An-Najah National University

Faculty of Graduate Studies

Techno- Economic Evaluation and Improvement Possibilities of Local Grid Connected House – PV Power System

By

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This thesis was defended successfully on 20/12/2015 and approved by:

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Dedication

To my parents

To my husband(Basem)

To my brothers, and sisters

To my teachers

To all friends and colleagues

To all of them,

I dedicate this work

Acknowledgment

I would like to express my special appreciation and thanks to my advisor Prof. Dr. Marwan Mahmoud who has always been providing kindest support, encouragement, and guidance throughout the accomplishment of this thesis.

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family: my parents, husband, brothers, and sisters for supporting me throughout this venture.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Techno- Economic Evaluation and Improvement Possibilities of Local Grid Connected House – PV Power System

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي انتاج جهدي الخاص، باستثناء ما تم الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم لنيل أي درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

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

Student's Name: **إسم الطالبة:** آلاء عنان محمود عواد

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Date: **التاريخ :** ٢٠١٥/١٢/٢٠

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List of Abbreviation

AC	Alternative current
AW	Annual Worth
A/F	Economic factor(Find annual value given future value)
A/G	Economic factor(find annual value given gradient)
A/P	Economic factor(Find annual value given present value)
CO_2	Carbon dioxide
DC	Direct current
FIT	Feed In Tariff
GPP	Gaza Power Plant
IEC	Israel Electrical Corporation
kWh	Kilo watt hour
LCC	Life Cycle Cost
Mpp	Maximum power point
PA	Palestinian Authority
PSH	Peak sun hour
PSI	Palestinian Solar Initiative
PV	Photo voltaic
PW	Present worth
RES	Renewable Energy Strategy
ROR	Rate Of Return
STC	Standard Test Condition
TEDCO	Tubas District Electricity Company
Wh	Watt hour
WHO	World health organization
W_p	Watt Peak
$	United State Dollar

List of Symbols

Ac	Area of solar cell(m^2)
AM	Air Mass
E_{dl}	Daily load energy (Wh/day)
E_{PV}	Photovoltaic energy (Wh)
Esd	The average daily solar radiation intensity for a month
G_o	the peak solar radiation intensity = 1000W/m^2
I_{mpp}	Current at maximum power point (A)
I_{sc}	Short circuit current (A
L_{at}	Latitude (degree)
NOCT	Nominal Operating Cell Temperature (°C)
P_M	Module power (Wp)
P_{PV}	Photovoltaic power (Wp)
PSH	The average Peak Sun Hours around the year (h)
PSH_m	The average Peak Sun Hours around month
T	Temperature (°C)
T_a	Ambient temperature (°C)
T_c	Cell temperature (°C)
V_{mmp}	Voltage at maximum power point (V)
V_{OC}	Open circuit voltage (V)
X	Amount of CO2 produced by burned of 1 liter diesel (kg/L)
η	Efficiency (%)
β	Tilt angle of the PV array on a horizontal level amounting to (degree)

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Abstract

The daily average of solar radiation intensity on horizontal surface in Palestine is 5.4 kWh/m²-day while the total annual sunshine hour amounts to about 3000. The implemented renewable energy projects in Palestine are focused on PV applications, as a part of its concentration on solar renewable energy PENRA setup the Palestinian Solar Initiative(PSI). The initiative target is to achieve 20 MW by 2020 through installing PV panels on the rooftops of households with 5 kWp for each house.

This thesis discusses the rooftops PV systems, the techno-economic issues, improvement possibilities, and environmental analysis of such systems.

Three houses in Tubas area are studied, the energy produced by house no.(1) is 8496.6 kWh/ year then the total average revenue is 8759.33 NIS/year, and the annual saving after paying the electrical bills to the company is 5,690.34 NIS/year. House no.(2) produces 9617.66 kWh/year, the total revenue is 9,914.44 NIS/year, and the annual saving after paying the bills is 6,978.64 NIS/year. House no.(3) produces 9304 kWh/year, the total revenue is 7443.200 NIS/year, and the annual saving 5596.59 NIS/year.

Economic analysis shows that the cost of 1kWh produced by these systems is 0.40 NIS.

Environmental analysis shows that these systems preserve the environment of production CO_2, house no.(1) reduces CO_2 by 7,919.08 kg/year, house no.(2) reduces CO_2 by 9,006.62 kg year, and house no.(3) reduces CO_2 by 8,702.26 kg/year.

Chapter One

Introduction

Chapter One

Introduction

Solar energy is one of the main promising clean energy sources in the future of the world. The technology of Photovoltaic PV is always on continuous developing in many applications, so it generates electricity without dangerous effects on environment. It can be utilized in pipelines catholic protection. Furthermore, Photovoltaic systems are today largely used in rural electrification, and in supplying the electric grid, also in water pumping irrigation projects, in desalination of brackish and sea water, and for supplying of communication systems.

Palestine has high solar energy potential, about 3000 sunshine hours per year and an average daily solar radiation intensity of 5.4kWh/m^2 –day which is suitable for using solar energy in electricity generation. One of the important applications is the residential PV systems. Residential solar panel installations have been used since the 1970's but in recent years these installations have become increasingly prevalent due to government programs and to the increase of awareness on the advantages of renewable energy towards economic and environment.

On 31/1/2012, the Palestinian Energy and Natural Resources authority issued the Palestine solar initiative, the initiative's target is to achieve 20 MW of solar energy by 2020 through installing PV panels on the roof tops of Palestinian households as illustrated in chapters four and five.

This thesis aims at investigation the present PV systems depending on real measurements, in order to evaluate the performance of these systems, considering the actual efficiency and the energy produced as well as to figure out the economic and environmental revenues.

Thesis Objectives

The main purpose of this thesis is to evaluate the performance of the top roof PV's connected to the grid , and to investigate different possibilities to improve their efficiency and safety .Implementation of this project has in particular the following objectives :-

1. Investigating module types and their characteristics.
2. Examine the support structure (the type) with tilt angle, it's direction, height and do calculations to determine the optimum tilt angles necessary to achieve maximum output power .
3. Check the used inverter types , the nominal power and the output voltage.
4. Measure the daily average of produced energy (kWh) from the studied homes .
5. Figure out the ways of improving the system performance and efficiency .
6. Illustration of the expected advantages through the improvement .
7. Determining the economic benefits through the improvement in comparison to the current situation .
8. The environmental impacts of using such systems.

Thesis Structure

The works done in this thesis are illustrated in eight chapters as follows:

Chapter 1: Introduction

Chapter 2: Solar Energy in Palestine

This chapter describes the potential of solar energy in Palestine and the ambient temperatures in Palestine.

Chapter 3: Photovoltaic Cell Technology

This chapter illustrates the PV cell technology in terms of operating principles, cell types, (I-V) curve for PV cell and (STC). Also this chapter studies the effect of solar radiation and cell temperature on PV performance, and presents the types of PV system.

Chapter 4: Energy Situation in Palestine

This chapter talks about energy situation in Palestine , the main sources of the Palestinian energy sector, the strategy of renewable energy in Palestine with its targets, stages, implementation, and the PSI. Then the area of the study (Tubas District Electricity Company) is discussed.

Chapter 5: Case Study Project Area Tubas

In this chapter we selected three houses in Tubas area to perform the study. The measured monthly energy produced by the three houses are presented in tables and the related energy values for each hour are analyzed to enable performing a comparison among them.

Chapter 6: Economic Analysis and Environmental Impact Of ON-Roof Solar Power System

This chapter presents the economic analysis and total revenue of each house, then the total revenue on the life cycle of the system, cash flow analysis, the cost of energy produced, simple payback period and economic analysis using rate of return(ROR) method. Also it explains the environmental impacts of using Solar PV systems.

Chapter 7: Improvements of the Systems Performance and Efficiency

This chapter presents ways of improving the PV system performance and efficiency, illustration of the expected advantages through the improvement as well as determining the economic benefits through the improvement in comparison to the current situation .

Chapter 8: Conclusions and Recommendations

This chapter presents the main conclusions and recommendation related to the roof PV generators.

Chapter Two

Solar Energy In Palestine

Chapter Two

Solar Energy In Palestine

2.1 Introduction

Palestine locates between the longitude meridian 34.15° and 35.40° east and between the latitude circle 29.30° and 33.15° North, The area of Palestine is 27000 Km^2 .The atmosphere of Palestine is clear and its air is pure. In summer temperatures reach 35° centigrade while in winter temperature may drop to Zero.[1]

2.2 Potential of Solar Energy in Palestine

Palestine has a high solar energy potential, the daily average of solar radiation intensity on horizontal surface is 5.4 kWh/m^2, while the total sunshine hours about 3000 and this is enough to produce solar energy in a sustainable way [2]. During summer months, high solar intensities exceeding 8 kWh/m^2-day has been measured. The lowest average intensity has been registered during January with a value of 3.01 kW h/m^2- day. The table (2.1) shows the monthly average solar radiation in Jordan valley.

Table (2.1): Monthly average solar radiation (kWh/m²-day)in Jordan Valley [3].

Month	Solar radiation in Al Maleh (daily average) kWh/m²-day
Jan	3.01
Feb	3.38
Mar	5.05
Apr	6.7
May	7.05
Jun	8.34
Jul	7.69
Aug	7.29
Sep	5.92
Oct	4.65
Nov	3.28
Dec	2.65

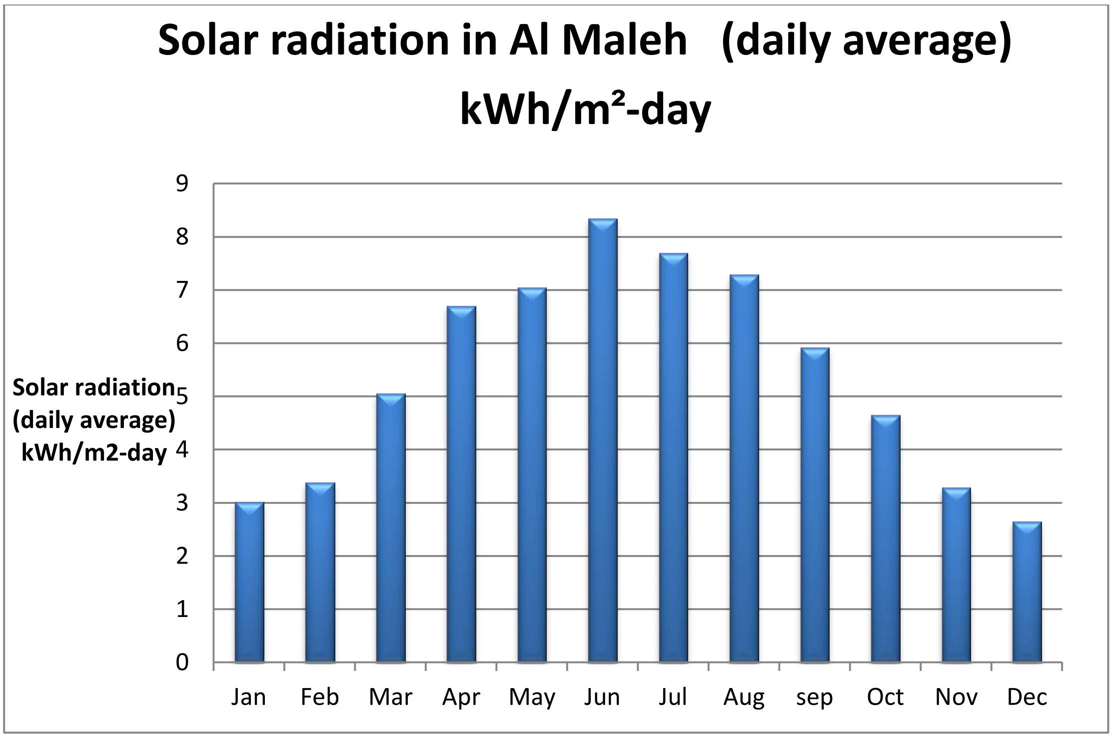


Figure (2.1): Monthly average solar radiation in Jordan Valley .

Data in table (2.1) have been measured in almaleh village, the horizontal distance between Almaleh and Tubas about 22 km, and within 30 km distance the data doesn't change.

2.3 Ambient Temperature in Palestine

Ambient temperature affects the PV generators efficiency, the higher PV cell temperature the lower efficiency, figure (2.2) shows variation of efficiency with temperature at solar radiation of $1000W/m^2$. the linear relation between PV cell temperature and the module efficiency is shown. By changing temperature around the PV module the efficiency will be affected. [4]

The ambient temperature in Palestine varies through the seasons, January is the coldest month, with temperatures from 5°C to 10°C, and August is the hottest with temperatures from 35°C to 38°C.

In summer the temperatures are high so the efficiency of the PV generators will decrease, so the energy produced from the modules will be affected, in winter the temperature is low then the efficiency will increase, so the modules can generate energy near their rated power.

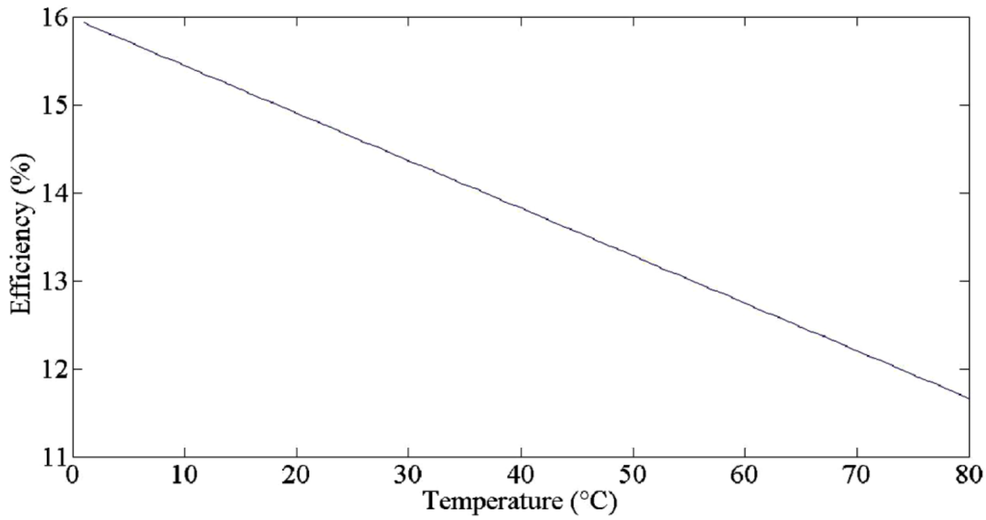


Figure (2.2): Variation of PV module efficiency with PV cell temperature [4].

Chapter Three

Photovoltaic Cell Technology

Chapter Three

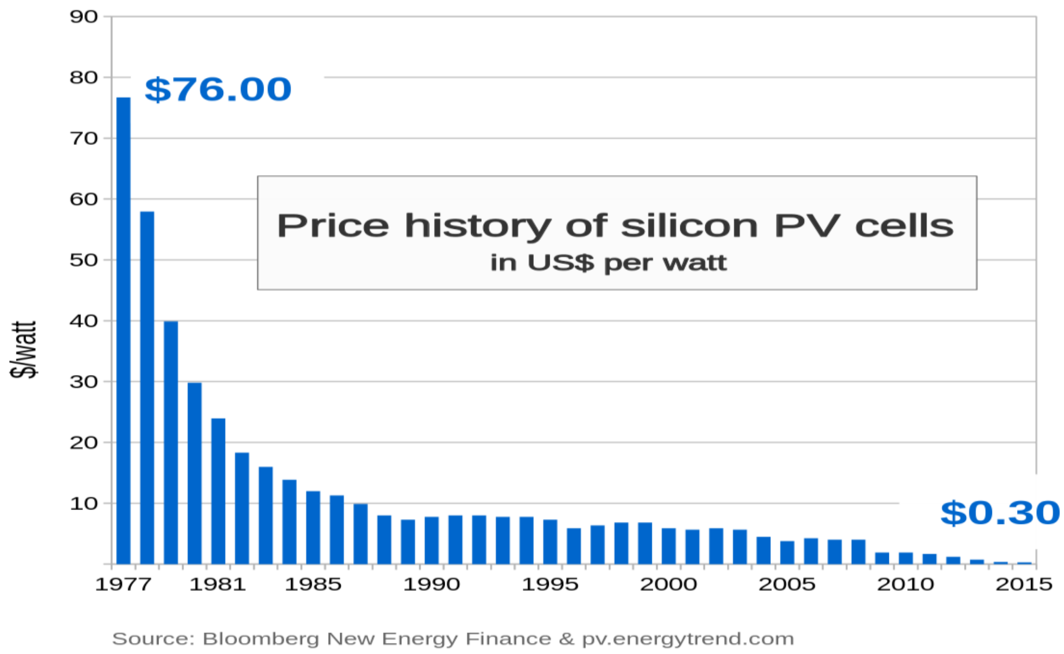
Photovoltaic Cell Technology

3.1 Introduction

Photovoltaic offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Because the source of light is usually the sun, they are often called solar cells. The word photovoltaic comes from “photo” meaning light and “voltaic” which refers to producing electricity. Therefore, the photovoltaic process is “producing electricity directly from sunlight". Photovoltaic are often referred to as PV[5].

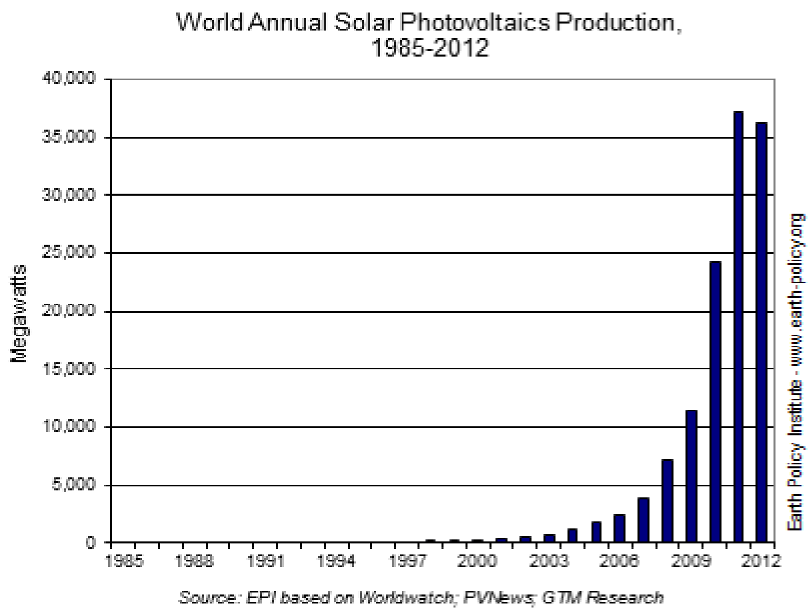
The history of PV goes back to the year 1839, when Becquerel discovered the PV effect .Bell laboratories produced the first solar cell in 1954, the efficiency of that cell was about 5%, and the cost was not a major issue, because the first cells were designed for space applications [2].

In the following years solar cell production have decreased significantly while the efficiency of the cell increased and the cost decreased. Figure(3.1) shows the change of PV cost until now.



Figure(3.1): Price history of silicon PV cells.

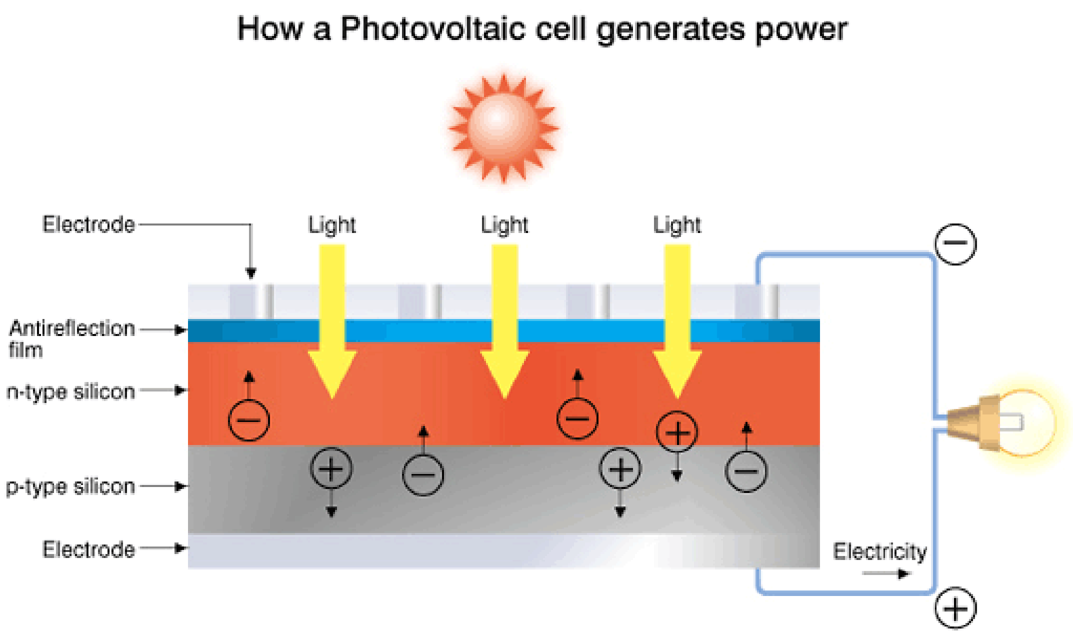
All desired generator sizes can be realized from milli watt range for the supply of pocket calculator to megawatt range for the public electricity supply [2]. PV module production increased since 1985 as shown in figure (3.2).



Figure(3.2): World annual solar photovoltaic production, 1985-2012.[6]

3.2 PV Operating Principle

Sunlight is composed of photons, or particles of radiant solar energy. These photons contain various amounts of energy depending on the wavelength of the solar spectrum. When the photons strike a solar cell some are absorbed while others are reflected. When the material absorbs sufficient photon energy, electrons within the solar cell material dislodge from their atoms. The electrons migrate to the front surface of the solar cell, which is manufactured to be more receptive to the free electrons. When many electrons, each carrying a negative charge, travel toward the front surface of the cell, the resulting imbalance of charge between the cell's front and back surfaces creates a voltage potential like the negative and positive terminals of a battery. When the two surfaces are connected through an external load, electricity flows [7]. Figure (3.3) shows the cell construction and how it produce electricity.



Figure(3.3): How a photovoltaic cell generates power.[8]

3.3 PV Cell Types

There are many types of PV cells, these types are:

- **Mono-crystalline silicon**
  - The open circuit voltage is (0.6-0.62) for each cell.
  - The short circuit current (3.4A/100cm^2).
  - Efficiency (10-15) %.
  - The most expensive to produce and buy.
  - It has very slow degradation (typically 0.25-0.5% per year).
  - Usually provide best warranties typically 25 years, with best over 90% power generation output for 10 years and 80% output to 20 years.
- **Poly-crystalline silicon**
  - The open circuit Voltage (0.55-0.58).
  - The short circuit current (2.6-3.1A/100cm^2)
  - The efficiency (8-13) %.
  - Moderately expensive to produce and buy.
  - Output efficiency decreases by approximately 0.5% per degree C° above the standard test temperature of 25°C [9].
- **Amorphous silicon (non-crystalline, “thin film”)**
  - Open circuit Voltage (0.65-0.78).
  - Short circuit current (1-2 A/100cm^2)
  - Efficiency (4.5-8) %.
  - Least expensive to produce and buy.

- Efficiency degradation with time up to 30% of the initial efficiency after one year of operation.
- Output efficiency decreases slightly less than crystalline modules above the standard test temperature of 25°C [9].

Figure (3.4) shows different type of commercially PV cells.

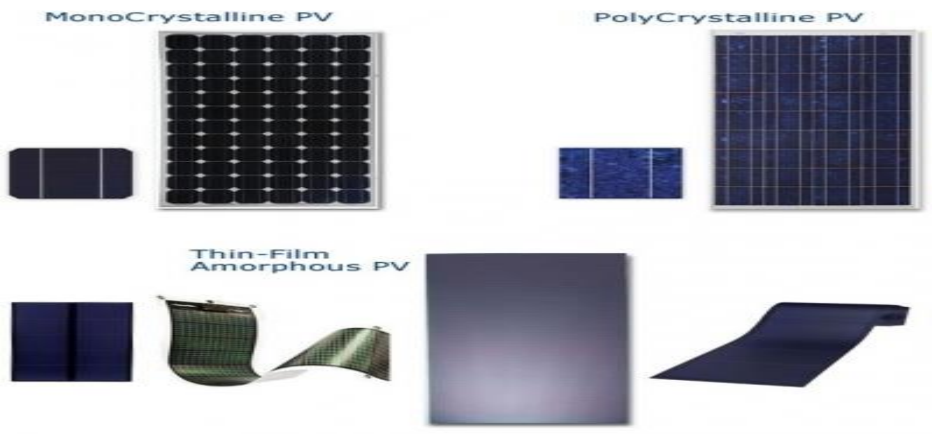


Figure (3.4): PV panel types.[10]

The PV cell is the basic building block of a PV system. Individual cells can vary in size from about 1 cm² to about 10 cm². However, one cell only produces 1 or 2 watts, which isn't enough power for most applications. To increase power output, cells are electrically connected to form module. Modules can be further connected to form an array as illustrated in figure (3.5). The term array refers to the entire generating plant, whether it is made up of one or several thousand modules. The number of modules connected together in an array depends on the amount of power output needed.[11]

Figure (3.5): Cells, modules and arrays.[12]

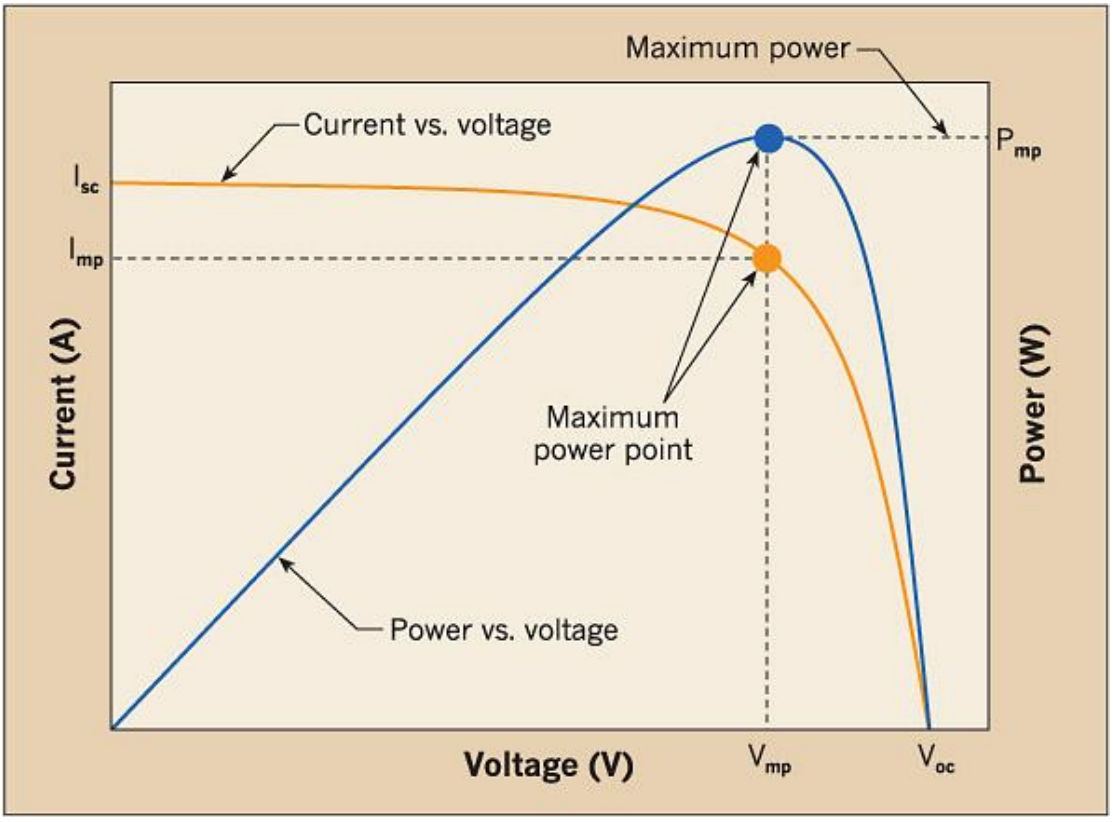
3.4 Standard Test Conditions (STC)

To compare different cells or, indeed, PV modules with one another, uniform conditions are specified for determining the electrical data with which the solar cell characteristic I-V curve is then calculated. These STC as they are known, relate to the IEC 60904/DIN EN 60904 standards:

- Vertical irradiance G of 1000 W/m²;
- Cell temperature T of 25°C with a tolerance of ± 2°C;
- Defined light spectrum (spectral distribution of the solar reference irradiance according to IEC 60904-3) with an air mass AM =1.5.

3.5 (I-V) Curve of the PV Cell

Photovoltaic modules have current voltage relationship which is represented in I-V curve, as shown in figure (3.6) .



Figure(3.6): (I-V) Characteristics of a typical silicon PV cell.[13]

Basically, the I-V curve is characterized by the following three points:

a. The maximum power point (MPP) value, is the point on the I-V curve at which the solar cell works with maximum power. For this point, the power P_{MPP}, the current I_{MPP} and voltage V_{MPP} are specified. This MPP power is given in units of peak watts (W_p).

b. The short circuit current I_{SC} is approximately 5 % to 15 % higher than the MPP current. With crystalline standard cells (10cm x 10cm) under STC, the short circuit current I_{SC} is around the 3A.

c. The open circuit voltage V_{OC} registers, with crystalline cells, approximately 0.5V to 0.6V, and for amorphous cells is approximately 0.6V to 0.9V.[9].

3.6 Effect of Solar Radiation on PV Performance

The irradiance will affect the current generated by a solar cell, the higher the irradiance the higher the current. The effect of irradiance on voltage is minimal .The change in Irradiance can be calculated, the manufacturer's standards will provide the user with a short circuit current, which can be recalculated for the new irradiance value by equation (5.1).

$$I_{sc}(G) = (I_{sc}\ \text{rated}@1000\ W/m^2) \times (G/G_{stc}) \qquad (3.1)$$

I_{sc}**:** Short circuit current.

G: The actual radiation.

G_{stc}: STC value of radiation ($1000 W/m^2$).

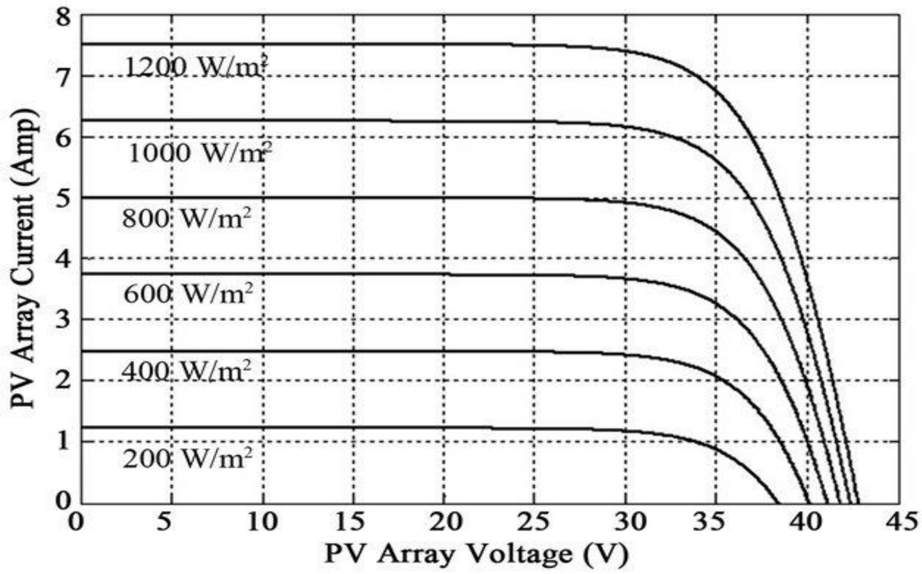


Figure (3.7): The effect of irradiance on the voltage and the current of the PV array.[14]

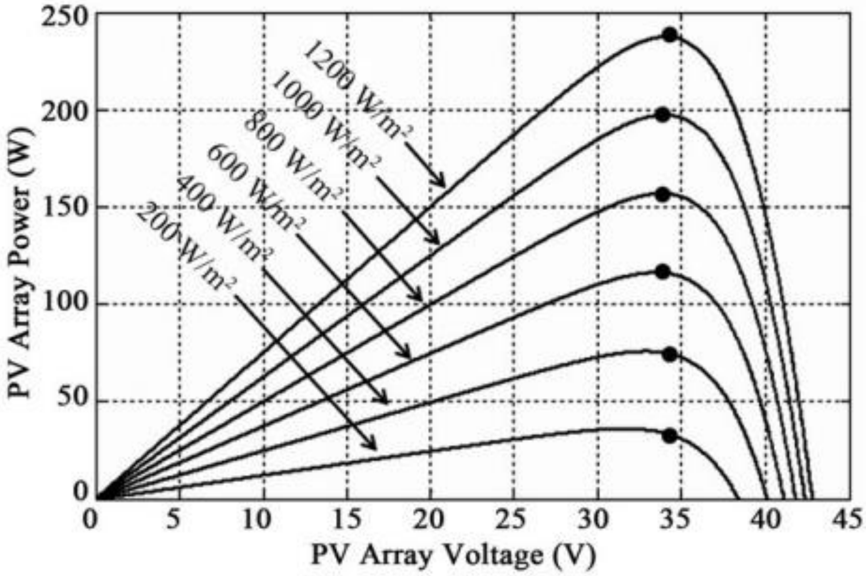


Figure (3.8): The effect of the irradiance change on power production of PV array.[14]

3.7 Effect of Cell Temperature on PV Performance

The change in temperature affects the power output from the cells. The voltage is highly dependent on the temperature , the increase in temperature will decrease the voltage. Each solar module will have manufacturing standards; the normal operating cell temperature (NOCT) is one of these standards.

The NOCT is the temperature that cells will reach when operated at open circuit in an ambient temperature of 20°C at AM 1.5 irradiance conditions, G = 0.8 kW/m^2 and a wind speed less than 1 m/s. For variations in ambient temperature and irradiance the cell temperature in (C°) can be estimated with the linear approximation that:

$$Tc = Ta + ((NOCT-20)/0.8) \times G \quad (3.2)$$

The figure (3.9) shows the effect of cell temperature variation at PV module.

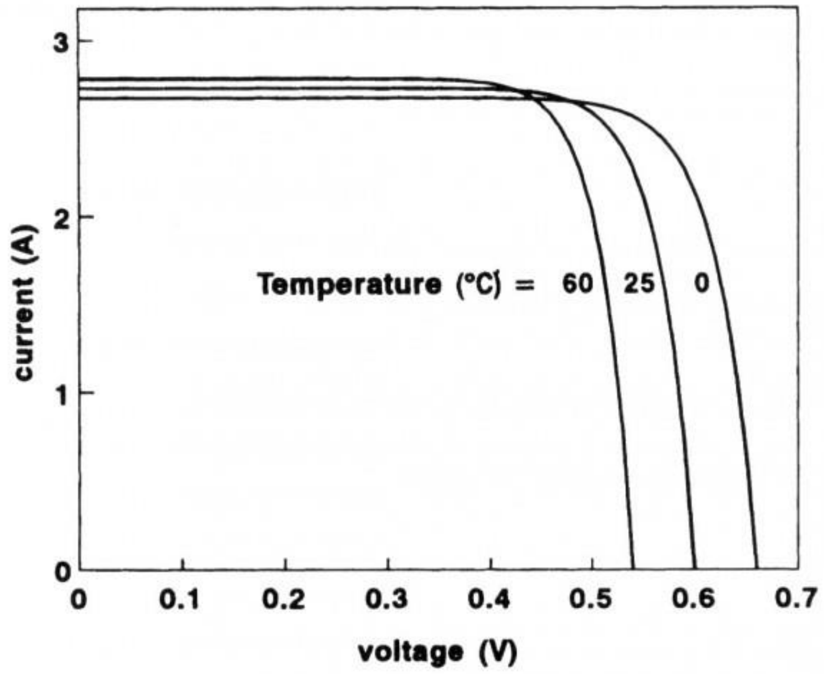


Figure (3.9): Effect of cell temperature variation at PV module.[15]

3.8 Types of PV System:

Photovoltaic power systems are generally classified according to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads. The two principal classifications are grid-connected or utility-interactive systems and stand-alone systems. Photovoltaic systems can be designed to provide DC and/or AC power service, can operate interconnected with or independent of the utility grid, and can be connected with other energy sources and energy storage systems.[16]

3.8.1 Stand-alone Systems

The Off-Grid or Stand-Alone PV System incorporates large amounts of battery storage to provide power for a certain number of days (and nights) in a row when sun is not available. The array of solar panels must be large enough to power all energy needs at the site and recharge the batteries at the same time. Most Off-Grid systems benefit from the installation of more than one renewable energy generator and may include Wind and/or Hydro power. A gas generator is often employed for emergency backup power. You may have seen mini versions of the stand-alone system on remote road signs and radio towers.[17]

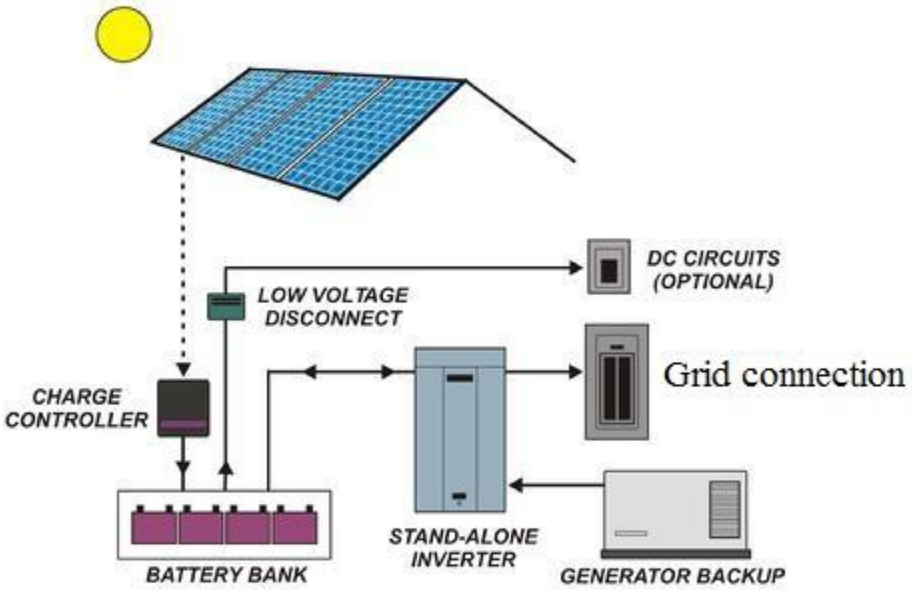


Figure (3.10): Stand-Alone PV System.[17]

3.8.2 PV System (PV direct)

PV Direct systems are usually very simple systems where the photovoltaic module is connected directly to a motor or pump which matches the voltage and amperage output of the module. When the sun shines and the PV module produces electricity, the device runs, when the sun is not available, the device stops. This system is often used for livestock where a well-pump lifts water out of the ground to a watering trough in remote locations. Other applications include solar powered attic fans, irrigation systems and small day-time garden waterfalls or fountains.

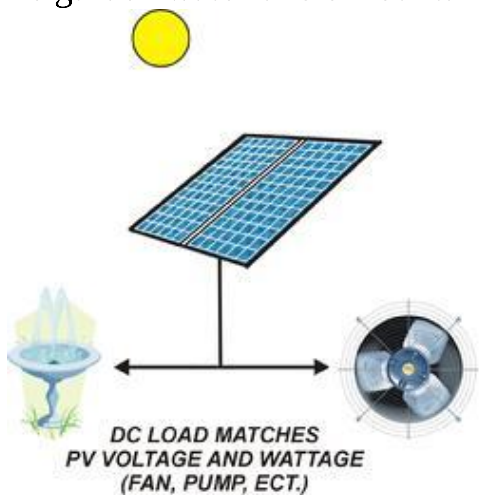


Figure (3.11): PV direct system.[17]

3.8.3 Grid- Tied PV power system (Battery free)

The simplest and most cost effective PV design for most sites is the "Grid-Tie" (sometimes referred to as intertied or utility-interactive) system. This system does not provide backup power during a power outage (even if the sun is shining) but for sites with reliable grid power, this is usually the logical system choice.[17]

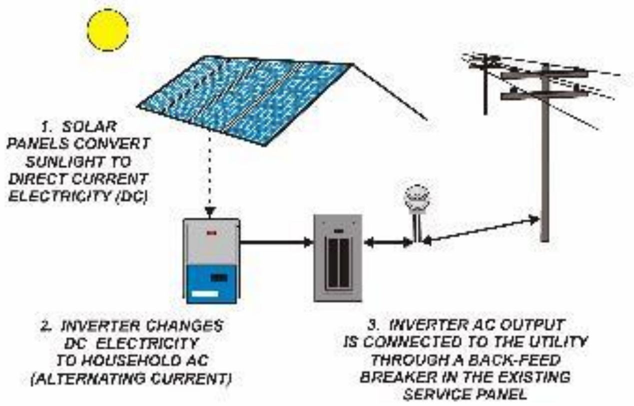


Figure (3.12): Grid-Tie Battery less PV System.[17]

3.8.4 Grid-Tied PV system with battery backup

The Grid-Tie with battery backup system can also push excess electricity produced to the electric utility grid but has the added feature of batteries in order to power some selected backup loads when the grid is down. With this benefit comes increased complexity, cost and maintenance requirements.[17]

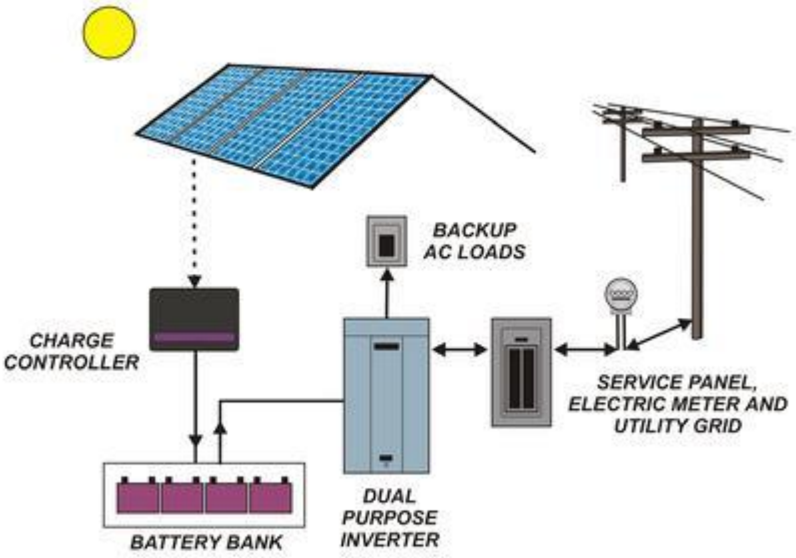


Figure (3.13): Grid-Tied PV System with Battery Backup.[17]

Chapter Four

Energy Situation In Palestine

Chapter Four

Energy Situation In Palestine

4.1 Introduction:

Palestine is considered as one of the poorest countries in terms of conventional energy resources. Gaza Power Plant (GPP) is the only significant generation, with a capacity of 140MW. Indigenous energy resources are almost limited to solar energy for photovoltaic and thermal applications (mainly for water heating), and biomass (wood and agricultural waste) for cooking and heating in rural areas.

The Palestinian energy sector consists of three main sources:

- Fossil Fuels and Gas 51%
- Electricity 31%
- Renewable Energy (thermal) 18%.

Figure (4.1) illustrates the Palestinian energy sectors, the main dependence on fossil fuels and gas.

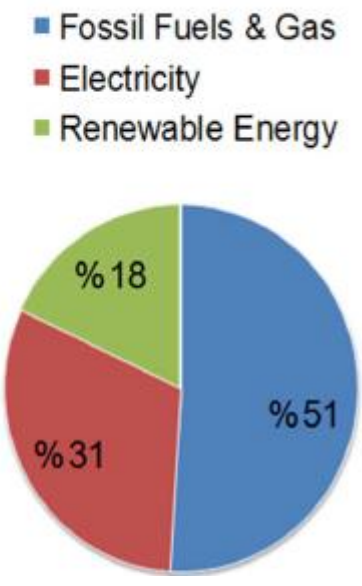


Figure (4.1): The Palestinian Energy Sector.[18]

West Bank depends almost entirely on Israel Electrical Corporation (IEC) for electricity supply. IEC supplies a maximum of 650 MW to the West Bank. West Bank has three 161/33 KV substations:

- South in area C close to Hebron.
- North in the Ariel settlement (area C) close to Nablus.
- Atarot industrial area (area C) near Jerusalem.[19]

Palestinian Authority (PA) agreement with Jordan:

- Grid connected 33 kV line at Jericho via King Abdullah Bridge with nominal power of 20 MW.
- JDECO requested line upgrade to 132 KV to be compatible with Jordanian voltage.

4.2 Electricity Situation in Palestine:

The electric power supply is characterized now as follows.

- Fully dependent on the IEC (88%).
- 99% of population benefit from electricity.
- High growth of electricity consumption 7% every year.
- High tariff imposed from the IEC compared with neighboring countries.
- High rate of electricity losses (26%).

4.3 Renewable Energy Situation:

- The daily solar radiation in Palestine is between 2.63 kWh/m^2-day in December to 8.5 kWh/m^2-day in June.

- Daily average of solar radiation intensity on horizontal surface is (5.4 kWh/m^2-day) while the total annual sunshine hour amounts to about 3000.
- Average Wind speed in Palestine about 2-6 m/s.
- About 72% of Palestinians are using now solar water heating system in their houses.
- The implemented renewable energy projects in Palestine are focused on PV applications. The total installed capacity of PV is about 1 MW peak.[18]

4.4 The Overall Strategy for Renewable Energy in Palestine:

4.4.1 RES main purposes:

•The renewable energy strategy provides the basis for planning, implementing and monitoring RE in Palestine.

•The renewable energy strategy provides a roadmap for allocating external financing sources needed in the short-term.

4.4.2 RES Target:

By the year 2020:

- 240 GWh (130 MWp).
- 10% electricity from RES (locally generated).
- Raise RE to 25% (as Electric Energy).

Based on the assessment studies of RES conducted by the PEA 2010:

Table (4.1): The Overall Strategy for Renewable Energy in Palestine.[18]

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

4.4.3 Implementation Stages of the Strategy:

There are two phases to implement the strategy :

- **The first phase**, which is considered the starting point in the promotion of renewable energy technologies and their uses through:
  - Conducting feasibility studies, preparation of tenders
  - Implementation of projects with small capacities
  - Implementation of the Palestinian Solar Initiative (PSI)
- **The second phase**, which comes after the maturity of the domestic market to wards renewable energy technologies and their applications, through the implementation of projects with high capacity enables us to reach the desired goal by the year 2020.

Table (4.2):Renewable energy technology used in the first phase:

Renewable technology	2012	2013	2014	2015	Total
On Ground PV	✓	✓	✓	✓	5
Rooftops PV (Palestinian Solar Initiative)	✓	✓	✓	✓	5
Concentrated solar power plants	✗	✗	✗	✓	5
biogas from landfills	✗	✗	✗	✓	6
biogas from animal waste	✗	✓	✓	✓	0.5
Small-scale wind	✗	✓	✓	✓	1
Wind Farms	✗	✗	✓	✓	2.5

Table (4.3): The second phase of the renewable energy (2016-2020):

Technology used	(MW)
On Ground PV	20
Rooftops PV (Palestinian Solar Initiative)	15
Concentrated solar power plants	15
biogas from landfills	12
biogas from animal waste	2.5
Small-scale wind	3
Wind Farms	37.5
Total	105

4.5 Palestinian Solar Initiative (PSI):

As part of the overall RE strategy Palestinian solar Initiative (PSI) aims at achieving a target of 5 MW RE generation by 2015, through installing PV modules on the rooftops of Palestinian households. Based on the results of previous studies commissions by PENRA, solar energy is the RE application that is most convenient to Palestinian circumstances and needs. Therefore, PENRA focused on the RE technology when setting its RE capacity targets. As part of its concentration on solar RE, PENRA setup the Palestinian Solar Initiative (PSI).

The initiative 's target is to achieve 5MW of solar RE by 2015 through installing PV modules on the rooftops of Palestinian households throughout the west bank. In addition, the initiative will include capacity building and training component for all the relevant stakeholders and the preparation of required detailed studies and documents necessary for the implementation of the overall RE strategy. For the first stage of the initiative the cost of 1 kWh produced by the first 100 house is 1.07 NIS, while the remaining houses 0.80 NIS for the cost of 1 kWh, but as a result of funding problems the tariff have been reduced to 0.63 NIS.

Table (4.4): Phases of the Palestinian Solar Initiative.

Phase	2012-2013	2013-2014	2014-2015
Capacity Installed (MW)	0.5	1.5	3
Number of Homes	100	300	600
Percentage (geography distribution)	30% N	40% M	30% S

4.6 Tubas district Electricity Company(TDECO)

The company was established in 2006, but it began the actual work since 2002, the company is currently supplying forty area in Jenin and Tubas by electricity. It has one point link with Israel Electrical Corporation (IEC) with rated power 20 MVA.

The company, with funding from the Czech government has established the Maintenance Center in 2010 and started to use programs like (GIS) and (SCADA), but the solar projects is the most important. They were classified as follow:

1. Generating units owned by the company.

470KWp generating unit using solar energy There are two stages of this projects:

It has been implemented in two phases:

- **First stage :** the rated power is 120 kWp, it started working in June 2013, the cost of this stage is 465,000 $, built on 3000 m² area and produced 216,000 kWh/year and reduced the CO_2 by 205 ton/year.
- **Second stage:** the rated power is 370 kWp, it started working in 2015 the cost was 700,000 $, the yearly energy production will be 630,000 kWh and reduces the CO_2 by 600 ton/year.

  The production of the whole generating units will represent 1.05% of the company consumption.

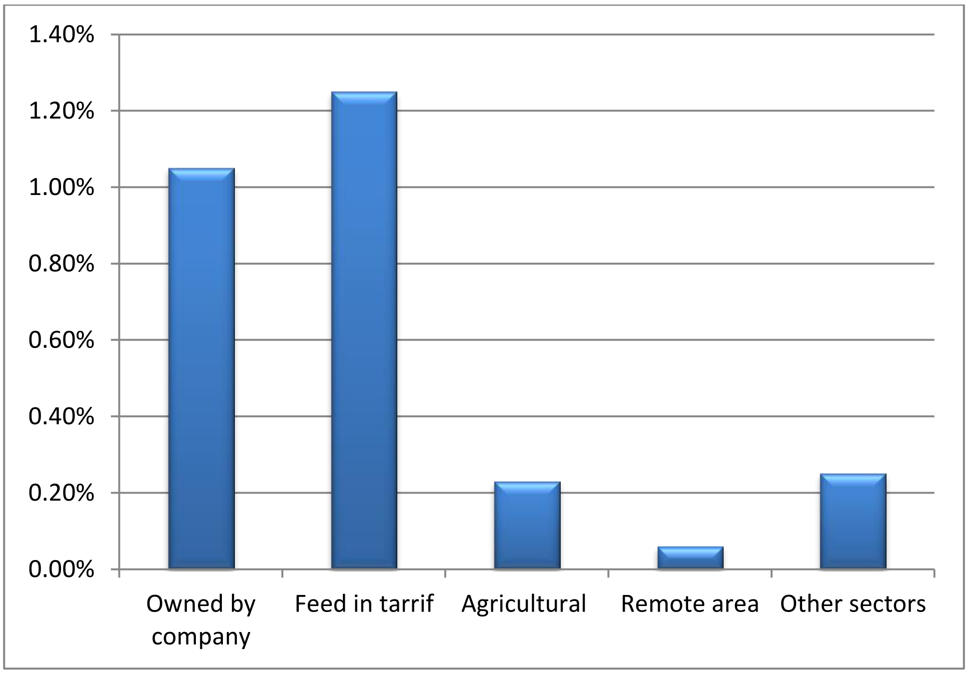
2. Generating units using solar energy to serve the agricultural sector.
   - **First stage:** Three generating units each rated 15 kWp were implemented in 2013.
   - **Second stage:** 90 kWp will be implemented soon**.**

   After the completion of these phases, they will represent 0.23% of the company consumption.
3. Feed In Tariff (FIT) : initiative has been called "the Palestinian Solar Initiative" "PSI" designed to encourage investment in the energy sector**.** The first phase was planned for the first hundred houses in the West Bank at a price 1.07 shekels ($ 0.31) and joined by 48 house on the area of Tubas Electricity Company which represent 48% of the phase. Although the tariff is reduced to 0.8 shekels, the joined houses increased to 112 houses. The yearly energy production from these generators is 1008,000 kWh which cost 134,467 $, this will represent

1.25% of the company consumption, and reduce the CO2 by 957 ton/year.

4. PV generators to light the remote villages: PV generators on grid and off grid in some villages like Atoof , Yerza and Ibziq with rated power 28 kWp were built. These plants produce 50,400 kWh/year and represent 0.06% from the company consumption.
5. PV generators for other sectors: 112 kWp was installed for this purpose to represent 0.25% of the company consumption, producing about 202,000 kWh/year.
6. PV stations for the private sectors: It is planned to establish a new station with rated power of 3MWp which will produce 5,400,000 kWh/year and represent 6.67% of the total consumption of TEDCO.

In 2016 the energy produced from solar energy will represent 23% from the total consumption of TEDCO.[20]



Figure(4.2): The production of PV generators of TEDCO company as percentage of total consumption.

Chapter Five

Case study Project area Tubas

Chapter Five

Case study Project area Tubas

5.1 Introduction:

Solar energy is the conversion of the sun's radiation into useful forms of energy such as electricity or heat. The amount of solar radiation depends on many factors including geographic location (latitude, longitude) ,time of the day, season ,and the local weather.[9]

On 31/1/2012, the Palestinian energy and natural resources authority issued the Palestine solar initiative. The Palestinian Authority had set a goal in which 10% of electricity generated in Palestine is going to be generated through renewable resources by the year 2020. The initiative's target is to achieve 5 MW of solar energy by 2015 through installing PV modules on the rooftops of Palestinian households through the west bank.[18]

These PV power systems consist of modules, inverter, electric equipment (cable,joint boxes, swiches ,etc) , aluminum supports structure, earthing and the protection components. Each element of these affects the production of energy or the safety. In order to increase the energy output and improve the safety of these PV systems, there are different possibilities that have to be investigated.

In order to do that three houses in Tubas area were selected to be studied. We made visits to the three systems and took some measurements to do the study like energy produced and mounting tilt angles.

5.2 Energy Produced for the Systems.

5.2.1 House No.1:

This system started working on 22/8/2012. The PV power home system here, consists of only one string of 18 polycrystalline PV modules (Solar Edge-Chin) connected in series the data sheet of the PV module is in (Appendix A1), where each modules consists of 72 cells in series, the peak power of each module is 285 W, the inverter is grid tied type with a power of 5 kW.[21]

Figure (5.1) shows the PV system built on the roof of house no.(1). It is obvious that the installation is inappropriate since the PV module will be shaded especially during early morning hours by the wall and water storage tanks built east of the PV array. This shadowing decreases the energy production of the system and causes on the long term the damage of the shaded modules by the hot spot effect.

Figure (5.1): Photo of the system of house no.(1)

The IV characteristics of the used PV module is illustrated in Fig(5.2). This curve can be considered also for the modules that were used in house(2) and hosee(3), with the only difference that the peak power of each module is 280 W. The tilt angle for this system is 15° faced south, the area of one module is 1.940 m². For all systems the structure type is galvanized steel.

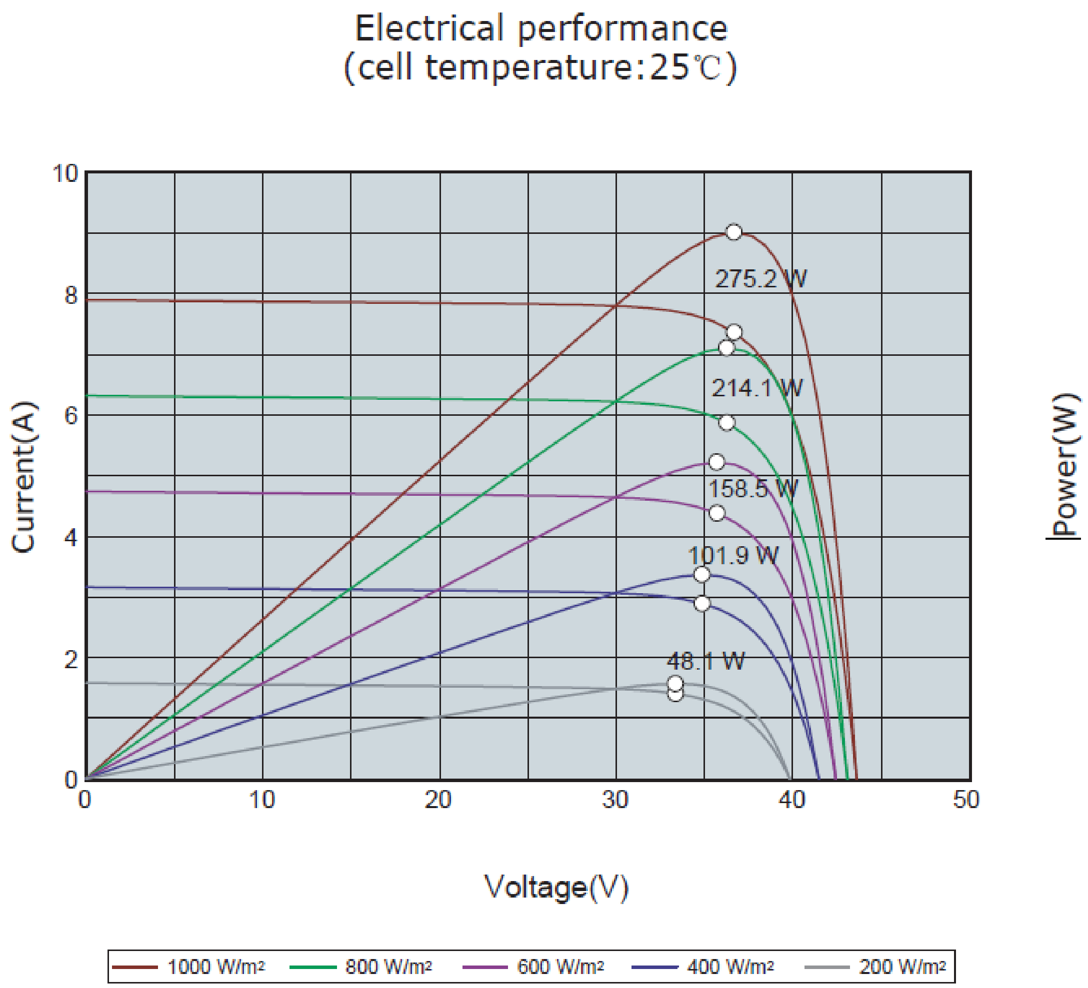


Figure (5.2): IV characteristic curve for One PV- Module in function of solar radiation intensity.[22]

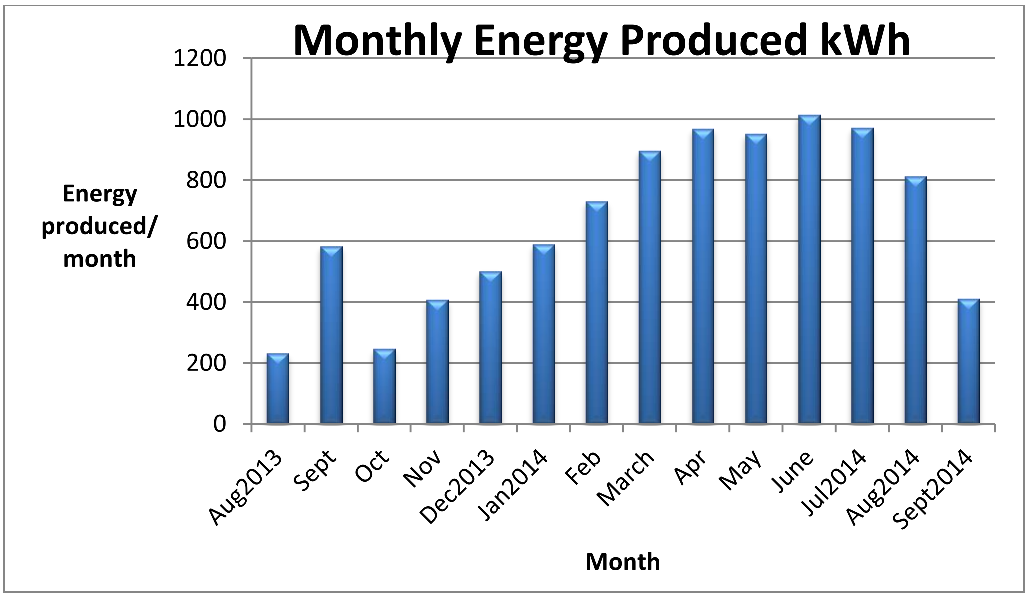
Note: the specifications are obtained under the Standard Test Conditions (STCs): 1000 W/m2 solar irradiance, 1.5 Air Mass, and cell temperature of 25 C°.

The NOCT is obtained under the Test Conditions : 800 W/m2, 20°C ambient temperature, 1 m/s wind speed, AM 1.5 spectrum.

The energy produced by house system (1) is illustrated in table 5.1 and figure (5.3).

Table (5.1): Monthly average energy production in (kWh) from Aug 2013 to Sep 2014 for house no.(1).

Month	Energy produced (kWh)
Aug2013	230.79
Sept	582.12
Oct	245.75
Nov	406.59
Dec2013	501.359
Jan2014	589.37
Feb	730.05
March	896.06
Apr	968.23
May	951.57
June	1014.8
Jul2014	971.478
Aug2014	811.62
Sept2014	409.69



Figure(5.3): Monthly average energy production in (kWh) from Aug 2013 to Sep2014 for house no.(1)

As we see from the previous table and curve the largest production was 1014.8 kWh in June, due to the largest solar radiation on this month. The lowest production was in Aug 2013 230.79 kWh.

Without respecting the year and rearranging the measured data (Jan- Dec) we obtain the distribution of the produced energy illustrated in Fig(5.4) .

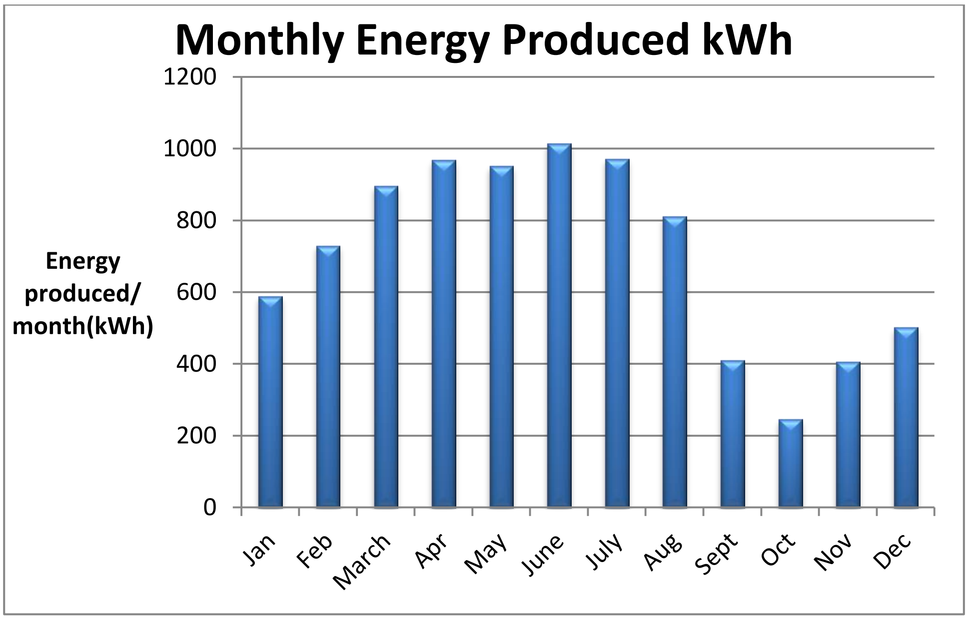


Figure (5.4): Monthly energy produced(without respecting the year).

Checking the obtained results in table (5.1) we can conclude that the results for August, September and October (2013) are less than expected if these are compared with the corresponding results in house no.(2) (Aug. 842.44 kWh, Sept. 732.24 kWh, Oct. 521.78 kWh) which is built at distance of about 70 m from house no.1. Therefore, the PV system of house 1 was shut off for unknown number of days during Aug, Sept , and Oct. 2013 which resulted in decreasing the monthly energy production.

This measuring results for the remaining corresponding months in the two houses are very closed which assures our above assumption for house no.(1).

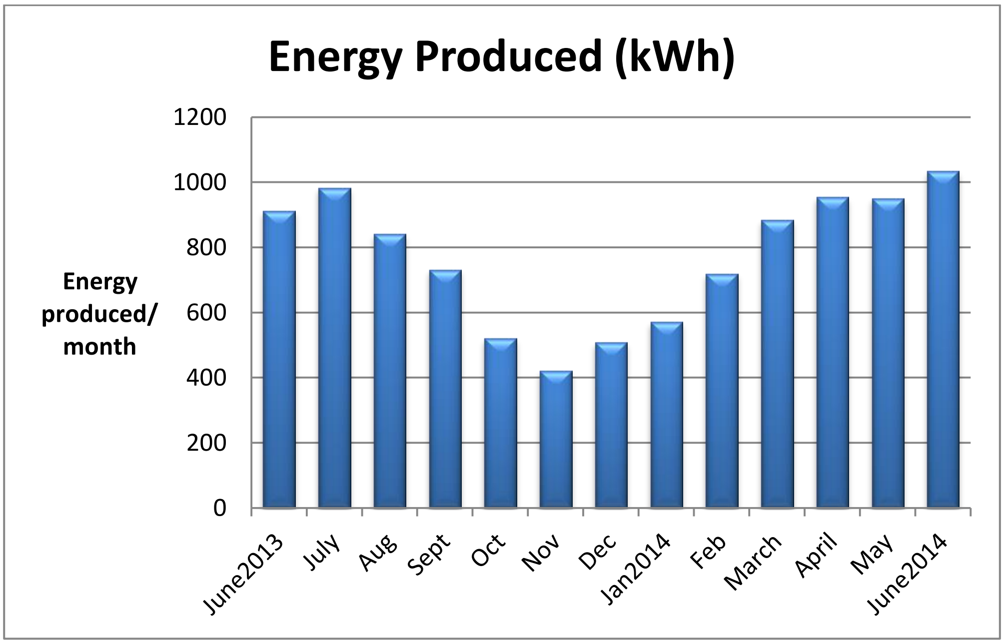
5.2.2 House no.2:

This system started working on 4/6/2013. The PV power house system here, consists of only one string consisting of 18 polycrystalline PV modules (ET Solar-China) connected in series, where each consists of 72 cells, peak power of each module is 280 W, the inverter is grid tied type with a nominal power of 5 kW. The tilt angle for this system is 15° faced south, the area of one module is 1.940 m². The energy produced by house system (1) is illustrated in table 5.2 and figure (5.6).

Figure (5.5): Photo of the PV generator of house no. (2).

Table (5.2): Monthly average energy production in (kWh) from June 2013 to June 2014 for house no.(2).

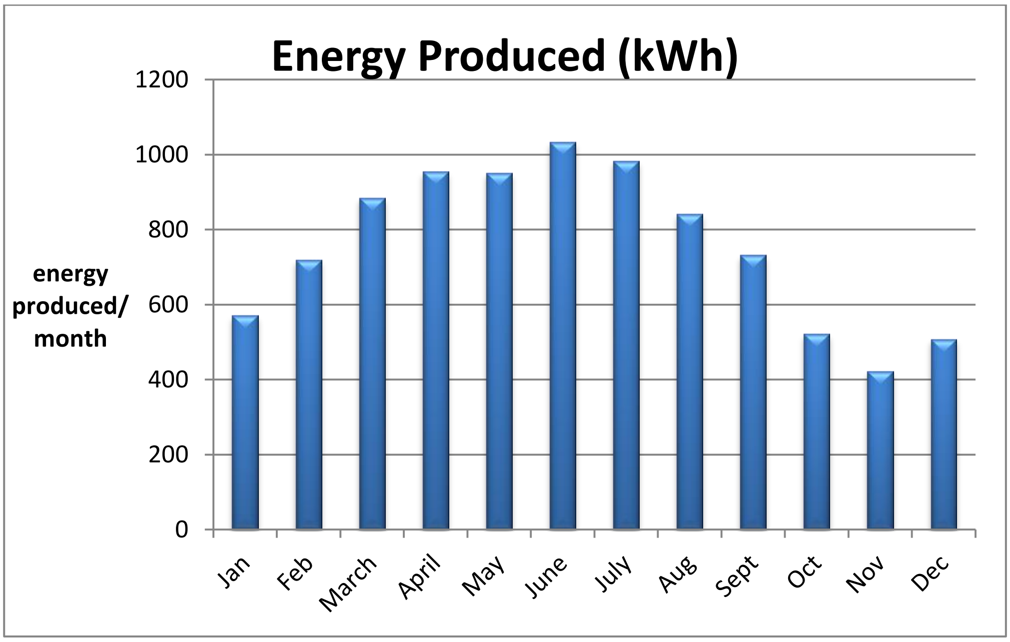
Month	Energy Produced (kWh)
June2013	913.33
July	983.59
Aug	842.44
Sept	732.24
Oct	521.78
Nov	422.33
Dec	508.24
Jan2014	571.29
Feb	719.44
March	884.87
April	955.04
May	951.18
June2014	1034.19



Figure(5.6): Monthly average energy production in (kWh) from June2013 to June2014 of house no.(2).

From table (5.2), the largest energy production was in July 2014 amounting to 1034.19 kWh , while the lowest energy production was in November 2013 amounting to 422.33 kWh.

Without respecting the year and rearranging the measured data (as usual Jan- Dec) we obtain the distribution of the produced energy illustrated in Fig(5.5) .



Figure(5.7): Monthly energy produced(without respecting the year) for house no.(2).

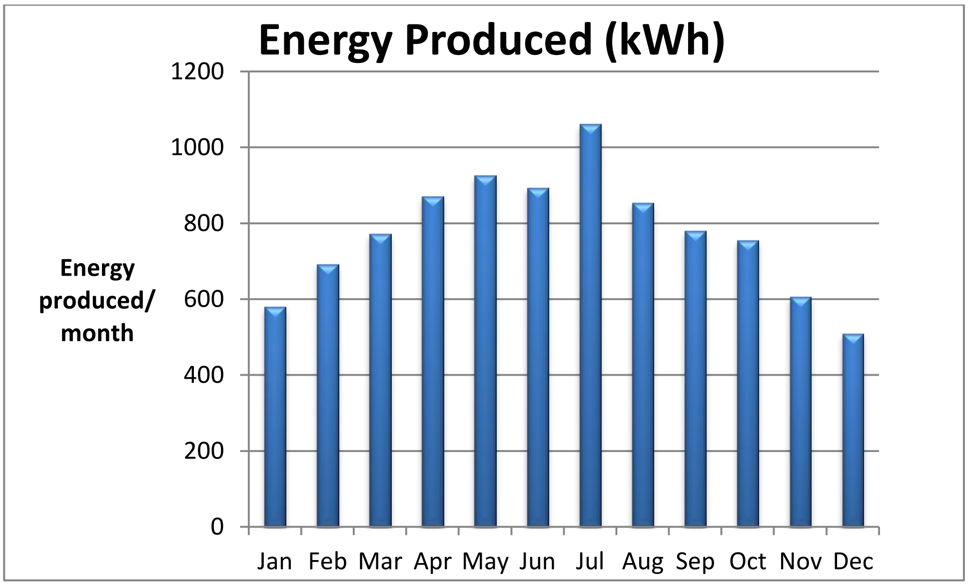
5.2.3 House No.3:

This system started working on 9/5/2013. The PV power house system here, consists of 18 polycrystalline PV modules (ET Solar-China) connected in two parallel stings where each string consists of 9 modules connected in series. Each PV module consists of 72 cells connected in series. The peak power of each module is 280 W. The inverter is grid tied type with a rated power of 5 kW. The tilt angle of this system is 25° and the area of each module is 1.940 m².

Figure (5.6): Photo of the PV system of house (3).

Table (5.3):Monthly average of energy production in (kWh) during 2014 of house no.(3).

Month	Energy produced(kWh)
Jan	580
Feb	693
Mar	772
Apr	871
May	926
Jun	894
Jul	1062
Aug	854
Sep	780
Oct	755
Nov	607
Dec	510



Figure(5.8): Monthly average energy production in (kwh) during 2014of house no.(3).

From the last table the largest production was in July 1062 kWh , while the smallest production was in December with 510 kWh.

5.3 Comparison of the energy produced from the three houses

The monthly energy produced by the three houses is illustrated in table 5.4.

Table (5.4): The energy produced from the three houses.

Month	House(1)	House(2)	House(3)
Jan	589.37	571.29	580
Feb	730.05	719.44	693
Mar	896.06	884.87	772
Apr	968.23	955.04	871
May	951.57	951.18	926
Jun	1014.8	1034.19	894
Jul	971.478	983.59	1062
Aug	811.62	842.44	854
Sep	409.69	732.24	780
Oct	245.75	521.78	755
Nov	406.59	422.33	607
Dec	501.359	508.24	510
Yearly avg	**8496.567**	**9126.63**	**9304**

As table (5.4) shows , different energy values were produced by the houses during the same month. This is due to many reasons as different array tilt angle, increased and decreased temperatures during different seasons.

Tilt angle is the angle between the surface of the PV-array and the horizontal axis. Fixing tilt angle at a certain angle all the year to the latitude value (32°) in Palestine increases the solar energy collected by the modules. Seasonal changes of tilt angle of solar modules collect higher solar energy than those of the fixed solar modules.[9]

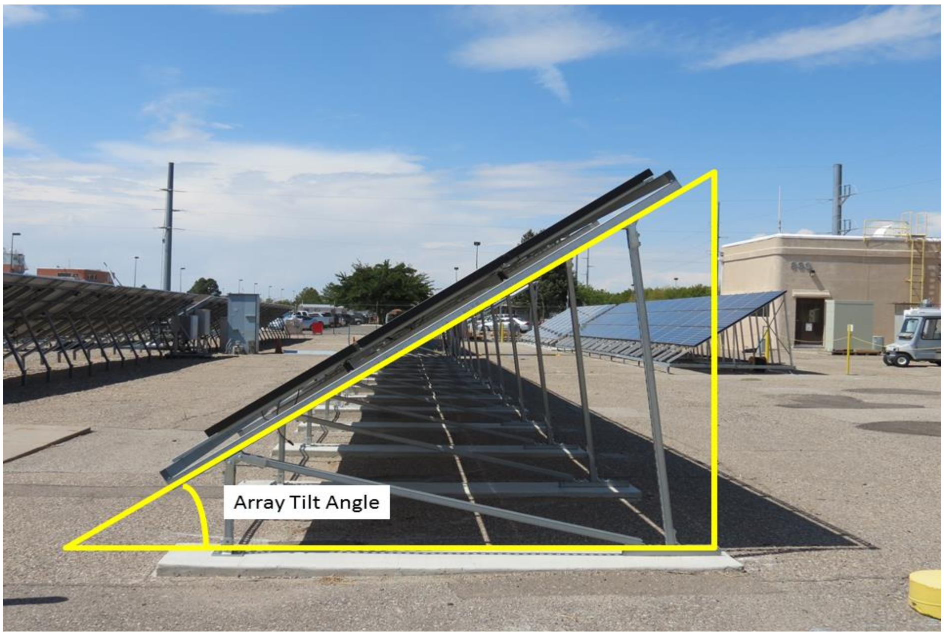


Figure (5.7): PV Array Tilt Angle.[23]

The tilted angle β should be seasonally changed to increase the annual produced energy as follows[23]:

β =L+20 =32 +20 =52 during winter period.

β =L=32 during spring and autumn period.

β = L-10 =32-10=22 during summer period.

5.4 Effect of Tilt angle on PV performance

During Jan higher tilt angle delivers more power, the tilt angle of house no.(1) and house no.(2) is 15°, while the tilt angle for house no(3) is 25°. The energy produced from house no.(3) should be higher than the energy of other houses. From the measured data we find that house no.(3) produced 580 kWh which is more than house no.(1) and (2) that produced 571.29 kWh, 579.37 kWh respectively. In June the energy produced from the house which has higher tilt angle should be smaller than the other houses. From the measured data, house (3) produced 894 kWh and the other two houses produced 1014.8 kWh, and 1034.19 kWh respectively which assures the assumption.

If we take another month as September the smallest value was the energy produced by house (3) 780 kWh which has the higher tilt angle.

The energy produced by house no(3) is the best, because its tilt angle is nearest to the latitude angle (32°). Also this house is located in Al Fari'a and the expected solar radiation is somehow higher than in Tubas, since Al Fari'a is elevated at about 150 m above sea level, while Tubas is located at about 450 m from sea level.

Although house no(1) and (2) are identical since they are located closed to each other, they have the same kind of modules, the same inverters, and the same tilt angle but their energy production differ, especially during September and October. This difference is referred to unknown reasons in house (1) resulting in unusual lower energy production during these two months. Probably the system was shut down for many days during these months.

However during the remaining months, it is obvious that the energy production of house (1) and house (2) are as expected very close

5.5 Effect of temperature on PV performance

Solar cell performance decreases with increasing temperature, The operating temperature plays a key role in the photovoltaic conversion process. Both the electrical efficiency and the output power of a photovoltaic (PV) module depend linearly on the operating temperature.[24]

Checking the obtained measured data we find the total energy produced during particular month like June for house (3) was only 894 kWh. This shows that the system produces only 0.74 of its peak power. This difference refers to the increment of temperature in June beside the higher tilt angle resulting in remarkable less power production.

At standard conditions (STC) this system should produce in June (PSH~ 8 hours)

Energy produced/day = 8*5.04 = 40.32 kWh/day.

Which means

Energy produced/ June = 40.32*30= 1209.6 kWh/June.

If we chick the measured data in January the energy produced is 580 kWh, the peak sun shine hours for this month is almost 3 hours.

At standard conditions:

Energy produced/day = 5.04*3= 15.12 kWh/ day.

Energy produced/Jan= 15.12*31=468.7 kWh/ Jan.

Measured data:

Energy produced in Jan =580 kWh/month

We find that the measured energy is higher than the energy at standard conditions. The reason is PSH for this month was higher than 3 hours so the PV modules produced more energy. Also the cold climate raised the efficiency of the PV modules beside the higher tilt angle of the PV array resulting in higher energy production.

Checking the data in Dec we find that the system performs almost at its standard conditions and the real data is the peak power.

For the same house if we calculate the PSH we find that:

P_{pv} * PSH_d * 31 = 580 kWh.

PSH_d = 580 kWh/ 5.04 kW_p * 31 =3.71 hours.

The calculated PSH was higher than the average daily PSH for Jan, which is 3 hours. Therefore higher produced energy was obtained.

If we calculate the PSH_d for Dec we will find that:

PSH_d=510/5.04*31= 3.26 hours.

Which means less produced energy than in Jan.

5.6 The energy produced of the three houses in a particular day:

The data was taken in a sunny day (18/7/2014) for all three houses in order to compare the production of the systems under the same climate conditions, (same solar radiation and ambient temperature).

House No.1:

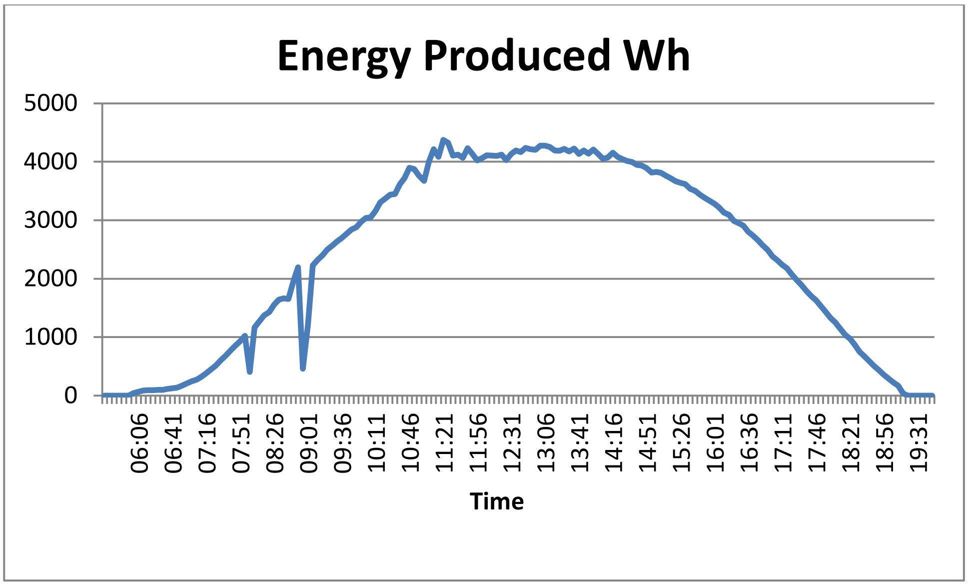


Figure (5.9): The electric energy produced on 18/7/2014 by house no.1.

House No.2:

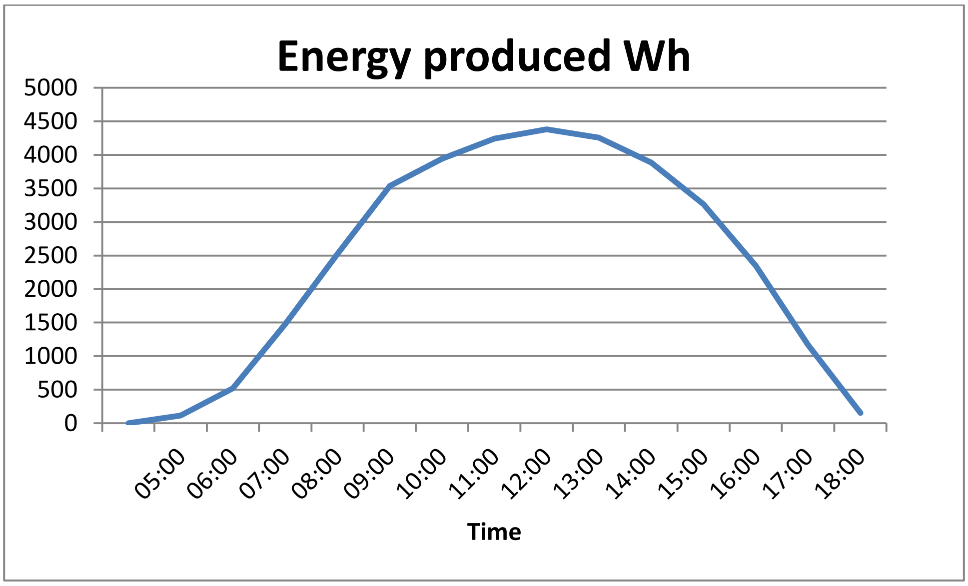


Figure (5.10): The electric energy produced on 18/7/2014 by house no.2.

House No.3:

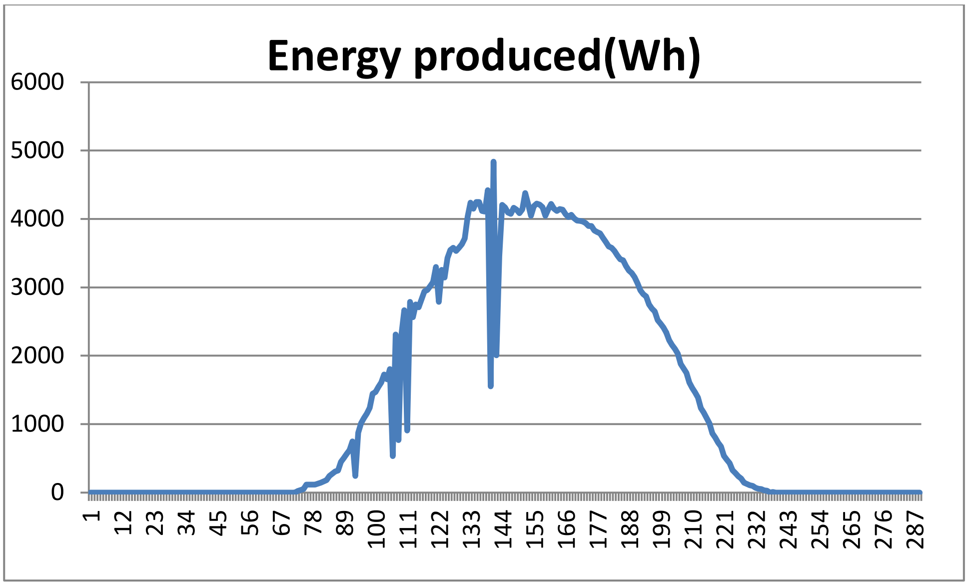


Figure (5.11): The electric energy produced on 18/7/2014 by house no.3.

From the previous three curve we notice many things:

- The difference in the energy produced from the three houses at noon, house no.1 and no.2 have the same tilt angle (15°) but the energy produced at noon 4.00 kWh and 4.300 kWh respectively. This difference is because house no.1 had some shading, this problem causes decrease in energy produced.
- The energy produced from house no.3 is 401.00 kWh which is lower than house no.2 due to the tilt angle (25°), as we mentioned before the higher tilt angle in summer delivers less power.
- All three houses delivers power lees than 5 kWh because of the high temperature on this day (as one of summer days), which rises the cell temperature and reduces the efficiency of the PV cells and thereby the output power of the PV generator.

5.7 Impacts of Electric Grid Connected PV Systems on the Power Systems

In general, grid-connected PV systems are installed to improve the performance of the electric network, PV arrays (as well as other distributed generation (DG) units) provide energy at the load side of the distribution network, reducing the feeder active power loading and improving the voltage as a result. PV systems can reduce the operation time of shunt capacitors and series voltage regulators, thus increasing their lifetime. PV systems can also reduce the losses in the distribution feeders if optimally sized and allocated.

However, PV systems has also several negative impacts on power networks, especially if their penetration level is high. These impacts are dependent on the size as well as the location of the PV system.

PV systems are classified based on their ratings into three categories:

(1) Small systems rated at 10 kW or less.

(2) Intermediate systems rated between 10 kW and 500 kW,

(3) Large systems rated above 500 kW.

The first two categories are usually installed at the distribution level, the last category is usually installed at the transmission/sub-transmission levels.

5.7.1 Impacts of small/medium PV systems

1. **Excessive reverse power flow.**

   In a normal distribution system, the power flow is usually unidirectional from the Medium Voltage (MV) system to the Low Voltage (LV) system. However, at a high penetration level of PV systems, there are instants when the net production is more than the net demand (especially at noon), and as a result, the direction of power flow is reversed, and power flows from the LV side to the MV side. This reverse flow of power results in overloading of the distribution feeders and excessive power losses. Reverse power flow has also been reported to affect the operation of automatic voltage regulators installed along distribution feeders as the settings of such devices need to be changed to accommodate the shift in load center. Reverse power flow may have adverse effects on online tap changers in distribution transformers especially if they are from the single bridging resistor type.

2. **Over voltages along distribution feeders.**

   Reverse power flow leads to over voltages along distribution feeders. Capacitor banks and voltage regulators used to boost voltage slightly can now push the voltage further, above the acceptable limits, when the voltage along the feeder is already boosted by transformer tap changers to compensate for voltage drop along the line.

3. **Increased difficulty of voltage control .**

   a power system with embedded generation, voltage control becomes a difficult task due to the existence of more than one supply point. All the voltage regulating devices, i.e., capacitor banks and voltage regulators, are designed to operate in a system with unidirectional power flow. The impacts of the back feed of PV units on these devices need to be studied.

4. **Increased power losses.**

   DG systems in general reduce system losses as they bring generation closer to the load. This assumption is true until reverse power flow starts to occur. A study showed that distribution system losses reach a minimum value at a penetration level of approximately 5%, but as the penetration level increases, the losses also increase and may exceed the no-DG case.

5. **Severe phase unbalance.**

   Inverters used in small residential PV installations are mostly single phase inverters. If these inverters are not distributed equally among different phases, phase unbalance may take place shifting the neutral voltage to unsafe values and increasing the voltage unbalance. This problem occurred in the PV installation at Freiburg, Germany, where the power unbalance between L1 and L3 was found to be around 6%.

6. **Power quality problems.**

   Power quality issues are one of the major impacts of high PV penetration on distribution networks; power inverters used to interface

PV arrays to power grids are producing harmonic currents; thus, they may increase the total harmonic distortion (THD) of both voltage and currents at the point of common coupling (PCC).

7. **Increased reactive power requirements.**

PV inverters normally operate at unity power factor for two reasons. The first reason is that current standards (IEEE 929-2000) do not allow PV inverters to operate in the voltage regulation mode. The second reason is that owners of small residential PV systems in the incentive-programs are revenued only for their kilowatt-hour yield, not for their kilovolt-ampere hour production.

8. **Electromagnetic interference issues.**

The high switching frequency of PV inverters may result in electromagnetic interference with neighboring circuits such as capacitor banks, protection devices, converters, and DC links leading to mal-function of these devices. Thus, they prefer to operate their inverters at unity power factor to maximize the active power generated and accordingly, their return. As a result, the active power requirements of existing loads are partially met by PV systems, reducing the active power supply from the utility. However, reactive power requirements are still the same and have to be supplied completely by the utility. A high rate of reactive power supply is not preferred by the utilities because in this case distribution transformers will operate at very low power factor (in some cases it can reach 0.6). Transformers' efficiency decreases as their operating power factor decreases, as a result, the overall losses in distribution transformers will increase reducing the overall system efficiency.

9. **Difficulty of islanding detection.**

   IEEE Std. 929-2000 recommends that photovoltaic inverters should be disconnected within 6 cycles if an islanding condition is detected. Many techniques can be used to detect islanding, such as passive, active, hybrid, and communication based techniques[25].

5.8 Impact of PV Systems on Tubas District Grid.

In this section we will talk about the effects of solar systems on the grid in Tubas.

5.8.1 The losses

Installation of generating units as close as possible from the center of loads is one of the targets of networks designer; because of its effects of reducing losses in electric networks. A study was performed by using ELECTROGIS program(which is a program that integrates both GIS and MV and LV network analysis), this program was designed to TEDCO.

Table (5.5) shows the losses before and after installation of PV systems on the (Karag transformer).

Table (5.5): Losses of Karag transformer before and after PV installation.

Transformer name	Karag
Number of feeders	3
TR Core losses before PV installation	0.3 KW
TR Core losses after PV installation	0.3 KW
TR Copper losses before PV installation	1.3916 KW
TR Copper losses after PV installation	1.15343 KW
Losses before PV installation	4.25427 KW
Losses after PV installation	2.98507 KW

As we notice from the table (5.5) that the PV systems decrease the total losses on transformer from 4.25427 KW to 2.98507 KW.

5.8.2 Impacts of PV systems on voltage.

This study represents the effect of PV generators on the voltage at the load. Table (5.6) shows the technical losses and voltage of Karag transformer.

Table (5.6): Technical losses and the voltage of Karag transformer.

Transformer name	Karag
Apparent power	400 kVA
Load factor	77%
Number of participants	423
Number of PV systems	7
Peak power	35 kWp
Percentage of PV	9%
Losses before PV	4.25427 KW
Losses after PV	2.98507 KW
Voltage before PV installation	207.9 V
Voltage after PV installation	213.6 V

The effects of PV system on voltage are:

- Voltage rise in LV network, as we see from the table, during light load conditions the voltage at the point of interconnection may increase by

2%–3% above the no-load voltages especially when the PV cluster is located far from the distribution transformer. This voltage rise may exceed the accepted limits when the voltage along the feeder is already boosted by transformer tap changers to compensate for voltage drop along the line.[25]

5.8.3 Impacts of PV generators on power factor(PF)

Through the studying of PV systems the power factor was decreased during the day light hours, this case is clear in table (5.7) which represent the information of (Safeh nourth / housing staff).

Table (5.7): Technical information of Safeh north transformer before install PV system.

Transformer name	Safeh nourth / housing staff
Number of feeders	2
TR Core losses before PV installation	0.25 KW
TR Core losses after PV installation	0.25 KW
TR Copper losses before PV installation	0.274518 KW
TR Copper losses after PV installation	0.0965383 KW
Total PF on TR before PV installation	0.865518
Total PF on TR after PV installation	0.801754

As we notice that the PF decrease from 0.855 to 0.801, this problem can be solved by install capacitor banks to improve the power factor.

5.9 The Inverters

Depending on the requirements of the load, a number of different types of inverters are available. Selection of the proper inverter for a particular application depends on the waveform requirements of the load and on the efficiency of the inverter. Inverter selection will also depend on whether the inverter will be a part of a grid-connected system or a stand-alone system. Many opportunities still exist for the design engineer to improve the inverters, since inverter failure remains one of the primary causes of PV system failure.

5.9.1 The inverters are used in house (1) and (2)

The inverters are used in house (1,2) are the same, Solar Edge is the manufacture company. Figure (5.12) shows Solar Edge inverter in house (1,2).

Figure(5.12): The inverter used in house (1) and (2), Solar Edge Type.

SPECIFICATIONS:

	SE3000A-US	SE3800A-US	SE5000A-US	SE6000A-US	SE7600A-US	SE10000A- US	SE11400A-US	
OUTPUT								
Nominal AC Power Output	3000	3800	5000	6000	7600	9980 @ 208V 10000 @240V	11400	VA
Max. AC Power Output	3300	4150	5400 @ 208V 5450 @240V	6000	8350	10800 @ 208V 10950 @240V	12000	VA
AC Output Voltage Min.-Nom.-Max.[1] 183 - 208 - 229 Vac	-	-	✓	-	-	✓	-	
AC Output Voltage Min.-Nom.-Max.[1] 211 - 240 - 264 Vac	✓	✓	✓	✓	✓	✓	✓	
AC Frequency Min.-Nom.-Max.[1]	59.3 - 60 - 60.5 (with HI country setting 57 - 60 - 60.5)							Hz
Max. Continuous Output Current	12.5	16	24 @ 208V 21 @ 240V	25	32	48 @ 208V 42 @ 240V	47.5	A
GFDI Threshold	1							A
Utility Monitoring, Islanding Protection, Country Configurable Thresholds	Yes							Yes
INPUT								
Maximum DC Power (STC)	4050	5100	6750	8100	10250	13500	15350	W
Transformer-less, Ungrounded	Yes							
Max. Input Voltage	500							Vdc
Nom. DC Input Voltage	325 @ 208V / 350 @ 240V							Vdc
Max. Input Current[2]	9.5	13	16.5 @ 208V 15.5 @ 240V	18	23	33 @ 208V 30.5 @ 240V	34.5	Adc
Max. Input Short Circuit Current	45							Adc
Reverse-Polarity Protection	Yes							
Ground-Fault Isolation Detection	600kΩ Sensitivity							
Maximum Inverter Efficiency	97.7	98.2	98.3	98.3	98	98	98	%
CEC Weighted Efficiency	97.5	98	97.5 @ 208V 98 @ 240V	97.5	97.5	97 @ 208V 97.5 @ 240V	97.5	%
Nighttime Power Consumption	< 2.5					< 4		W

Figure (5.13): shows the specifications solar edge inverter in houses 1 and 2.[26]

5.9.2 The inverter used in house (3)

The inverter used in house (3) is 5 kW grid tied inverter. The rated power at 230 V and 50 Hz is 5,200 W.

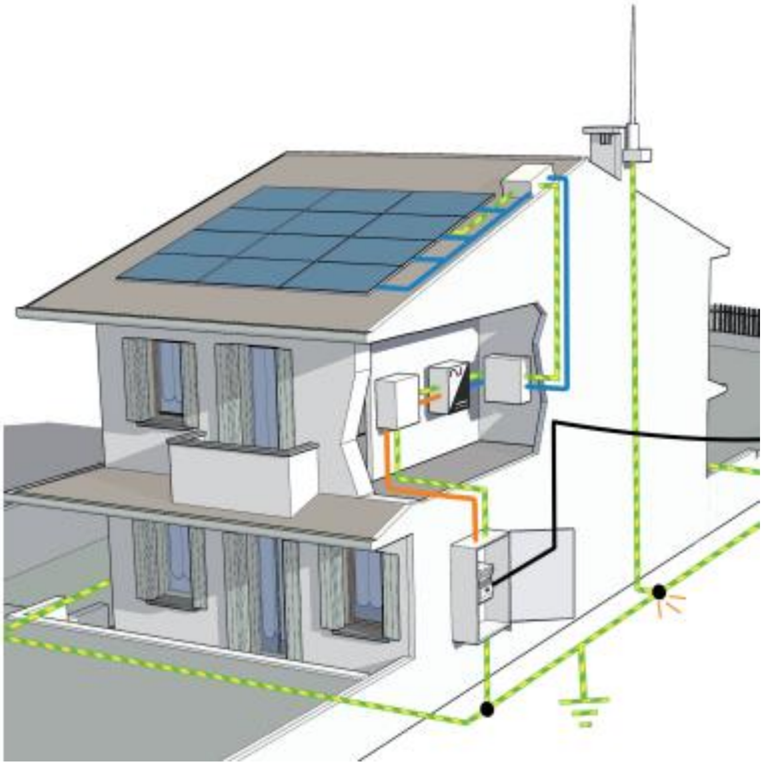
Figure(5.14): SMA inverter that used in home (3).

	SB 5000US	SB 6000US	SB 7000US
Max. Recommended Array Input Power (DC @ STC)	6250 W	7500 W	8750 W
Max. DC Voltage	600 V	600 V	600 V
Peak Power Tracking Voltage	250 - 480 V	250 - 480 V	250 - 480 V
DC Max. Input Current	21 A	25 A	30 A
DC Voltage Ripple	< 5%	< 5%	< 5%
Number of Fused String Inputs	4	4	4
PV Start Voltage	300 V	300 V	300 V
AC Nominal Power	5000 W	6000 W	7000 W
AC Maximum Output Power	5000 W	6000 W	7000 W
AC Maximum Output Current (@ 208, 240, 277 V)	24 A, 20.8 A, 18 A	29 A, 25 A, 21.6 A	34 A, 29 A, 25.3 A
AC Nominal Voltage / Range	183 - 229V @ 208 V 211 - 264 V @ 240V 244 - 305 V @ 277 V	183 - 229V @ 208 V 211 - 264 V @ 240V 244 - 305 V @ 277 V	183 - 229V @ 208V 211 - 264 V @ 240V 244 - 305 V @ 277 V
AC Frequency / Range	60 Hz / 59.3 Hz - 60.5 Hz	60 Hz / 59.3 Hz - 60.5 Hz	60 Hz / 59.3 Hz - 60.5 Hz
Power Factor	1	1	1
Peak Inverter Efficiency	96.8 %	97.0 %	97.1 %
CEC weighted Efficiency	95.5 % @ 208 V 95.5 % @ 240 V 95.5 % @ 277 V	95.5 % @ 208 V 95.5 % @ 240 V 96.0 % @ 277 V	95.5 % @ 208 V 96.0 % @ 240 V 96.0 % @ 277 V
Dimensions W x H x D in inches	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5	18.4 x 24.1 x 9.5
Weight / Shipping Weight	143 lbs / 154 lbs	143 lbs / 154 lbs	143 lbs / 154 lbs
Ambient temperature range	- 13 to + 113 °F	- 13 to + 113 °F	- 13 to + 113 °F
Power Consumption: standby / nighttime	< 7 W / 0.25 W	< 7 W / 0.25 W	< 7 W / 0.25 W
Topology	PWM, true sinewave, current source	PWM, true sinewave, current source	PWM, true sinewave, current source

Figure (5.15): The specification SMA inverter used in house no.(3).[27]

5.10 The Surge Protective Device (surge arrestor)

Installed outside, almost always in wide open areas, photovoltaic plants are particularly subject to atmospheric phenomena and can sustain damage from surges caused by lightning strikes. For this reason, and given the high value of the components and the high cost of any down time, it is always best practice to fit PV plants with suitable surge protection. It is necessary to protect both the direct current and alternating current circuits from surges: lightning is not interested in what type of current is flowing in the cables!.



Figure(5.16): Surge protection in photovoltaic plants (Domestic plant).[28]

Only house no. (1) has surge arrestors for AC and DC currents, house no.(2) and no.(3) must have arrestors to protect them.

5.11 Impacts of Existence of Air Conditions on the Home

Air conditioners have evolved a lot over the years. The models produced in the year 2000 used 30 to 50 percent less energy than the ones that were manufactured in 1970s. Nowadays, the newer models are designed with better energy efficiency features.

Before going into the details about the energy consumed by air conditioners, it is essential to know how the device works. Air conditioners work on the same principle as a refrigerator, where circuit of pipes and a pump form the cooling system. The room is cooled by the indoor cold evaporator coil, and the hot coil ejects the heat outside the rooms.

The cost of running an AC depends on various factors like:

- The type of AC used
- How long you use it every day
- Price of energy or power
- Usage of air conditioners
- Energy-Efficiency Ratio or the EER of the AC unit.

Figure (5.17): Air condition(split unit) used is cooling houses.

For instance, figure (5.18) shows the specifications of an air condition unit used in houses.

Figure (5.18): Specification of air condition unit(Tornado).

The existence of air condition in a house cause higher electric power consumption, let us take the air condition in figure (5.18) as an example:

I = 3.8 A from the specification in figure (5.22)

V = 230 V from the specification in figure (5.22)

P = 3.8* 230* 0.92 = 978.88 W

Energy consumed if the air condition used for 6 hours per day is:

E = P* 6 = 5873.28 Wh = 5.873 kWh

Cost of energy consumed = 5.873 * 0.65= 3.817 NIS/ day

Cost of 1 kWh from the utility = 0.65 NIS

Assume that the month is June:

The cost of energy consumed by the air condition in June = 114.529 NIS

So the electric bill will increase by 114.529 NIS this will reduce monthly revenue from the PV system.

As seen before the air condition energy consumption is very high this will increase the electric bill, so decrease the revenue from PV system.

Chapter Six

Economic Analysis

Chapter Six

Economic Analysis

6. Introduction

The need for engineering economy is primarily motivated by the work that engineers do in performing analyses, synthesizing, and coming to a conclusion as they work on projects of all sizes. In other words, engineering economy is at the heart of making decisions. These decisions involve the fundamental elements of cash flows of money, time, and interest rates. This chapter will talk about the outcome of the PV systems, cash flows, and other economic calculations.

6.1 Economic Study of PV House System

A) Initial cost of PV system

The initial cost includes the costs of equipment represented in PV modules, inverter, wires and other components used in installation. It includes also labor and technicians costs for installation. These costs depend on the size and type of a component. All these costs are summed to give the overall initial cost.

Initial cost=(components cost+ installation cost) (6.1)

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

Inverter available in different sizes and types. The price of the inverter depends on its capacity, efficiency, protection feature and type. On this systems the size of the inverter is 5 kW, grid tie inverter.

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

B) Operation and maintenance cost of PV system

The operation costs considered are incurred after installation in order to run the system for a certain number of years (system life time). On this systems the operation cost is negligible, the only thing that needs is cleaning by water only.

C) Salvage value

The salvage value is considered as the value of the project components after the system life time is finished. The salvage value is assumed to be 2% of the capital cost.

6.2 Cash Flow Analysis of PV System 5 kWp:

Cash Flow: It’s the estimated outcomes (costs) and incomes (revenues) of money over a identified time period. In this section the cash flow charts will show the incomes money and outcomes money for PV generators 5kWp.

Notice that operating and maintenance (O&M) cost is Zero because such a small system doesn't need maintenance beside just periodic cleaning with water that the owner can do cleaning by himself, in order to absorb higher solar radiation.

Ground cost is free, the system is installed on the roof of the home, so there is no need to ground cost. In other system which installed on ground the cost of ground is important.

The inverter works for over 20 years because it is indoor, not affected by sunlight and temperature fluctuations.

The interest rate we assume is 7%, it varies according to several economic parameters in the world.

Salvage value at the end of system life can be estimated to 2% from the capital cost which is equal 38000 NIS for all systems.

Cost of 5 kWp PV system = 38000 NIS

Salvage value= .02*capital cost= 760 NIS

6.2.1 Economic Analysis of House no.(1):

This house is in Tubas area as we mentioned before, the table below shows the monthly measured energy produced by the first house which was 8496.606 kWh per year. This house was from the first 100 household who installed PV on rooftops ,(PSI) so the tariff is 1.07 NIS/kWh. The outcome from this system is 9091.368 NIS in this year

Outcome = Energy produced * Tariff (6.2)

Outcome = 8496.606*1.07

Yearly Outcome = **9091.36832 NIS**

Table (6.1): Monthly outcome of house no.(1).

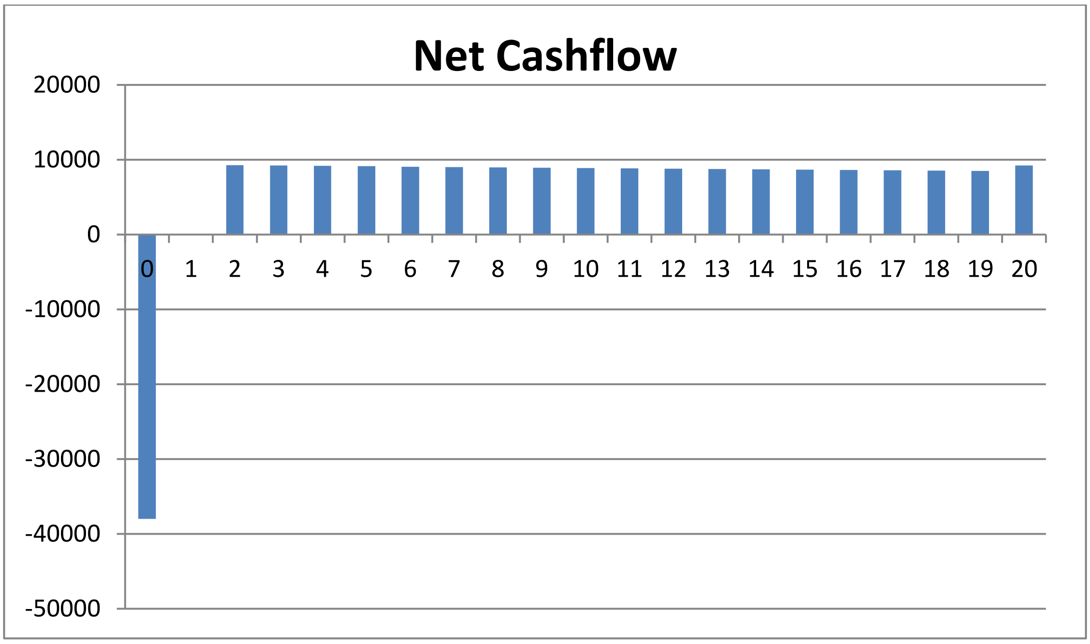
Month	House(1) E produced kWh	monthly outcome NIS
Jan	501.359	536.45
Feb	589.36	630.62
Mar	730.049	781.15
Apr	896.059	958.78
May	968.23	1036.00
Jun	951.56	1018.17
Jul	1014.8	1085.88
Aug	971.47	1039.48
Sep	811.62	868.43
Oct	409.69	438.36
Nov	245.74	262.95
Dec	406.58	435.04
yearly avg	**8496.6**	**9091.368**

In order to do calculation, the cash flow is necessary. Table (6.2) shows the cash flow components for the all houses.

The energy produced each year will be degreased because of degradation, the efficiency of the solar cells decreased each year. We assume that the degradation in the efficiency is 0.5% each year.

Table (6.2): Cash flow components of the houses.

Description	**NIS**
Capital cost	**38000**
Ground cost	**Free**
Maintenance cost	**Free**
Inverter replacement cost	**Free**
Interest	**7%**
n (number of years)	**20**
Degradation in yearly energy produced	**0.5%**
Salvage value	**2% capital cost**



Figure(6.1): Net cash flow for House no.1.

Cost of energy produced by solar energy:

On this procedure we are going to calculate the cost of energy produced by solar energy (the cost of 1 kWh) .

Tariff(NIS/ kWh)= LCC(AW)/ Energy produced yearly. (6.3)

Life Cycle Cost in Annual worth (LCC)= Investment Cost in annual worth + Annual running cost- Salvage Value in annual worth (6.4)

Annual fixed cost = Capital cost * (A/P, 7%, 20) (6.5)

Annual fixed cost= 38000* 0.09439 = 3586.82 NIS/year

The Recovery Factor (A/P, 7%, 20) = 0.09439 from the appendix A2.

Salvage Value in annual worth = 760 (A/F, 7%, 20)

The factor(A/F, 7%, 20) = 0.02439 from the appendix A2

Salvage Value in annual worth = 760* 0.02439= 10.54 NIS/year

Life Cycle Cost in Annual worth (LCC)= 3,576.28 NIS/year

Revenue From Energy Produced/year =

9091.93 –(.005*9091.93)(A/G,7%,20)

The factor (A/G,7%,20)= 7.3163 from the table on the appendix A2.

Annual Revenue From Energy Produced = 8759.33 NIS/year

Tariff (NIS/ kWh) =3576.28/8759.33 = 0.408 NIS/kWh

The yearly energy consumption of house no.(1) is 5114.99 kWh, so they pay to the company :

Yearly electric bill = annual consumption* cost of kWh.

Yearly electric bill = 5114.99 * 0.6 = 3,068.99 NIS.

The total average revenue from the PV generators/ year= 8759.33/year

So the annual saving after paying the electrical bills to the company is:

Annual saving =8759.33– 3,068.99 = **5,690.34 NIS/year.**

The total revenue for the life cycle of the system (20 year) is :

Total revenue = 5,690.34 * 20 = **113,806.8 NIS.**

6.2.2 Economic Analysis of House No.(2):

As the previous house table (6.3) shows the energy produced from the system and the outcome. The tariff used was 1.07 NIS, so the energy produced was **9617.66** kWh and the revenue **10290.90092** NIS.

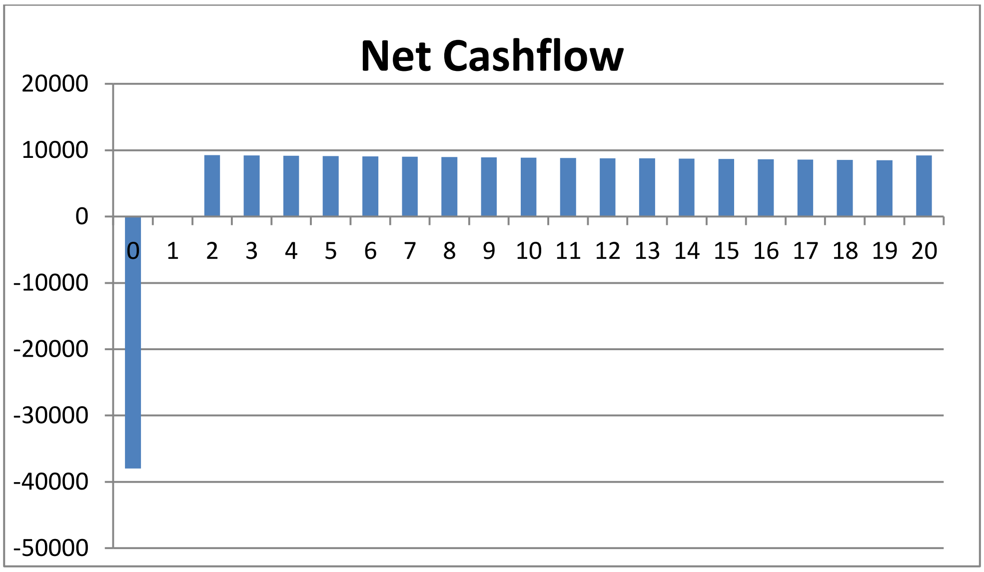
Outcome = Energy produced * Tariff

Outcome =9617.66 *1.07

Yearly Outcome = **10290.90092** NIS

Table (6.3): Monthly outcome of house No.(2).

Month	E produced kWhHouse(2)	Monthly outcome NIS
Jan	508.243	543.82
Feb	571.29	611.28
Mar	719.44	769.80
Apr	884.87	946.81
May	955.041	1021.89
Jun	951.179	1017.76
Jul	1034.185	1106.57
Aug	913.33	977.26
Sep	983.59	1052.44
Oct	842.44	901.41
Nov	732.24	783.49
Dec	521.78	558.31
yearly avg	**9617.66**	**10290.90**



Figure(6.2): Net cash flow for House no.(2).

We are going to calculate the cost of energy produced by solar energy (the cost of 1 kWh) ,by using the equation (6.3)

Like the previous house the Life Cycle Cost in Annual worth (LCC)= 3,567.28 NIS/year .

It is the same for the three houses.

Annual Revenue from Energy Produced = 10290.90 – (.005*10290.90)(A/G,7%,20)

The factor (A/G,7%,20)= 7.3163 from the table on the appendix A2.

Annual Revenue From Energy Produced = 9,914.44 NIS/year

Tariff (NIS/ kWh) = 3,567.28/9414.44 = 0.3789 NIS/kWh

The yearly energy consumption of house no.2 is 4893 kWh, so they pay to the company :

Yearly electric bill = annual consumption* cost of kWh.

Yearly electric bill = 4893 * 0.6 = 2935.8 NIS/year.

The total revenue from the PV generators is 9,914.44 NIS so the annual saving after paying the electrical bills to the company is:

Annual saving = 9,914.44 – 2,935.8 = **6,978.64 NIS/year.**

The total revenue after 20 years:

Total revenue = 6,978.64* 20 = **139,572.8 NIS.**

6.2.3 Economic Analysis House No.(3):

On this house the average yearly energy production was 9304 kWh , the tariff used was 0.80 NIS because the Palestinian Energy Authority changed the tariff from 1.07 NIS to 0.80 NIS after the first 100 home. The outcome was 7443.200 NIS which was less than the other houses as a result of a different Tariff.

Outcome = Energy produced * Tariff

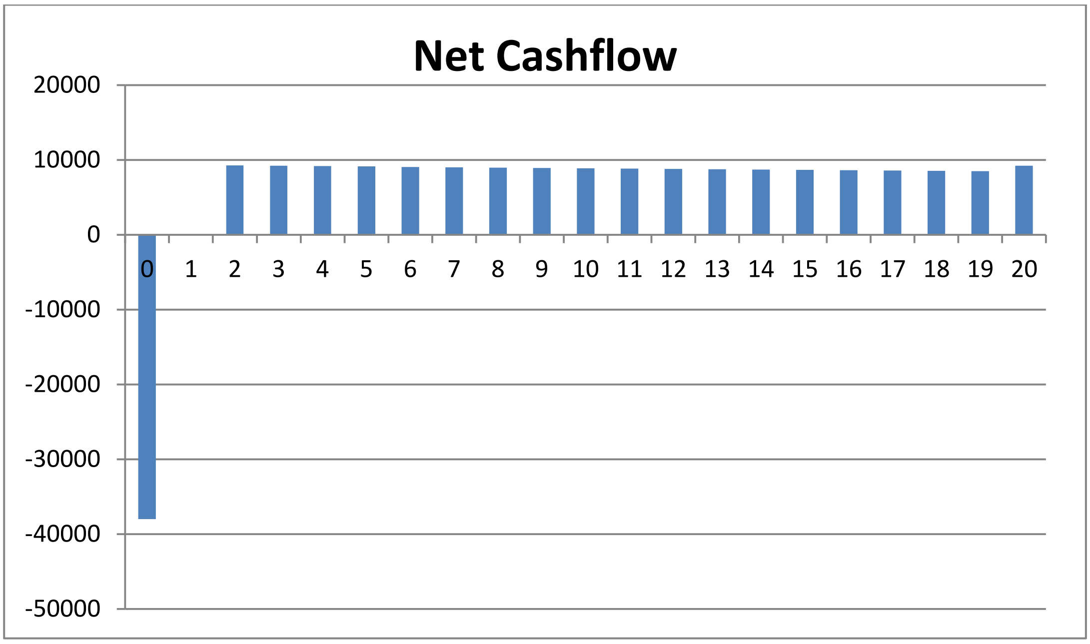
Outcome =9304.00 * 0.80

Yearly Outcome = **7443.200 NIS**

Table (6.4): Monthly outcome of house No.(3).

Month	Energy produced kWh House(3)	Monthly outcome NIS
Jan	580	464.000
Feb	693	554.400
Mar	772	617.600
Apr	871	696.800
May	926	740.800
Jun	894	715.200
Jul	1062	849.600
Aug	854	683.200
Sep	780	624.000
Oct	755	604.000
Nov	607	485.600
Dec	510	408.000
yearly average	**9304.000**	**7443.200**

The cash flow components of house no.3are the same as house (1) and (2). Figure (6.3) shows the net cash flow of house no.(3).



Figure(6.3): Net cash flow for house no.(3).

We are going to calculate the cost of energy produced by solar energy (the cost of 1 kWh) .

Tariff(NIS/ kWh)= Total annual cost/ Energy produced yearly.

Annual running cost due the degradation of the efficiency will decrease along the life cycle of the project then it will be calculated as follows :

Like the previous homes the Life Cycle Cost in Annual worth (LCC)= 3,567.28 NIS/year .

Annual Revenue = 7443.2 – (.005* 7443.2)(A/G, 7%, 20)

Annual Revenue = 7170.9 NIS/year

Tariff (NIS/ kWh) = 3,567.28/7170.9 = 0.497 NIS/kWh

The yearly energy consumption of home no.3 is 2623.84 kWh, so they pay to the company :

Yearly electric bill = annual consumption* cost of kWh.

Yearly electric bill = 2623.84 * 0.6 = 1,574.304 NIS.

The total revenue from the PV generators is 7170.9 NIS so the annual saving after paying the electrical bills to the company is:

Annual saving = 7170.9 – 1,574.304 = 5596.596 NIS.

If we suppose that the life cycle of the PV generator is 20 year then the total revenue is:

Total revenue (for 20 year) =5596.596 * 20 = **111,931.9 NIS**.

The total revenue of house no.3 is less than other houses due to the tariff = 0.8 NIS which is less than the tariff was used in the other houses and equal 1.07 NIS.

6.3 Simple Payback Period Analysis:

This is a simple way that doesn't take into account the life time for the project, and doesn't take into account the time value for money.

Table (6.5): Simple payback period for the PV generators of the three houses.

House	Cost/unit US $/Wp	System Capital Cost US $	Annual Revenue	Payback Period (year)
House no.(1)	2	10000	2392.46	4.17
House no.(2)	2	10000	2708.13	3.67
House no.(3)	2	10000	1958.7	5

As we see from the previous table the simple payback period of the three houses is less than five years which is a very good investment.

6.4 Economic Analysis Using NPV

6.4.1 Net Present Value (NPV) of House no.(1)

The NPV of an investment project at time t=0 is the sum of the present values of all cash inflows and outflows linked to the investment [3].

NPV=PW (income) – LCC **(6.6)**

A project is profitable when NPV>0 and the greater the NPV the more Profitable is the project. Negative NPV indicates that minimum interest rate will not be

met [3].

PWincome = PW(Revenue of energy produced per year)+ PW(salvage value)

PWincome = 8759.33* (P/A,7%,20) + 760* (P/F,7%,20)

PWincome = 92,992.726 NIS

(P/A,7%,20) = 10.5940 from appendix (A1)

(P/F,7%,20) = 0.2584 from appendix (A1)

PWoutcome = fixed cost(initial value)

PWoutcome = 38,000 NIS

NPV = 92,992.726 – 38,000 =54,992.726 NIS

NPV>0 then the investment in such system is feasible.

6.4.2 Net Present Value (NPV) of House no.(2)

PWincome = PW(Revenue of energy produced per year)+ PW(salvage value)

PWincome = 9,914.44* (P/A,7%,20) + 760* (P/F,7%,20)

PWincome = 105,229.96 NIS

(P/A,7%,20) = 10.5940 from appendix (A2)

(P/F,7%,20) = 0.2584 from appendix (A2)

PWoutcome = fixed cost(initial value)

PWoutcome = 38,000 NIS

NPV = 105,229.96 – 38,000 =67,229.96 NIS

NPV>0 then the investment in such system is feasible.

6.4.3 Net Present Value (NPV) of House no. (3)

PWincome = PW(Revenue of energy produced per year)+ PW(salvage value)

PWincome = 7170.9* (P/A,7%,20) + 760* (P/F,7%,20)

PWincome = 76,164.89 NIS

(P/A,7%,20) = 10.5940 from appendix (A2)

(P/F,7%,20) = 0.2584 from appendix (A2)

PWoutcome = fixed cost(initial value)

PWoutcome = 38,000 NIS

NPV = 76,164.89 – 38,000 = 38,164.898 NIS

NPV>0 then the investment in such systems is feasible.

6.5 Economic Analysis Using ROR

It is the effective annual interest rate earned on an investment and it is one of the important economic methods to justify whether the project is feasible or not.

We can find ROR by using the following equation.

$$\text{PWincome} - \text{PWoutcome} = 0 \tag{6.7}$$

Where:

- PW income, it means present worth income (positive value in cash flow) and the formula for it is :

$$\text{PW income} = \text{annual saving } (P/A, i^*, 20) + \text{Salvage value } (P/F, i^*, 20) \tag{6.8}$$

- (P/A, i*,20): find the present value from the annual value at the interest rate of i*% and at the life time of 20 years.
- (P/F, i*,20): find the present value from the future value at the interest rate of i% and at the life time of 20 years.

- PW outcome it means present worth outcome (negative value in cash flow), the formula for it.
- PW outcome = annual cost(P/A,i*,20)+capital investment (6.9)

  20 is the lifetime of the project in years.
- i* is the interest rate ROR.

6.5.1 ROR of house no.(1):

For house no.1 we use equation (6.7) to find ROR, and other values from cash flow figure (6.1):

To find PW income and PW outcome, we use equations (6.8) and (6.9) as follows:

PW income=8759.33 (P/A, i*, 20) +760 (P/F, i*, 20)

PW outcome = capital investment = 38000 NIS (since there is no annual cost)

Using equation(6.6):

8759.33 (P/A, i*, 20) +760 (P/F, i*, 20) – 38000 = 0

By solving this equation we obtain **i*=ROR = 25%** using (appendix A3).

6.5.2 ROR of house no.(2):

For house no.2 we use equation (6.7) to find ROR, and other values from cash flow figure (6.2):

To find PW income and PW outcome, we use equations (6.8) and (6.9) as follows:

PW income=9,914.44 (P/A, i*, 20) +760 (P/F, i*, 20)

PW outcome = capital investment = 38000 NIS (since there is no annual cost)

Use equation (6.6):

9,914.44 (P/A, i*, 20) + 760 (P/F, i*, 20) – 38000 = 0

By solving this equation we obtain **i*= ROR = 25.7 %** using (appendix A3).

6.5.3 ROR of house no.(3):

For house no.2 we use equation 1 to find ROR, and other values from cash flow figure (6.3):

To find PW income and PW outcome, we use equations (6.7) and (6.8) as follows:

PW income=7170.9 (P/A, i*, 20) +760 (P/F, i*, 20)

PW outcome = capital investment = 38000 NIS (since there is no annual cost)

Using equation (6.6):

7170.9 (P/A, i*, 20) + 760 (P/F, i*, 20) – 38000 = 0

By solving this equation **ROR = 22 %** using (appendix A4).

ROR for all systems are more than minimum attractive rate of return (MAROR) this mean that the investment in such systems is feasible.

Environment impact of PV system

The PV technologies have great environmental advantages over conventional technologies for electricity generation. The operation of PV systems does not produce any noise, toxic-gas emissions, and greenhouse gases. PV energy help to meet the growing worldwide demand for electricity, and can do so without incurring the high economic and environmental costs of installing power lines or burning fossil fuels. Relative to burning coal, every gaga watt-hour of electricity generated by PV would prevent the emission of about 10 tons of SO_2 , 4 tons of NO_x, 0.7 tons of particulates (including 1 kg of Cd and 120 kg of As), and up to 1000 tons of CO_2 .[26]

The PV systems also require less area than other facilities, total land area requirements estimates from 8-13 m^2 per 1 kW_p. Smaller scale solar PV arrays, which can be built on houses or commercial buildings, have minimal land use impact.

Solar PV cells do not use water for generating electricity. However, as in all manufacturing processes, some water is used to manufacture solar PV components , and in periodic cleaning of the PV modules.

1 kWh of electricity produced from a coal powered station emits 0.97kg of CO2 to the atmosphere, so producing 1 kWh from solar energy will reduce 0.97 kg of CO2 .

If we calculate how this systems can reduce CO2 emissions we find this results:

CO_2 reduced by house no.1= 0.97 * 8164.00 = **7,919.08 kg/year**.

After 20 years the amount of CO2 reduced by this system:

CO_2 reduced by house no.1= **158,381.6 kg**

CO_2 reduced by house no.2= 0.97 * 9,285.18 **= 9,006.62kg/year.**

After 20 years the amount of CO2 reduced by this system:

CO_2 reduced by house no.2=**180,132.4 kg**

CO_2 reduced by house no.3 = 0.97 * 8971.41 **= 8,702.26 kg/year**

After 20 years the amount of CO2 reduced by this system:

CO_2 reduced by house no.3= **174,045.35 kg**

Chapter Seven

Improvement Possibilities

Chapter Seven

Improvement Possibilities

There are many simple ways to improve the PV generators energy production discussed hereafter:

7.1 Three Different Tilt Angles Surface

The amount of direct-beam solar energy that strikes the PV surface is optimized by keeping the surface at right angles to the sun's direct radiation all the day. In most cases, maneuvering a surface is impractical and affects the system reliability negatively. The cost of the energy and the mechanical assembly required to track the sun consistently each day generally outweighs the extra energy obtained through tracking when fiat-plate solar-cell modules without concentrators are used.

The next best propositions are to fix the surface's position so that the sun's angle on the plane is closest to the perpendicular most of the time, or to make it able to be constructed for seasonal adjustment.[19]

Since the optimum tilt angle over a full year must balance the summer maximum and winter minimum declination angle, and to maximize the solar energy received during the winter and summer months, the PV mounting structure has to be constructed for seasonal mounting at three tilt angles (latitude, latitude -10, latitude +20).

According to a previous literature [19] the variable angle mounting structure shows an annual average of 5.6% improvement in radiation received over the structure with fixed optimum tilt angle. The above mentioned percentage increases to achieve the double value during the main winter months. It is worth mentioning, that this improvement is achieved without considerable additional cost. The owner of the home can vary the position by himself so it is easy to be done.

As a result of this improvement, the energy produced by PV systems will be increased according to the following calculations.

7.2 Economic Analysis After Improvement

7.2.1 Economic analysis after improvement (house no.(1))

From the previous chapter the total revenue by PV system on the roof of house (1) is 113,806.8 NIS, as the solar radiation increases by 5.6% the energy produced also increases by 5.6%, so :

The increment after 20 year(after improvement) = 5.6% * 113,806.8.

The increment after 20 year(after improvement)= 6,373.18 NIS.

The total revenue after 20 year = **120,179.98 NIS**

Since this is a small investment it is important to improve it as possible as we can.

7.2.2 Economic analysis after improvement(home no.(2))

From the previous chapter the total revenue by PV system on the roof of home no.(2) is 139,572.8 NIS, as the solar radiation increases by 5.6% the energy produced also increases by 5.6%, so :

The increment after 20 year(after improvement) = 5.6% * 139,572.8

The increment after 20 year(after improvement)= 7,816.07 NIS.

The total revenue after 20 year = **147,388.88 NIS**

7.2.3 Economic analysis after improvement(house no.(3))

From the previous chapter the total revenue by PV system on the roof of house no.(3) is 111,931.9 NIS, as the solar radiation increases by 5.6% the energy produced also increases by 5.6%, so :

The increment after 20 year(after improvement) = 5.6% * 111,931.9

The increment after 20 year(after improvement)= 6268.18 NIS.

The total revenue after 20 year = **118,200.08 NIS**

7.3 Cleaning PV Modules

Many studies assessing how dust, dirt and bird droppings accumulated on PV modules decrease the module efficiency. A test was performed by a team to study short-term effect of cleaning performed on a smaller sample of PV modules in which the modules were left exposed to the usual environmental soiling in urban areas for three summer months and then cleaned. The comparison of the measurement results before and after the cleaning showed that cleaning increased module efficiency by up to 5.06 %, with an average of 4.73 %[30].

The modules are cleaned with a brush and de-mineralized water. The hard part (especially for roof mounted solar panels is reaching them). Assuming the owner can reach his solar modules, cleaning the surface of a solar module is like cleaning a car, with warm water and dishwashing soap to remove any accumulation of dirt and grime.[31]

Figure (7.1): Cleaning the solar panel.

When the solar modules become dirty there are many options:

Option 1: Solar Panel Cleaning by the owner

Option 2 : Use a Nano-Cleaning Product

Basically a nano-cleaning product can reduce the need for frequent solar panel cleaning and if the area where it rains often using a nano-cleaning product lets the rain to do most of the cleaning. In a drier area the panels can be cleaned using an air-hose (if there is water rationing) or a garden hose (if water is easily available).

Option 3 : Use a Cleaning Robot

It is possible to use robots for cleaning the solar PV modules.

Option 4 : Automated Self-Cleaning Technology

This method is appropriate for large commercial or public utility sites, especially those in remote and dry locations.

Chapter Eight

Conclusions and recommendations

Chapter Eight

Conclusions and recommendations

8.1 Conclusions

Based on this study the following conclusions can be made**:**

- Palestine has a distinguished high solar energy potential estimated in average to 5.4 kWh/m^2-day, therefore it is appropriate to use this energy in electricity production.
- The economic analysis has shown that the cost of 1kWh produced from solar energy is 0.40 NIS as an average, while the Israel company provides the energy with 0.4527 NIS, so the energy produced from the sun is more reliable and economically feasible.
- The simple payback period of a house_ PV power system is about 4 years, which is good investment for home owners.
- Provided tangible economic result of the establishment and use of energy-generating systems, the amount of 7000 NIS is the yearly average for each generating unit to the Palestinian economy.
- The total revenue after 20 years for house no.(1) is 113,806.34 NIS/ year, house no.(2) 139,572.8 NIS/ year , and house no.(3) 111,931.9 NIS/year.
- Reduction of the emission of carbon dioxide is 160,000 kg per annum at least, for each house- PV power system.

- By doing simple improvement, the production of the systems will be increased, variable-angle mounting structure improves the production by 5.6%.
- The usage of three tilt angles improves the energy production by 5.6% and thereby the revenue of the systems.
- Cleaning the PV panels increases module efficiency by up to 5.06 %, with an average of 4.73 % .

8.2 Recommendations and Perspectives

Depending on the carried out investigations, the measuring results and the analysis within these thesis, the following recommendations are made:

- Based on the technical and economical results obtained through investigation the three home PV- systems, it is recommended to increase the PV- generators on the roof tops.
- Adoption of the Palestinian Solar Initiative by the Energy Authority, by using motivational fixed prices.
- Form a technical committee at the national level to test new types of PV system components, and to identify the names of certified equipment lists pre-marketing.
- Providing each house- PV system with a proper surge arrestor and grounding is very necessary to protect the PV system and the home from any dangerous caused weather conditions.
- The installation of the PV system should be properly located and performed to that no PV module can be shaded all the day.

- It is highly recommended to use PV- support structure with three adjustable tilt angles(β= latitude, latitude- 10°, latitude= 20°) in order to increase the annual energy production along the year.
- Intensifying advertising campaigns and awareness about renewable energy, to encourage people to use solar energy and make investment, since the PV- system is a feasible project and the owner retrieves his money after about 4 years or less.
- Providing a special training in the field of solar energy for to contracting companies to secure for better performance of PV systems.
- Developing policies that encourage investment in solar energy and continue to work out, and facilitating the access to private financing for low-income home owners.

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Appendix

Appendix A1

ELECTRICAL SPECIFICATIONS

Model Type	ET-A-P672295	ET-A-P672290	ET-A-P672285	ET-A-P672280	ET-A-P672275
Peak Power (Pmax)	295W	290W	285W	280W	275W
Module Efficiency	15.20%	14.95%	14.69%	14.43%	14.17%
Maximum Power Voltage (Vmp)	35.47V	35.40V	35.33V	35.25V	35.15V
Maximum Power Current (Imp)	8.32A	8.19A	8.07A	7.95A	7.83A
Open Circuit Voltage (Voc)	46.20V	45.50V	44.81V	44.12V	43.45V
Short Circuit Current (Isc)	8.95A	8.82A	8.68A	8.55A	8.42A
Power Tolerance	0 to +5W	0 to +5W	0 to +5W	0 to +5W	0 to +5W
Maximum System Voltage	DC 600V				
Normal Operating Cell Temperature	46.8℃				
Series Fuse Rating (A)	15A				
Number of Bypass Diode	3				

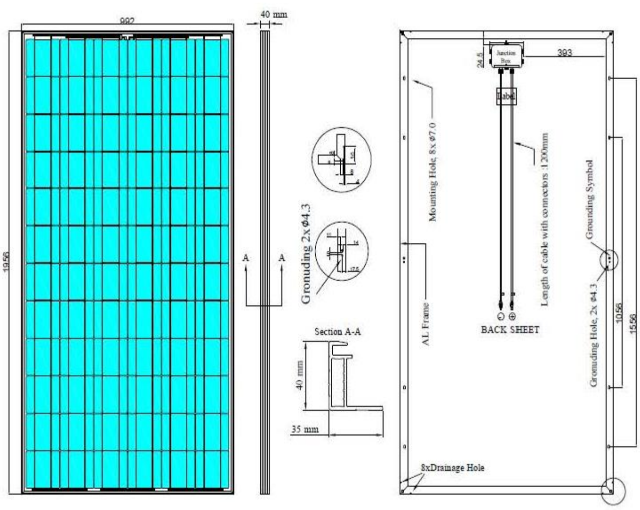
MECHANICAL SPECIFICATIONS

Cell type	156mm x 156mm
Number of cells	72 cells in series
Weight	23 kg (50.70 lbs)
Dimensions	1956×992×40 mm (77.01×39.06×1.57 inch)
Max Load	2400Pascals (45 lb/ft²)

TEMPERATURE COEFFICIENT

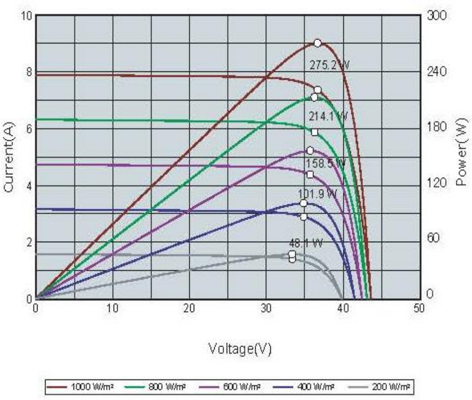
Temp. Coeff. of Isc (TK Isc)	0.07 %/ ℃
Temp. Coeff. of Voc (TK Voc)	-0.39 %/ ℃
Temp. Coeff. of Pmax (TK Pmax)	-0.55 %/ ℃

PHYSICAL CHARACTERISTICS Unit:mm

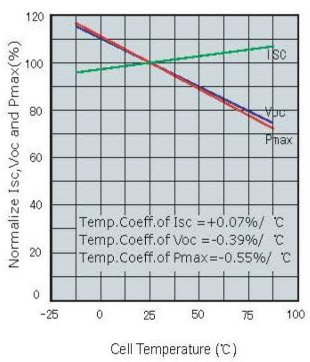


ELECTRICAL CHARACTERISTICS

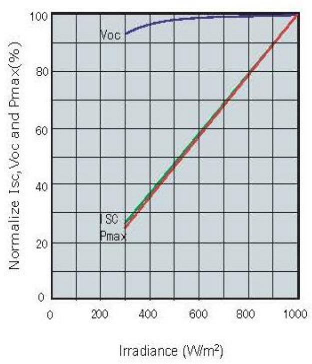
Electrical performance
(cell temperature:25℃)



Temperature dependence of Isc,
Voc and Pmax



Irradiance dependence of Isc,
Voc and Pmax (cell temperature:25℃)



Note: the specifications are obtained under the Standard Test Conditions (STCs): 1000 W/m² solar irradiance, 1.5 Air Mass, and cell temperature of 25℃.
The NOCT is obtained under the Test Conditions : 800 W/m², 20°C ambient temperature, 1 m/s wind speed, AM 1.5 spectrum.

Please contact **support@etsolar.com** for technical support. The parameters are for reference only, and are subject to change without notice or obligation.

Appendix A2

7% TABLE 12 Discrete Cash Flow: Compound Interest Factors 7%

	Single Payments		Uniform Series Payments				Arithmetic Gradients	
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Uniform Series A/G
1	1.0700	0.9346	1.00000	1.0000	1.07000	0.9346		
2	1.1449	0.8734	0.48309	2.0700	0.55309	1.8080	0.8734	0.4831
3	1.2250	0.8163	0.31105	3.2149	0.38105	2.6243	2.5060	0.9549
4	1.3108	0.7629	0.22523	4.4399	0.29523	3.3872	4.7947	1.4155
5	1.4026	0.7130	0.17389	5.7507	0.24389	4.1002	7.6467	1.8650
6	1.5007	0.6663	0.13980	7.1533	0.20980	4.7665	10.9784	2.3032
7	1.6058	0.6227	0.11555	8.6540	0.18555	5.3893	14.7149	2.7304
8	1.7182	0.5820	0.09747	10.2598	0.16747	5.9713	18.7889	3.1465
9	1.8385	0.5439	0.08349	11.9780	0.15349	6.5152	23.1404	3.5517
10	1.9672	0.5083	0.07238	13.8164	0.14238	7.0236	27.7156	3.9461
11	2.1049	0.4751	0.06336	15.7836	0.13336	7.4987	32.4665	4.3296
12	2.2522	0.4440	0.05590	17.8885	0.12590	7.9427	37.3506	4.7025
13	2.4098	0.4150	0.04965	20.1406	0.11965	8.3577	42.3302	5.0648
14	2.5785	0.3878	0.04434	22.5505	0.11434	8.7455	47.3718	5.4167
15	2.7590	0.3624	0.03979	25.1290	0.10979	9.1079	52.4461	5.7583
16	2.9522	0.3387	0.03586	27.8881	0.10586	9.4466	57.5271	6.0897
17	3.1588	0.3166	0.03243	30.8402	0.10243	9.7632	62.5923	6.4110
18	3.3799	0.2959	0.02941	33.9990	0.09941	10.0591	67.6219	6.7225
19	3.6165	0.2765	0.02675	37.3790	0.09675	10.3356	72.5991	7.0242
20	3.8697	0.2584	0.02439	40.9955	0.09439	10.5940	77.5091	7.3163
21	4.1406	0.2415	0.02229	44.8652	0.09229	10.8355	82.3393	7.5990
22	4.4304	0.2257	0.02041	49.0057	0.09041	11.0612	87.0793	7.8725
23	4.7405	0.2109	0.01871	53.4361	0.08871	11.2722	91.7201	8.1369
24	5.0724	0.1971	0.01719	58.1767	0.08719	11.4693	96.2545	8.3923
25	5.4274	0.1842	0.01581	63.2490	0.08581	11.6536	100.6765	8.6391
26	5.8074	0.1722	0.01456	68.6765	0.08456	11.8258	104.9814	8.8773
27	6.2139	0.1609	0.01343	74.4838	0.08343	11.9867	109.1656	9.1072
28	6.6488	0.1504	0.01239	80.6977	0.08239	12.1371	113.2264	9.3289
29	7.1143	0.1406	0.01145	87.3465	0.08145	12.2777	117.1622	9.5427
30	7.6123	0.1314	0.01059	94.4608	0.08059	12.4090	120.9718	9.7487
31	8.1451	0.1228	0.00980	102.0730	0.07980	12.5318	124.6550	9.9471
32	8.7153	0.1147	0.00907	110.2182	0.07907	12.6466	128.2120	10.1381
33	9.3253	0.1072	0.00841	118.9334	0.07841	12.7538	131.6435	10.3219
34	9.9781	0.1002	0.00780	128.2588	0.07780	12.8540	134.9507	10.4987
35	10.6766	0.0937	0.00723	138.2369	0.07723	12.9477	138.1353	10.6687
40	14.9745	0.0668	0.00501	199.6351	0.07501	13.3317	152.2928	11.4233
45	21.0025	0.0476	0.00350	285.7493	0.07350	13.6055	163.7559	12.0360
50	29.4570	0.0339	0.00246	406.5289	0.07246	13.8007	172.9051	12.5287
55	41.3150	0.0242	0.00174	575.9286	0.07174	13.9399	180.1243	12.9215
60	57.9464	0.0173	0.00123	813.5204	0.07123	14.0392	185.7677	13.2321
65	81.2729	0.0123	0.00087	1146.76	0.07087	14.1099	190.1452	13.4760
70	113.9894	0.0088	0.00062	1614.13	0.07062	14.1604	193.5185	13.6662
75	159.8760	0.0063	0.00044	2269.66	0.07044	14.1964	196.1035	13.8136
80	224.2344	0.0045	0.00031	3189.06	0.07031	14.2220	198.0748	13.9273
85	314.5003	0.0032	0.00022	4478.58	0.07022	14.2403	199.5717	14.0146
90	441.1030	0.0023	0.00016	6287.19	0.07016	14.2533	200.7042	14.0812
95	618.6697	0.0016	0.00011	8823.85	0.07011	14.2626	201.5581	14.1319
96	661.9766	0.0015	0.00011	9442.52	0.07011	14.2641	201.7016	14.1405
98	757.8970	0.0013	0.00009	10813	0.07009	14.2669	201.9651	14.1562
100	867.7163	0.0012	0.00008	12382	0.07008	14.2693	202.2001	14.1703

Appendix A3

25% TABLE 25 Discrete Cash Flow: Compound Interest Factors 25%

	Single Payments		Uniform Series Payments				Arithmetic Gradients	
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Uniform Series A/G
1	1.2500	0.8000	1.00000	1.0000	1.25000	0.8000		
2	1.5625	0.6400	0.44444	2.2500	0.69444	1.4400	0.6400	0.4444
3	1.9531	0.5120	0.26230	3.8125	0.51230	1.9520	1.6640	0.8525
4	2.4414	0.4096	0.17344	5.7656	0.42344	2.3616	2.8928	1.2249
5	3.0518	0.3277	0.12185	8.2070	0.37185	2.6893	4.2035	1.5631
6	3.8147	0.2621	0.08882	11.2588	0.33882	2.9514	5.5142	1.8683
7	4.7684	0.2097	0.06634	15.0735	0.31634	3.1611	6.7725	2.1424
8	5.9605	0.1678	0.05040	19.8419	0.30040	3.3289	7.9469	2.3872
9	7.4506	0.1342	0.03876	25.8023	0.28876	3.4631	9.0207	2.6048
10	9.3132	0.1074	0.03007	33.2529	0.28007	3.5705	9.9870	2.7971
11	11.6415	0.0859	0.02349	42.5661	0.27349	3.6564	10.8460	2.9663
12	14.5519	0.0687	0.01845	54.2077	0.26845	3.7251	11.6020	3.1145
13	18.1899	0.0550	0.01454	68.7596	0.26454	3.7801	12.2617	3.2437
14	22.7374	0.0440	0.01150	86.9495	0.26150	3.8241	12.8334	3.3559
15	28.4217	0.0352	0.00912	109.6868	0.25912	3.8593	13.3260	3.4530
16	35.5271	0.0281	0.00724	138.1085	0.25724	3.8874	13.7482	3.5366
17	44.4089	0.0225	0.00576	173.6357	0.25576	3.9099	14.1085	3.6084
18	55.5112	0.0180	0.00459	218.0446	0.25459	3.9279	14.4147	3.6698
19	69.3889	0.0144	0.00366	273.5558	0.25366	3.9424	14.6741	3.7222
20	86.7362	0.0115	0.00292	342.9447	0.25292	3.9539	14.8932	3.7667
22	135.5253	0.0074	0.00186	538.1011	0.25186	3.9705	15.2326	3.8365
24	211.7582	0.0047	0.00119	843.0329	0.25119	3.9811	15.4711	3.8861
26	330.8722	0.0030	0.00076	1319.49	0.25076	3.9879	15.6373	3.9212
28	516.9879	0.0019	0.00048	2063.95	0.25048	3.9923	15.7524	3.9457
30	807.7936	0.0012	0.00031	3227.17	0.25031	3.9950	15.8316	3.9628
32	1262.18	0.0008	0.00020	5044.71	0.25020	3.9968	15.8859	3.9746
34	1972.15	0.0005	0.00013	7884.61	0.25013	3.9980	15.9229	3.9828
35	2465.19	0.0004	0.00010	9856.76	.025010	3.9984	15.9367	3.9858
36	3081.49	0.0003	0.00008	12322	0.25008	3.9987	15.9481	3.9883
38	4814.82	0.0002	0.00005	19255	0.25005	3.9992	15.9651	3.9921
40	7523.16	0.0001	0.00003	30089	0.25003	3.9995	15.9766	3.9947
45	22959		0.00001	91831	0.25001	3.9998	15.9915	3.9980
50	70065				0.25000	3.9999	15.9969	3.9993
55					0.25000	4.0000	15.9989	3.9997

Appendix A4

22% TABLE 23 Discrete Cash Flow: Compound Interest Factors 22%

	Single Payments		Uniform Series Payments				Arithmetic Gradients	
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Uniform Series A/G
1	1.2200	0.8197	1.00000	1.0000	1.22000	0.8197		
2	1.4884	0.6719	0.45045	2.2200	0.67045	1.4915	0.6719	0.4505
3	1.8158	0.5507	0.26966	3.7084	0.48966	2.0422	1.7733	0.8683
4	2.2153	0.4514	0.18102	5.5242	0.40102	2.4936	3.1275	1.2542
5	2.7027	0.3700	0.12921	7.7396	0.34921	2.8636	4.6075	1.6090
6	3.2973	0.3033	0.09576	10.4423	0.31576	3.1669	6.1239	1.9337
7	4.0227	0.2486	0.07278	13.7396	0.29278	3.4155	7.6154	2.2297
8	4.9077	0.2038	0.05630	17.7623	0.27630	3.6193	9.0417	2.4982
9	5.9874	0.1670	0.04411	22.6700	0.26411	3.7863	10.3779	2.7409
10	7.3046	0.1369	0.03489	28.6574	0.25489	3.9232	11.6100	2.9593
11	8.9117	0.1122	0.02781	35.9620	0.24781	4.0354	12.7321	3.1551
12	10.8722	0.0920	0.02228	44.8737	0.24228	4.1274	13.7438	3.3299
13	13.2641	0.0754	0.01794	55.7459	0.23794	4.2028	14.6485	3.4855
14	16.1822	0.0618	0.01449	69.0100	0.23449	4.2646	15.4519	3.6233
15	19.7423	0.0507	0.01174	85.1922	0.23174	4.3152	16.1610	3.7451
16	24.0856	0.0415	0.00953	104.9345	0.22953	4.3567	16.7838	3.8524
17	29.3844	0.0340	0.00775	129.0201	0.22775	4.3908	17.3283	3.9465
18	35.8490	0.0279	0.00631	158.4045	0.22631	4.4187	17.8025	4.0289
19	43.7358	0.0229	0.00515	194.2535	0.22515	4.4415	18.2141	4.1009
20	53.3576	0.0187	0.00420	237.9893	0.22420	4.4603	18.5702	4.1635
22	79.4175	0.0126	0.00281	356.4432	0.22281	4.4882	19.1418	4.2649
24	118.2050	0.0085	0.00188	532.7501	0.22188	4.5070	19.5635	4.3407
26	175.9364	0.0057	0.00126	795.1653	0.22126	4.5196	19.8720	4.3968
28	261.8637	0.0038	0.00084	1185.74	0.22084	4.5281	20.0962	4.4381
30	389.7579	0.0026	0.00057	1767.08	0.22057	4.5338	20.2583	4.4683
32	580.1156	0.0017	0.00038	2632.34	0.22038	4.5376	20.3748	4.4902
34	863.4441	0.0012	0.00026	3920.20	0.22026	4.5402	20.4582	4.5060
35	1053.40	0.0009	0.00021	4783.64	0.22021	4.5411	20.4905	4.5122
36	1285.15	0.0008	0.00017	5837.05	0.22017	4.5419	20.5178	4.5174
38	1912.82	0.0005	0.00012	8690.08	0.22012	4.5431	20.5601	4.5256
40	2847.04	0.0004	0.00008	12937	0.22008	4.5439	20.5900	4.5314
45	7694.71	0.0001	0.00003	34971	0.22003	4.5449	20.6319	4.5396
50	20797		0.00001	94525	0.22001	4.5452	20.6492	4.5431
55	56207				0.22000	4.5454	20.6563	4.5445

جامعة النجاح الوطنية

كلية الدراسات العليا

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قدمت هذه الأطروحة استكمالا لمتطلبات درجة الماجستير في هندسة الطاقة النظيفة واستراتيجية الترشيد، في كلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين .

2015

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الملخص

يبلغ معدل الاشعاع الشمسي اليومي المقاس في فلسطين على سطح افقي 5.4 كيلوواط ساعه لكل متر مربع يوميا بينما يصل عدد الساعات الشمسية الي حوالي 3000 ساعه سنويا. يتم التركيز في فلسطين على مشاريع الطاقة الشمسية كجزء من التركيز على الطاقة المتجددة. سلطة الطاقة والموارد الطبيعية في فلسطين اصدرت المبادرة الشمسية الفلسطينية وهدفها انتاج 20 ميغاواط حتى عام 2020 من خلال تركيب الخلايا الشمسية على اسط المنازل بقدرة 5 كيلوواط لكل منزل.

هذه الرسالة تدرس الانظمة الشمسية المركبة على أسطح المنازل، كما تقيم ادائها تقنيا واقتصاديا،و تبحث في سبل تحسين ادائها.

تم دراسة ثلاثة بيوت في محافظة طوباس، كان انتاج البيت الاول من الطاقة 8496.6 كيلوواط ساعة سنويا وكان العائد الاقتصادي من استخدام هذا النظام 8759.33 شيكل سنويا، بينما كان التوفير بعد دفع فواتير الكهرباء للشركة 5690.34 شيكل سنويا. أنتج البيت الثاني 9617.66 كيلوواط ساعة سنويا وكان العائد 9914.44 شيكل سنويا وحقق توفيرا بمقدار 6978.64 شيكل سنويا. وانتج البيت الثالث 9304 كيلوواط ساعه سنويا وعائدا بمقدار 7443.200 شيكل سنويا و كان مقدار التوفير 5596.59 شيكل سنويا.

التحليل الاقتصادي اظهر ان سعر الكيلوواط ساعه من هذه الانظمة 0.40 شيكل.

ويبين التحليل البيئي أن استخدام مثل هذه النظم الصغيرة يحافظ على البيئة من خلال تقليل إنتاج غاز CO_2. يقلل البيت الاول من انتاج غاز ثاني اكسيد الكربون 7919.08 بمقدار كغـــم مـــن غاز ثاني اكسيد الكربون والبيت الثاني 9006.62 كغم والبيت الثالث 8702.26 كغم سنويا.