operation costs are about 2% of the initial cost which is equal to 201.6 NIS/year, salvage value after 25 years is taken 15% from the initial cost and it is equal to 37800 NIS. The life cycle cost of the PV system is obtained by drawing cash flow as in figure 3.2.

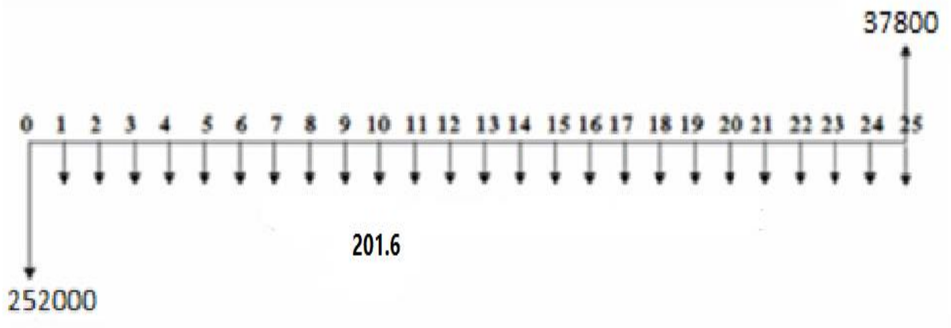

Figure 3.2 Cash flow of grid-tie PV system for Dar Salah school.

The life cycle cost of the PV system = 252000 + 201.6 (P / A, i, n) – 37800 (P / F, i,n).

PW = 252000 + 201.6 (P / A 10%, 25) – 37800 (P / F 10%, 25).

The factors in the above equation are Calculates from eg 3.1 and 3.2

PW = 252000 + 201.6 x 9.0770 – 37800 x 0.0923 = 250340.9832 NIS.

AW = PW (A / P, i , n) = 250340.9832 (A / P 10% , 25).

For eg (3.1) the term (A / P 10%, 25) is equal to 0.11017,

then:

AW = 250340.9832 (A / P 10%, 25)

AW =250340.9832 x 0.11017 =27580.06612NIS.

The cost of 1 kWh from the PV generator = 27580.06612NIS / 135000 kWh = 0.204 NIS/kWh.

3.5 Grid-Tied System Tariffs

Electricity delivered to the grid can be compensated in several ways such as net metering

3.5.1 **Net Metering Tariff**

A solar photovoltaic system generates electricity by converting sunlight into electricity that can be used in your home and school. This reduces the amount of electricity you need to purchase from your utility. If your system is producing more electricity than you need at any time, it will cycle your meter backward to supply the grid. Your utility tracks how much electricity you supply to the grid as well as how much you buy and bills you only for your net electricity consumption (via net metering). At the end of any billing period, if total electricity production exceeds consumption (indicated by a negative meter reading), a billing credit will be applied to your next bill [37].

Adheres to net metering scheme Customers with photovoltaic systems have a two-way kWh-meter as shown in Figure 3.3 This meter measures Energy consumed from the grid when photovoltaic generation is less than consumption and measures excess power It is injected into the grid when it exceeds PV generation Consumption.

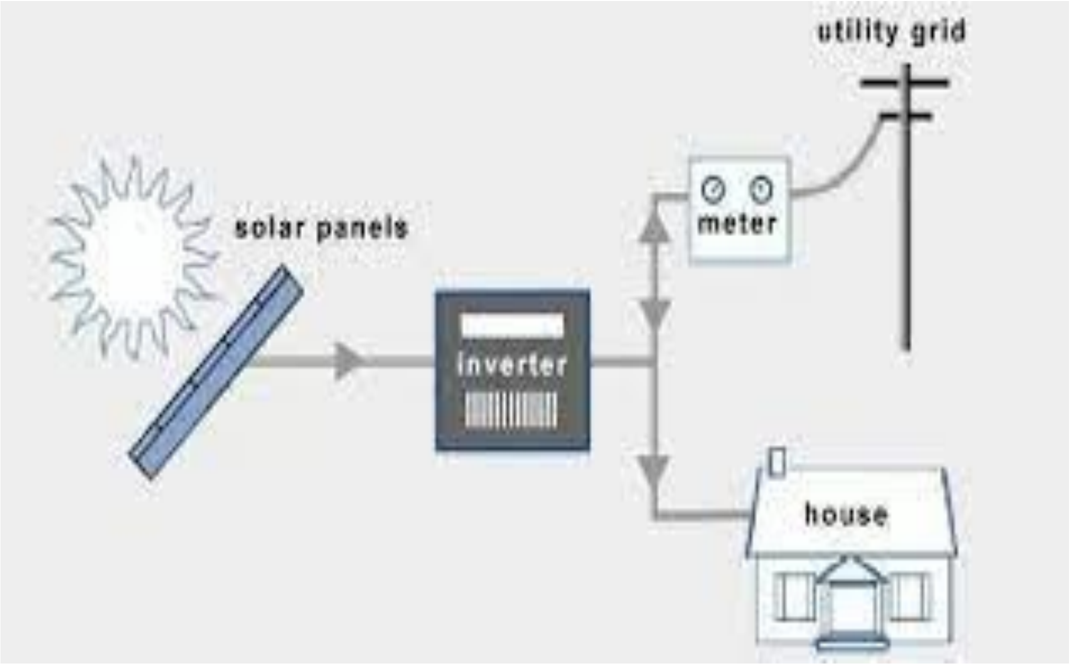

Figure 3.3. Grid-tied net metering tariff.

3.5.2 **Evaluation of the Economic Impact of Dar Salah school Grid-Tied PV system**

As shown in Figure 3.4 the two-way energy meter measures the net value between the load energy consumption and the energy transmitted to the grid.

The following equation determines the annual total energy cost measured by the two-way energy meter.

The annual cost for energy measured by the meter = (PV energy − Energy consumption before PV installation) x cost of 1kWh = (135000 kWh −16513 kWh) X 0.55 NIS = 65167.85 NIS.

Figure 3.4. provides the Dar Salah school project system grid connected electrical construction, which elucidates how the PV array connected to the inverter.

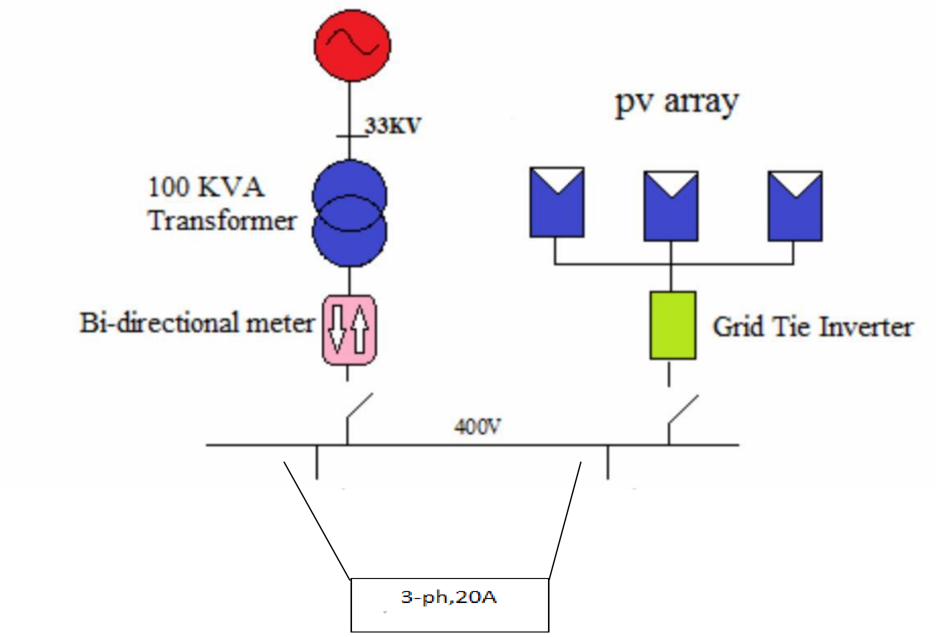

Figure 3.4 Dar Salah school grid-tied PV system electrical construction

To find the annual saving money for Dar Salah school:

Annual saving money for School = the cost of the annual total bill after PV installation **-** Cost of the annual total bill before PV installation

= 65167.85NIS – (16513 kWh X 0.55NIS) .

Saving = 65167.85NIS – 9082.15 NIS =56085.7 NIS

Chapter four

Data and methods

4.1 Introduction

To conduct the study the monthly and annual electricity consumption bills of the school were obtained for the year (2019-2020) from Jerusalem District Electricity Company and the Ministry of education. The monthly and annual output of the PV system (Pv system V6.7) were provided by Massader Company and their comparison with the school consumption using the PV system software in addition to the study investment surplus as well as the solar PV panel specifications. Accurate information of average solar radiation data, percentage of radiation, angle of inclination of cells from the surface, and annual system loss rate using Ret screen system, this system will be used to calculate the output theoretically and compare it with system output in practice.

PV system software, is a PC software package used globally for the study, scaling, simulation, and data analysis of complete solar PV systems, and Ret screen Expert, is a comprehensive program to identify energy and its plans, in addition to measuring and verifying the performance of facilities and identifying opportunities to provide production capacity.

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4.2 Study area.

The photovoltaic station was installed on the roof of the Dar Salah secondary school for boys in Bethlehem-Palestine and it is located at 31.87 N, 35.22 E [38]. The rooftop solar PV plant grid system consists of 213 mono-crystalline silicon solar modules. The installed system capacity is 80.94 KW and covers a total area of 430 square meters. The site is shown in figure 4.1 [39].

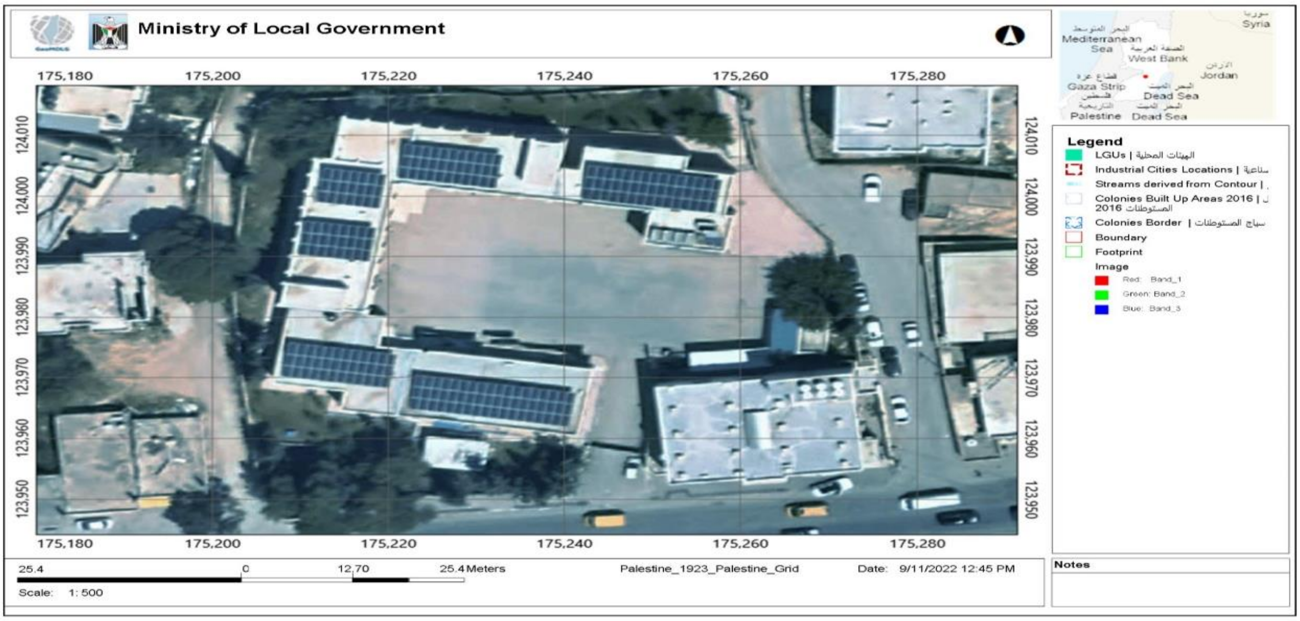


Figure 4.1. Location and graphic design: Palestine- Bethlehem-Dar Salah secondary school

4.3 Data and method.

A) Dar Salah Secondary School.

Technical and engineering information and electricity consumption for the existing school in Table 4.1 were obtained with the assistance of the Ministry of Education - Bethlehem, Dar Salah Village Council, and the Electricity Company.

Table 4.1: School building specifications

Type of building	school students
Owner of building	The Ministry of Education
Location	Palestine - Bethlehem - Dar Salah
Number of floors	2 floors
Details of building	The second floor is classrooms, and the first floor is a teachers' room, an administration room, a library, a science lab, a computer lab, and classrooms
The monthly bill ranges	301-2080 NIS
The surface area of the school	(680) m^2

B) Electricity consumption

Table 2.4 shows the school's annual electricity consumption and its financial cost. We need this information and use it to calculate the capacity of the system needed to cover the school's needs and financial cost [40**].**

Table 4.2: Electricity consumption and financial cost (kWh and NIS)

The month/year	Meter reading	The consumption value (kwh)	The bill value (NIS)
Jan-1-2019	14761	1913	1780
Feb-2-2019	15805	1044	736
Mar-3-2019	17725	1920	2080
Apr-4-2019	19205	1480	1259
May-5-2019	20729	1524	1399
Jun-6-2019	22305	1576	1436
Jul-7-2019	22629	324	218
Aug-8-2019	23062	433	301
Sep-9-2019	23495	433	301
Oct-10-2019	25876	2381	2076
Nov-11-2019	26063	1801	1530
Dec-12-2019	29361	1615	1619
		Total at annual	Total at annual
		16513	14735

Figure 4.2 shows the lowest percentage of electricity consumption and the lowest financial cost during the seventh and eighth months due to the summer vacation and non-attendance of students, and the highest percentage of electricity consumption and the highest financial cost during school hours, especially in winter

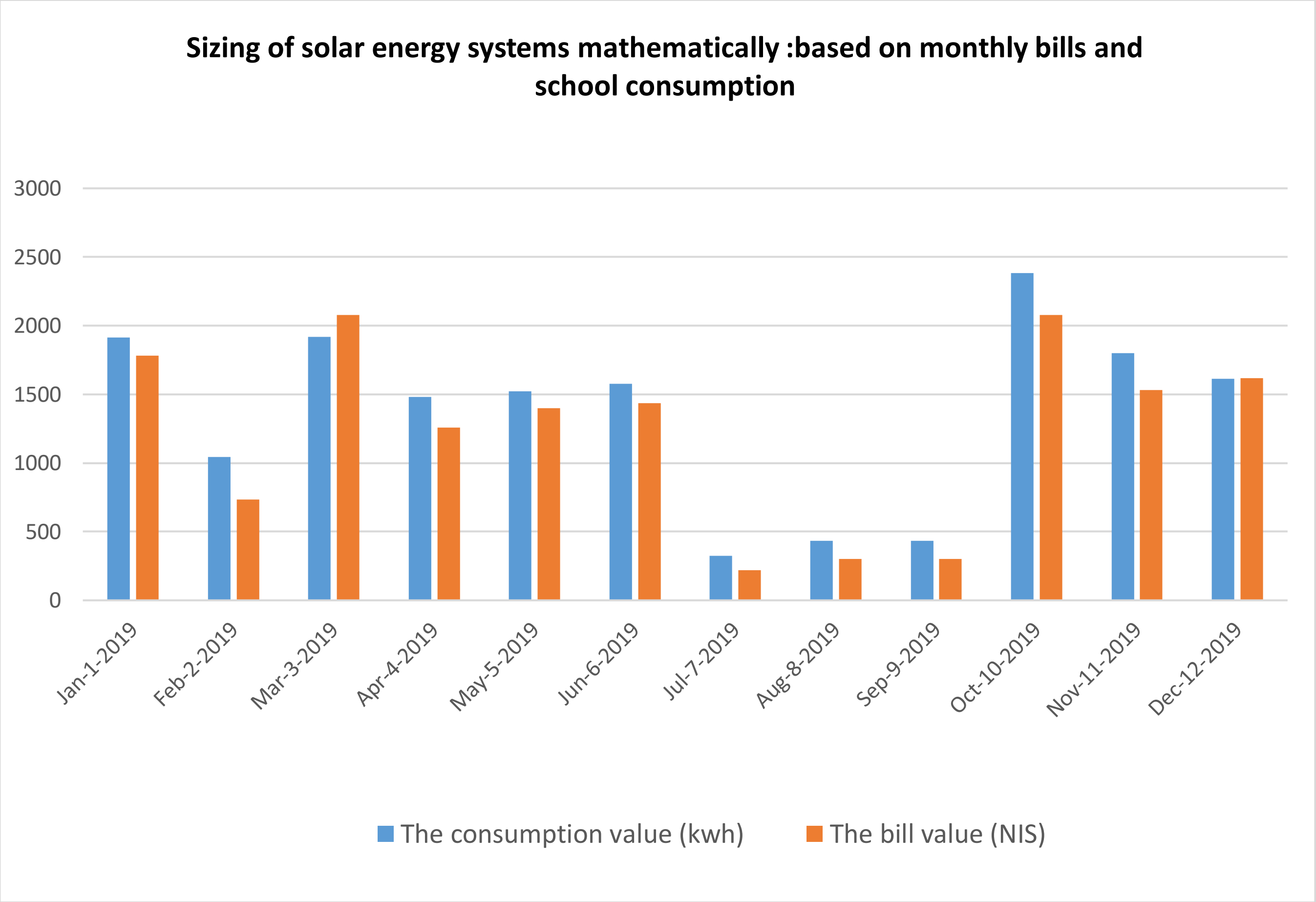


Figure 4.2 histogram Sizing solar systems mathematically.

C) Solar cell specifications

The specifications of the installed solar PV modules are shown in Table 4.3
The system characteristics are used in the installation of any photovoltaic system, to calculate the capacity of the system, calculate the minimum and a maximum number of cells that can be connected in series and parallel, calculate the output current and voltage, and compare them with the inverter loads that they bear.

Table 4.3 Specification of solar PV modules

	Medicine Faculty
Number of panels	213
Maximum power (pmax)	380w
Solar Module type	JKM380 M-72-V (Made in China)
System capacity	80.94KW
The voltage at Maximum Power (Vmpp)	40.5V
Current at Maximum Power (Impp)	9.39A
Open Circuit Voltage (Voc)	48.9 V
Short Circuit Current (Isc)	9.75A
Panel Efficiency (%)	19.07%
Maximum system voltage	1500 VDC
Cell Type	Mono – Crystalline
Panel dimension (m)	40 X1002X 1979 mm
Panel area (m2)	1.983≈2
Panel weight (Kg)	22.5 kg
Operating Temperature C	-40^{o}C UP to + 85^{o}C

4.4 On Grid Inverter:

An inverter is one of the most important pieces of equipment in a solar power system. It is a device that converts direct current (DC), which is what the solar panels generate, into alternating current (AC), which is used by the electrical grid. In DC, electricity is maintained at a constant voltage in one direction. In alternating current, electricity flows in both directions in the circuit as the voltage changes from positive to negative. Inverters are just one example of a class of devices called power electronics that regulate the flow of electrical energy. Tables 4.4 and 4.5 show the types of inverters and their characteristics in this research.

Table 4.4: Characteristics and technical data of the first.

Dar Salah Boys School		
System capacity	80.94 k W	
(ABB Solar inverters) Type code	TRIO-TM-50. O-400(from **50** to 60 KW)	
Input		
Manufacturer	ABB	
Absolute Maximum Input voltage	(Vmax, ab)	1000 V
Number of independent MPPT inputs/string per MPPT		3MPPT/3 String
Maximum Input power for each MPPT	(Pmppt, max)	17500w
MPP Input DC Voltage Range	(VMPPT, min)-(VMPPT,MAX)	480- 800 V
Maximum DC Input Current for each MPPT	(Idc, max) /MPPT	36A
Maximum Short Circuit Current for each MPPT	ISC	55A/ (165A in case of parallel MPPT)
Number of DC Input pairs for each MPPT		5
Output		
Maximum AC output power		3 Phase
Rated AC Power	Pacr	50000w=50 kw
Maximum AC Output power	Pac, max	50000w=50 KW
Rated AC Output voltage	Vacr	400 V
Maximum AC Output current	Iac, max	77A
Rated output Frequency	Fr	50HZ/60 HZ
Maximum Efficiency		98.3%
Nominal power factor and setting interval		0.995
Dimension	H*W*D	698.5*1491*315mm

Table 4.5: Characteristics and technical data of the second inverter.

Dar Salah Boys School		
System capacity	80.94 k W	
(ABB Solar inverters) Type code	TRIO-20.0TL-OUTD/ **27.6** –TL-OUTD (20 TO 27.6KW)	
Input		
Manufacturer	ABB	
Absolute Maximum Input voltage	(Vmax, ab)	1000 V
Number of independent MPPT inputs/string per MPPT		2 MPPT/ 2 String
Maximum Input power for each MPPT	(Pmppt, max)	12000w
MPP Input DC Volage Range	(VMPPT, min) (VMPPT, MAX)	480- 800 V
Maximum DC Input Current for each MPPT	(Idc, max) /MPPT	25.0 A
Maximum Short Circuit Current for each MPPT	ISC	30.0A
Number of DC Input pairs for each MPPT		1(4in-S2X, S2F, -S1J, -S2J Versions)
Output		
Maximum AC output power		3 Phase
Rated AC Power	Pacr	20000w=20 kw
Maximum AC Output power	Pac, max	220000w=22 KW
Rated AC Output voltage	Vacr	400
Maximum AC Output current	Iac, max	33.0A
Rated output Frequency	Fr	50HZ/60 HZ
Maximum Efficiency		98.2%
Nominal power factor and setting interval		0.8with max 22.2.2 kVA
Dimension	H*W*D	1061mm*702mm*292mm

4.5 Distribution of the Ret screen in Palestine

Monthly global solar insolation and daily average bright sunshine hours in Bethlehem- Dar Salah are presented in table 4.6. These values are an average of solar insolation from an expert **Ret screen program.**

Table 4.6: Monthly global solar insolation at Bethlehem-Dar Salah.

Month	Solar insolation (KWh/m^2-day
January	3.37
February	4.20
March	5.30
April	6.81
May	7.88
June	8.57
July	8.40
August	7.85
September	6.73
October	5.28
November	3.74
December	3.05
Total PSH/year	71.13
Average insolation	5.94

By using the Ret Screen program, it was found that the average solar radiation in Bethlehem - Dar Salah = 5.9 kwh/ m^2-day.

Figure 4.3 shows the average monthly solar radiation hours throughout the year, as the maximum value of the radiation rate is during June and July, and the minimum value of the radiation rate is during December and January.

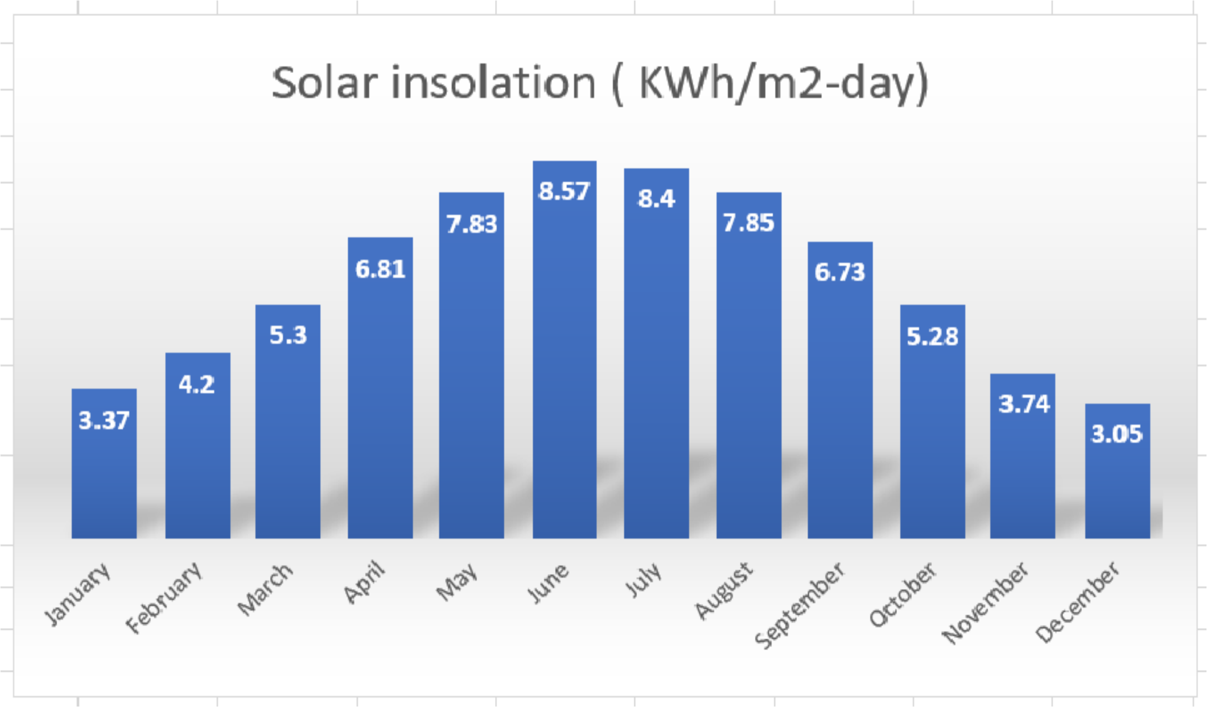
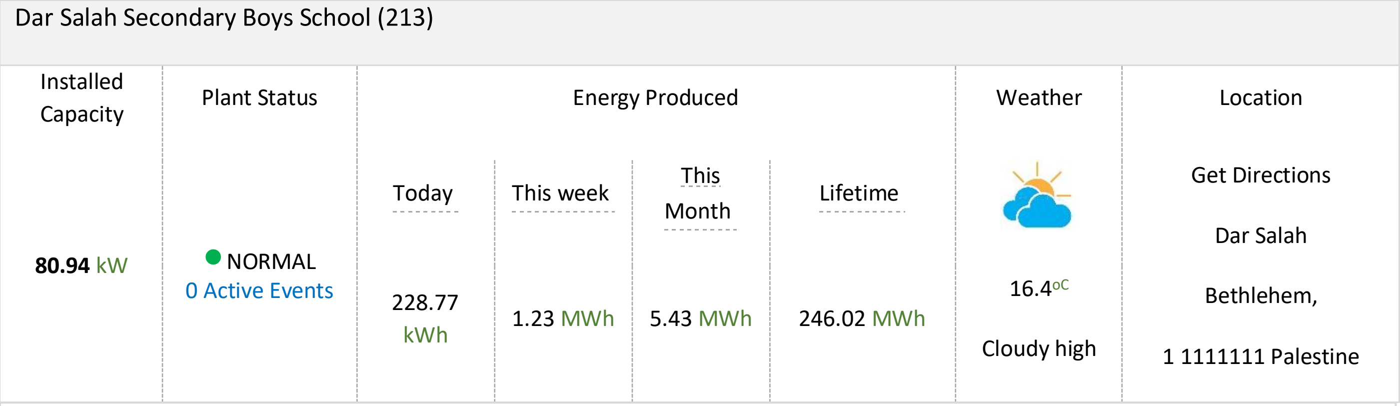


Figure 4.3 Histogram of monthly Average solar potential energy in Bethlehem

4.6 Energy production

The power production system uses the PV SYST program, and it appears that the output of the system from the date of connecting the system to the electricity company 1/1/2020 until 18/11/2021 is equal to 246.02 MWh as shown in Table 4.7. Figure 4.4 represents the monthly production rate of the system until 18/11/2021. The results showed that the highest rate of production was during May.

Table 4.7 The photovoltaic system of Dar Salah Secondary School for Boys came out.



Dar Salah Secondary Boys School (213)

Installed Capacity	Plant Status	Energy Produced				Weather	Location
		Today	This week	This Month	Lifetime		Get Directions Dar Salah Bethlehem, 1 1111111 Palestine
80.94 kW	● NORMAL 0 Active Events	228.77 kWh	1.23 MWh	5.43 MWh	246.02 MWh	16.4^{oC} Cloudy high	

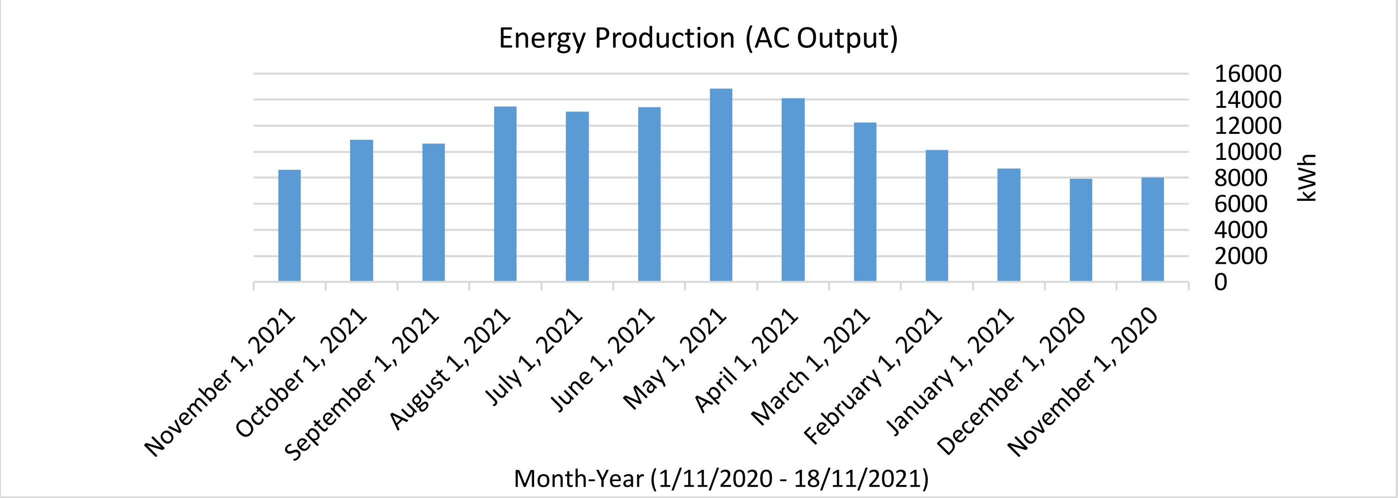


Figure 4.4 Monthly PV system output.

4.6.1 **Device Status.**

Table 4.8 shows the status of the first and second inverter readings of the system output on 18-11-2021 for one day only, and the total output was 228.77 kWh.

Table 4.8. Device status of the first and second inverter readings.

Inverters, Meters, and Weather Stations					
Category	Name	Model	Last Reported	Now(kW)	Today(kWh)
Logger	DAR SALAH SCHOOL (213)	Aurora Universal Logger	2021-11-18 21.21:16 GMT+02.00	-	-
Inverter	TRIO 27.6 (2×15+2×16)	TRIO 27.6 TL OUTD	2021-11-18 17.05:05 GMT+02.00	0.00	64.83
Inverter	TRIO-TM-50.0-400 (3×15+3×18+3×18)	TRIO-TM-50.0-400	2021-11-18 17.05:05 GMT+02.00	-0.01	163.94
Environmental Unit	VSN800-14 SN 001417PH1219	VSN800-14	2021-11-18 21.20:11 GMT+02.00	-	-1.00

Chapter five

Result and discussion

5.1 Introduction

In this study, the components and installation of the solar system were analyzed, and the long-term performance of the photovoltaic systems connected to the grid in Palestine was determined, as well as the performance and results of the system, and the problems facing the system were studied and an appropriate solution was found.

5.2 Calculations and results

Calculate Average monthly consumption:

Average monthly consumption=Total consumption at annual (Kwh) /12 month

=16513/12month = 1376 kwh per month

Calculate Average daily consumption:

Average daily consumption = Average monthly consumption /30 days

= 1376Kwh/30 days

= 45.86kwh per day

Note: The losses can reach up to (1.06 or 1.3) due to conductivity, quality of wires, as well as efficiency of solar panels and inverter. so, losses must be taken into consideration in this lead:

Average daily consumption = 45.86kwh*1.3= **59.**6 kwh per day

The rate of Solar radiation in Palestine = 5.94 kwh/m^{2}. day

The size of solar power system=Average daily consumption (with losses) / rate of solar radiation =

59.6kwh day/ 5.94 = 10.03367kw per day

So, turns out it needs a solar power system size of 10.03367kwh per day

Calculate several modules:

If the capacity of solar panels will be used at the project is (380 w or 0.38 kw)

The number of modules = size of solar power system /capacity of the module
= 10.03367/0.38
= 26.4044 = 27

This lead to the capacity of solar panel = capacity of solar panel *number of panels
= 380w* 26.4044 panels
= 10033.672w
= 10.033672kw per day.

Where the size of this solar system is suitable

The PV array is connected at all locations to the inverter through a DC junction box, and the specification of the solar inverter used to convert the DC power generated by the PV array into AC transformers is shown in Table 4.4

- The MPP tracker is used to ensure that the inverter is set to the MPP point and as far as possible the power is fed into the main power grid

- **First second and third strings**:

From characteristics of the inverter are used as follows: It consists of 3MPPT Where each MPPT Will range of maximum input dc voltage is 480- 800V and the Maximum DC Input current is 36 A.

Calculation of minimum module per string

Minimum module per string in series = Minimum input DC Voltage to MPPT/Rated Voltage of module.
= 480/40.5
=11.8 ≈ 12 modules per string

Calculation of maximum module per string.

Maximum modules per string in series = Maximum input DC voltage to MPPT/Rated voltage of module = 800/40.5 = 20 modules per string.

The engineering methods for installing the system and connecting the cells with the inverter to maintain the operation of the system and obtain the highest possible results are shown in Tables 5.1 and 5.2.

Table 5.1. First Inverter 3MPPT/ 3 String (From 50 to 60 KW)

	String. 1	String. 2	String. 3	VMPPT (V)	Idc (A)	Idc (A)cells in three-string parallel
MPPT (1)	15 cell series	15 cell Series	15 cell Series	15*48.9(Voc)=733.5	9.75	9.75*3=29.25
MPPT (2)	18 cell series	18 cell series	18 cell series	18*48.9 (Voc)=880	9.75	9.75*3=29.25
MPPT (3)	18 cell series	18 cell series	18 cell series	18*48.9 (Voc)=880	9.75	9.75*3=29.25
total cells	153					

Table 5.2 Second Inverter 2MPPT/ 2 String 27.6 KW)

	String 1	String .2	VMPPT (V)	Idc (A)	Idc (A)cells in two string parallel
MPPT (1)	15 cell series	15 cell series	15*48.9(Voc)=733.5	9.75	9.75*2= 19.5
MPPT (2)	15 cell series	15 cell series	15*48.9(Voc)=733.5	9.75	9.75*2= 19.5
total cells	60				

MPPT: (Maximum power point Tracking) can optimize the electrical current coming from the panels as it operates and made lower the voltage with rises ampere.

5.3 Energy output versus energy expected

The PV system outputs are measured against the expected PV simulated outputs in Table 5.3

Energy output = (system capacity X peak sun hour X Performance ratio X number of days) − (annual system losses X system capacity X peak sun a hour X Performance ratio)

The expected output of the system in the first year =

E (MWh) = (P * PSH *PR* number of days) – (1.06% * P * PSH *PR* number of days)

= (80.94X 5.94X 0.8275 X 365) – (1.06 % X 80.94 X 5.94 X 0.8275 X 365)

= (145.21467) – (1.06% X 145.21467)

=143.6754 MWh

Table 5.3 Output power difference.

System Capacity (80.94 kw)	Date	The energy produced (measured energy)	Theoretically expected
Today	17/11/2021	228 kwh	80.94*3.74=302.7 kWh
Week	10 /11-17/11/2021	1.2MWh	80.94*3.74*7=2.11Mwh
Month	November	5.43MWh	80.94*3.74*18=5.45Mwh
First-year	1/1/2020 - 2/1/2021	135MWh	143.6754 Mwh
Second Year	1/1/2020 - 18/11/2021	246.02MWh	273.388 – 2.12% X 273.388=267.59 Mwh
Third Year	1/1/2020 - 28/12/2022	396.083MWh	435.644 – 3.18% X 435.644= 421.79Mwh

The difference between the theoretical output that was expected and the actual output of the system is due to the technical problems facing the photovoltaic system despite the spread of these systems. However, it is accompanied by several challenges that reduce its efficiency and ability and does not take into account the most important of these challenges.

1- Shade is considered one of the most important elements in the design of solar fields, which must be taken into account when designing any solar system from solar cells that produce electrical energy because it reduces its productivity. Therefore, a distance should be left from the height of the object causing the shade, or the base of the panels should be raised to the top to reduce the distance between the object and the panels and follow the growth of trees and urbanization.

2- Lightning is the number one cause of catastrophic failure of solar electrical systems and their components worldwide, among other elements of nature, especially if protection measures are not taken into account when designing the system. Most damages occur as a result of strikes close to the system due to high electromagnetic waves. Damages can be caused by various faults in transformers and equipment and may lead to fires or complete failure of the system. These damages can be avoided when the necessary protection measures are taken, and the most important of these measures.

- Installing lightning discharge systems
- Grounding of panels, electrical equipment, and metal structures
- Installation of voltage discharge devices (spD)

3- Not paying attention to waterproofing. The panel wires must be waterproofed and ensured that they are properly insulated

4 - The best inclination tilt angle should be considered, and if the position is between 25 and 50 latitudes, the following equation should be used to calculate the inclination angle of the panels

Tilt angle = Latitude X 0.76+3

5- Failure to properly install the bases of the panels or to install the bases of the solar panels of light iron, which oxidizes and is easily affected by rust, leads to an inevitable catastrophe and the panels falling and sidelining, which could cause human harm. The bases must be solid, strong, and resistant to weather conditions (rain, heat, and humidity). It is better to use bases made of aluminum to last longer.

6- Wrong sizing of the wires used in the connection between the panels and the inverter, because the higher the ampere, we need wires of suitable thickness and calculating the appropriate wire section based on the system data, especially choosing the appropriate wires for solar energy with good insulation and high tolerance to heat resulting from high current

7- The system left for a long time without follow-up and checking. Therefore, the system must be checked periodically, continuously, and periodically within a period not exceeding one month. If the entire system is not producing any power, then the problem is with the inverter. If the power is less than required, the problem may be in the solar cells themselves or in their connections, so the following must be done:

- Inspect all circuit breakers and inverter fuses prone to combustion
- Cleaning all solar panels when there is dirt and exposure to dust, because this leads to a large decrease in the voltage generated by the panels, so the system must be cleaned continuously, especially at night.

8- Place the inverter in an open place exposed to heat, sunlight, humidity, and rain. The inverter should be in a cool place as possible and away from dirt, dust, and water**.**

5.4 Advantages and disadvantages of the on-grid type solar power system:

❖ **Advantages of the solar power system from the type on grid**

- Safe and reliable.
- Do not need continuous maintenance of the system compared with an off-grid system
- It does not need batteries to store excess power, but excess power is pumped into the grid
- Effective and economically feasible.
- Reducing the load on electricity companies and reducing the value of electricity bills on the population

❖ **Disadvantages of solar power systems from the type on the grid:**

- Since the inverter connected to the grid is automatically disconnected on failure, the system generates power only when the grid current is available and in the event of an interruption the system becomes idle and provides no power supply**.**
- The productivity of the panels decreases over time by 1.06% - 1.3% annually from the life of the project, which reduces the financial return.
- The user will get a blackout when the power goes off and the solar system turns off because there is no backup battery
- The cost of a utility line extension for grid ties

5.5 Generated profit and payback period

The Ministry of Education takes 18% of the production capacity

The percentage of the Ministry of Education in the first year = 18% *135

= 24.3 MWh

The amount provided by the Ministry in reducing the annual energy consumption of the school

=24.3 * 1000 KW* 0.55 NIS

= 13365 NIS

The net profit of the investment company at the end of the first year from the start of installing the system

= (135-24.3) *0.35

= 110.7*1000KW*0.35

= 38745NIS

The net profit of the investment company during each month from the beginning of the installation of the system = 38745/12

= 3228.75NIS

The total cost of the project = number of cells* cell capacity* Kilowatt price in dollars

= 213*0.38*890

= 72000 dollars = 252000NIS

Number of years to recover capital cost = total cost of project/ total money paid per month

= 252000 /3228.75

= 78 month

= 6.5 year

The productivity of the panels decreases over time of the life of the project as this reduces the financial return, so keep this in mind if the PR performance ratio of the system is 82.75% this leads to (PVSYST V6.70) **number of years to recover capital cost = 6.5 years/ 0.8275= 7.8years**

5.6 Conclusion:

This research evaluates the photovoltaic solar energy system on the roof of a school building affiliated with the Ministry of Education and studies the most important technical problems that may face the system and reduce its productivity and ways to address them to maintain the expected system productivity. System energy results showed that system performance was nearly constant and output over two years was slightly lower than expected. In conclusion, the following results were obtained:

1- The total electricity that was connected to the network from the date of installing the system until 28/12/2022 equal to 396.083 Mwh.
2- Based on the information, the energy generated covered the school's energy needs, in addition to providing the Ministry with an agreed percentage of surplus energy.
3- Reducing the costs and consumption of energy derived from the occupation
4- It represents a good investment case for many companies in exploiting renewable energy sources
5- The difference in the actual system output value and the expected value is due to not observing all technical and technological standards when installing the system

5.7 Recommendations:

1-The government and the electricity company can do more facilities and offer that encourage customers to install solar energy systems.

2-Recommend turning to solar energy to exploit it and reduce environmental pollution resulting from burning fossil fuels to generate electricity.

3- Develop means, guidelines, and incentives to improve energy efficiency to reduce the total cost of energy on the national economy, protect the environment from pollution, and get rid of the occupation's control over energy sources as much as possible.

4- Take into account the technical problems when installing any photovoltaic system, because of their impact on reducing the production rate of the systems.

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Appendix A: Input simulation report.

Version 7.2.5

PVsyst - Simulation report

Grid-Connected System

Project: Dar Salah School

Variant: New simulation variant

No 3D scene defined, no shadings

System power: 58.1 KWp

Dar Salah school - Palestine, State Of

Project: Dar Salah School

Pvsyst v7.2.5
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14/02/23 21:30
With v7 .2.5

variant: New simulation variant

Project summary

Geographical Site

Dar Salah school
Palestine, State Of

Situation

Latitude	31.90 °N
Longitude	35.20 °E
Altitude	834 m
Time zone	UTC+2

Project settings 0.20
Albedo

Meteo data

Dar Salah school
Meteonorm 8.0 (2006-2011), Sat=100% -
Synthetic

System summary

Grid-Connected System

No 3D scene defined, no shadings

PV Field Orientation
Fixed plane
Tilt/Azimuth 27 / 0 °

Near Shadings
No Shadings

User's needs
Unlimited load (grid)

System information

PV Array

Nb. of modules	153 units
Pnom total	58.1 kWp

Inverters

Nb. of units	1 Unit
Pnom total	50.0 kWac
Pnom ratio	1.163

Results summa

Produced Energy	97.51MWh/year	Specific production	1677 kWh/kWp/year	Perf. Ratio	82.75 %

General parameters

Grid-Connected System

No 3D scene defined, no shadings

PV Field Orientation
Orientation
Fixed plane
Tilt/Azimuth 27 / 0 °

Sheds configuration
No 3D scene defined

Models used
Transposition Perez
Diffuse Perez, Meteonorm
Circumsolar separate

Horizon
Free Horizon

Near Shadings
No Shadings

User's needs
Unlimited load (grid)

Table of contents

PV Array characteristics

PV module
Manufacturer Model
(Original PVsyst database)
Unit Nom. Power
Number of PV modules
Nominal (STC)

Jinkosolar
JKM380M-72-V
380 Wp
153 units
58.1 kWp

Inverter
Manufacturer
Model
(Original PVsyst database)
Unit Nom. Power
Number of inverters
Total power

ABB
TRIO-TM-50_0-400
50.0 kWac
1 Unit
50.0 kWac

Array #1 - PV Array
Number of PV modules
Nominal (STC)
Modules

45 units
17.10 kWp
3 Strings x 15 In series

Number of inverters
Total power

1 *
MPPT
33%
0.3
unit
16.7
kWac

At operating cond. (50°C)
Pmpp
U mpp
I mpp

15.55 kWp
554 V
28 A

Operating voltage 300-950 V
Pnom ratio (DC:AC) 1.03

Array #2 - Sub-array #2
Number of PV modules
Nominal (STC)
Modules

54 units
20.52 kWp
3 Strings x 18 In series

Number of inverters
Total power

1 *
MPPT
33%
0.3
unit
16.7
kWac

At operating cond. (50°C)
Pmpp
U mpp
I mpp

18.66 kWp
665 V
28 A

Operating voltage 300-950 V
Pnom ratio (DC:AC) 1.23

Array #3 - Sub-array #3
Number of PV modules
Nominal (STC)
Modules

54 units
20.52 kWp
3 Strings x 18 In series

Number of inverters
Total power

1 *
MPPT
33%
0.3
unit
16.7
kWac

At operating cond. (50°C)		Operating voltage	300-950 V
Pmpp	18.66 kWp	Pnom ratio (DC:AC)	1.23
U mpp	665 V		
I mpp	28 A		
Total PV power		**Total inverter power**	
Nominal (STC)	58 kWp	Total power	50 kWac
Total	153 modules	Nb. of inverters	1 Unit
Module area	303 m²	Pnom ratio	1.16
Cell area	274 m²		

Pvsyst v7.2.5
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With v7 .2.5

Project: Dar Salah School
variant: New simulation variant

Array losses

Array Soiling Losses
Loss Fraction 3.0 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0 W/m²K
Uv (wind)0.0 W/m²K/m/s

Serie Diode Loss
Voltage drop 0.7 V
Loss Fraction 0.1 % at STC

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): Fresnel AR coating, n(glass)=1.526, n(AR)=1.290

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

DC wiring losses

Global wiring resistance	10 mΩ
Loss Fraction	1.5 % at STC

Array #1 - PV Array

Global array res.	331 mΩ
Loss Fraction	1.5 % at STC

Array #2 - Sub-array #2

Global array res.	397 mΩ
Loss Fraction	1.5 % at STC

Array #3-Sub-array #3

Global array res.	397 mΩ
Loss Fraction	1.5 % at STC

AC wiring losses

Inv. output line up to injection point

Inverter voltage	400 Vac tri
Loss Fraction	0.22 % at STC

Inverter: TRIO-TM-50_0-400		**Inverter: TRIO-TM-50_0-400**	
Wire section (1 Inv.)	Copper 1 x 3 x 16 mm²	Wire section (1 Inv.)	Copper 1 x 3 x 25 mm²
Wires length	20 m	Wires length	0 m

Appendix B: Output simulation report.

Pvsyst v7.2.5
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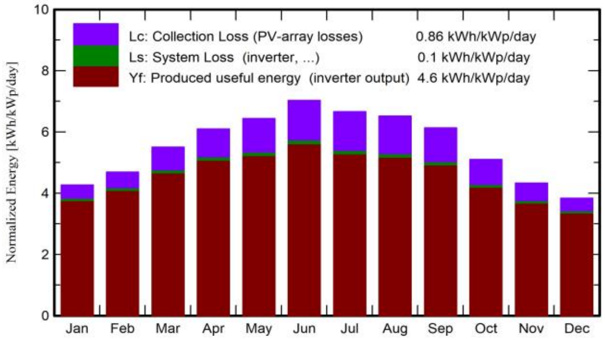
Project: Dar Salah School
variant: New simulation variant

Main results

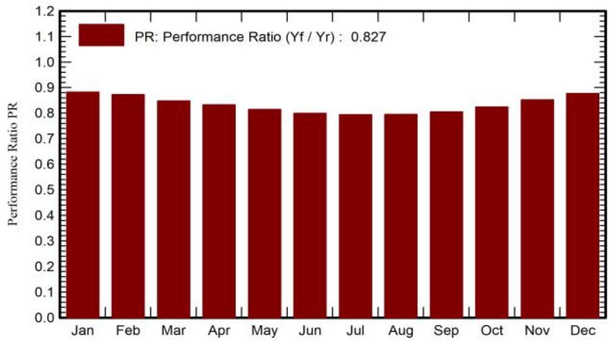
System Production 97.51 MWh/year Specific production 1677 kWh/kWp/year

Produced Energy Performance Ratio PR 82.75 %

Normalized productions (per installed kWp)



Performance Ratio PR



	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	91.7	37.85	7.80	132.3	126.1	6.93	6.785	0.882
February	100.8	43.02	9.28	131.3	125.2	6.81	6.665	0.873
March	148.0	61.99	12.95	170.7	162.4	8.60	8.413	0.848
April	175.0	74.16	16.88	183.0	173.7	9.06	8.862	0.833
May	208.7	79.94	21.56	199.4	188.9	9.64	9.439	0.814
June	231.1	63.50	24.36	210.9	199.5	10.02	9.805	0.799
July	221.0	71.96	26.62	206.5	195.3	9.74	9.529	0.794
August	200.9	67.90	26.30	202.1	191.5	9.55	9.345	0.795
September	165.6	59.40	23.81	183.9	174.7	8.79	8.605	0.805
October	127.9	52.99	20.55	158.2	150.4	7.74	7.579	0.824
November	94.3	38.35	14.34	129.7	123.8	6.57	6.426	0.852
December	81.8	35.68	9.70	118.9	113.3	6.19	6.060	0.877
Year	1846.7	686.73	17.89	2026.9	1924.9	99.63	97.513	0.827

Legends

GlobHor	Global horizontal irradiation
DiffHor	Horizontal diffuse irradiation
T Amb	Ambient Temperature
GlobInc	Global incident in coll. plane
GlobEff	Effective Global, corr. for IAM and shadings

Project: Dar Salah School

Pvsyst v7.2.5
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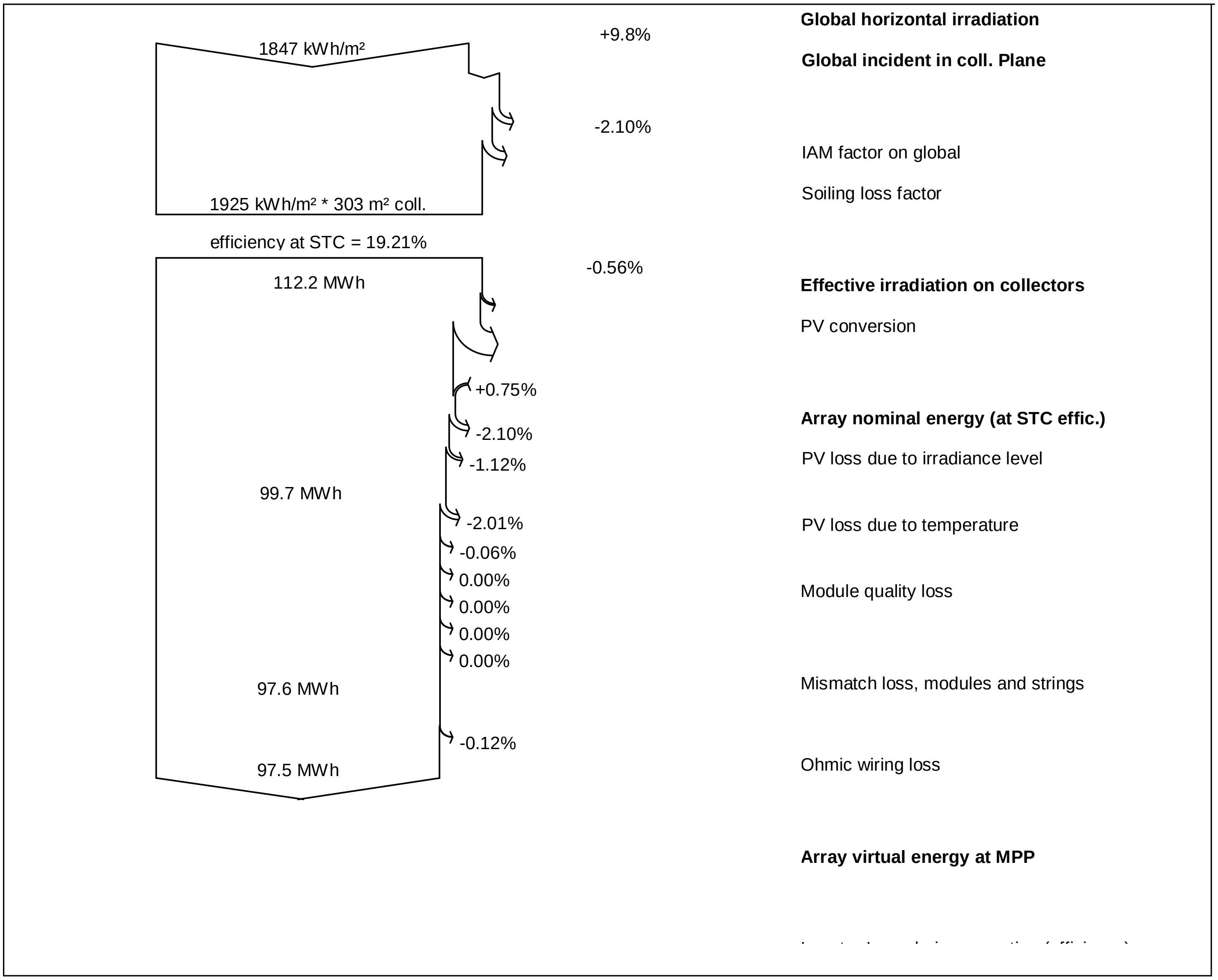
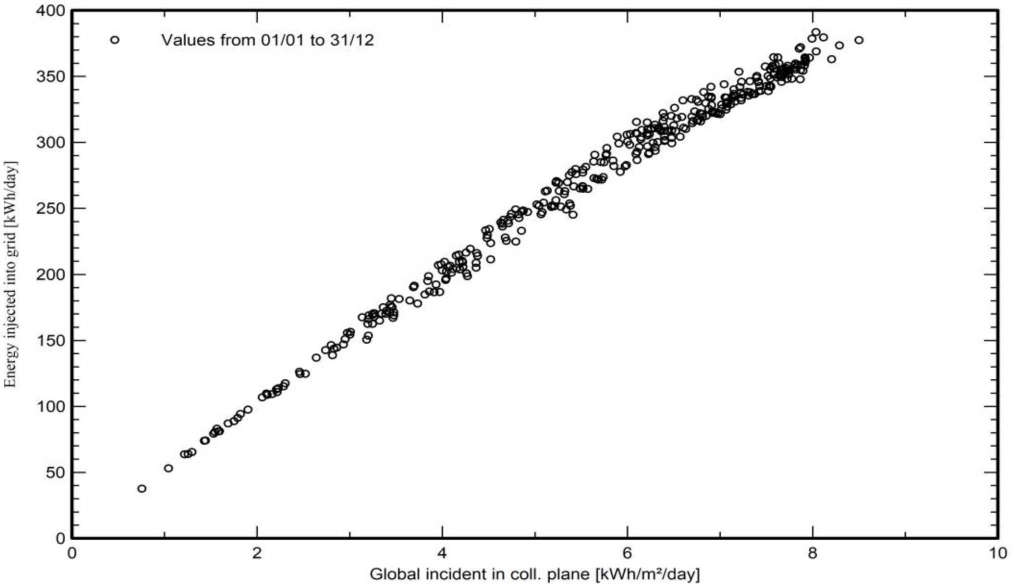
variant: New simulation variant

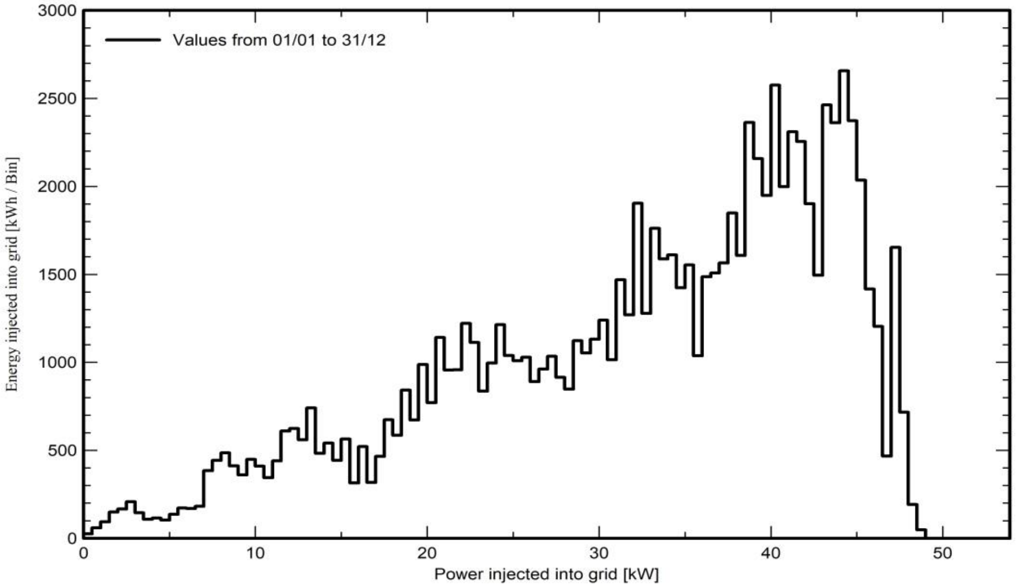
Loss diagram



Special graphs

Daily Input/Output diagram





نظام الشبكة الكهروضوئي في فلسطين: دراسة حالة للتأثير التقني-الاقتصادي لمدرسة دار صلاح

إعداد: بسام عودة سلامة سليم

إشراف: د – حسين سمامرة

ملخص:

زيادة استهلاك الطاقة الكهربائية والحاجة الفورية للكهرباء في فلسطين يقودنا الى تعزيز وتطوير نظام الطاقة الكهربائية. في هذا العمل تم دراسة النظام الكهروضوئي في مدرسة دار صلاح للبنين والتي تم تركيبها في 2020/1/1. ركز عملي على التركيب والميزات وتحديد أداء النظام ومخرجاته وتحليل الجدوى الاقتصادية وكفاءة هذا النظام باستخدام Ret screen & PV System)).

عند الانتهاء من دراسة تقييم أداء النظام تبين ان مخرجات النظام اقل من المتوقع لأسباب فنية وعوامل خارجية لم يتم اخذها بعين الاعتبار عند تثبيت النظام. تم تحديد هذه المشاكل التي تواجه النظام وطرح طرق معالجتها للحفاظ على إنتاجية النظام المتوقعة

يمثل النظام حالة استثمارية جيدة لوزارة التربية والتعليم لأنه يغطي تقريبا احتياجات المدرسة من الطاقة حسب النسبة المتفق عليها مع الشركة المثبتة للنظام وسعر الكيلو واط. ساعة مع شركة الكهرباء. يمثل حالة استثمارية جيدة للعديد من الشركات لاستغلال مصادر الطاقة المتجددة إذا كانت هنالك قوانين وأنظمة حكومية مشجعة.