An-Najah National University

Faculty of Graduate Studies

POWERING OF RADIO COMMUNICATION STATIONS IN REMOTE AREAS BY SOLAR PV: OPTIMAL SYSTEM DESIGN AND ECONOMICS

By

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This Thesis was defended successfully on 22 /12/2015 and approved by:

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– Dr. Basim Alsayid/ External Examiner	....
– Dr. Kamel Subhi Saleh / Internal Examiner	....

Dedication

I am thrilled to dedicate this work

To those who inspire me the most

My Parents

My Sister and Brothers

My Family

My Friends

…

Acknowledgment

First and foremost I would like to express how deeply indebted I am to my supervisor, Prof. Dr. Marwan Mahmoud, who has supported me throughout my thesis with his patience, knowledge, encouragement, guidance and kindness, I attribute the level of my Master's degree to his encouragement and effort, I simply could not wish for a better or friendlier supervisor.

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Most importantly, I would like to warmly thank my immediate and extended family, they are my truly inspiration, they have always been a constant source of love, concern, support and strength all these years.

الإقرار

أنا الموقعة أدناه مقدمة الرسالة التي تحمل العنوان:

POWERING OF RADIO COMMUNICATION STATIONS IN REMOTE AREAS BY SOLAR PV: OPTIMAL SYSTEM DESIGN AND ECONOMICS

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Declaration

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

Student's name: Rawan Abu Shmeis **:اسم الطالبة**

Signature: Rawan **:التوقيع**

Date: 22/12/2015 **:التاريخ**

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List of abbreviations

AC	Alternative current
AC	Air conditioning
AW	Annual Worth
BSC	Base Station Controller
BTS	Base Transceiver Station
C_{Ah}	Amper hour capacity
CAPEX	Capital cost
CR	Charge regulator
D.F	Depreciation Factor
D.G	Diesel generator
DC	Direct current
DCF	Discounted cash flow technique
DOD	Depth of Discharge
Ed	The average daily solar radiation intensity
GHG	Greenhouse gasses
GSM	Global system of mobile
HLR	Home Location Register
KVA	Kilo volt ampere
KWh	Kilo watt hour
LCC	Life Cycle Cost
MARR	Minimum attractive rate of return
MPPT	Maximum power point track
MS	Mobile switch
MSC	Mobile Switching Center
MT	Mega ton
NIS	New Israeli shekel
NPV	Net Present Value
NPW	Net-present-worth
OPEX	operational cost
PSH	Peak sun hour
PV	Photo voltaic
PVG	Photo voltaic generator
PW	Present worth
RBS	Radio base station
RF	Radio frequency
STC	Standard Test Condition
TM	Transmission equipment
USD	United states dollar
VA	Volt ampere
Wh	Watt hour
Wp	Watt Peak

Powering of Radio Communication Stations in Remote Areas by Solar PV: Optimal System Design and Economics

By

Rawan Abu Shmais

Supervisor

Prof. Dr. Marwan M. Mahmoud

Abstract

This thesis presents a methodology to design optimum PV power systems for powering radio mobile communication stations in Palestinian remote areas instead of the currently used diesel generator power systems. Analysis are carried out to provide economic evaluation in terms of several economic screening methods based on life cycle cost and energy unit cost. The obtained results show that PV power systems are economically more feasible than diesel power systems for radio communication stations in the remote areas of Palestine. An average amounting to 57% of total yearly energy cost can be saved by using PV instead of diesel. In addition, an average of 0.49 USD/kWh is the cost of PV energy unit compared to an average of 1.14 USD/kWh for diesel. Furthermore, the use of PV solar systems reinforces healthy Palestinian environment due to the positive impact represented in protecting the environment by reducing 2.63 kg of CO_2 emissions for each 1 liter of diesel used for power generation. Moreover, the use of PV power contributes in the independency policy of energy sources and consequently in supporting the Palestinian economy.

CHAPTER ONE

INTRODUCTION

1 Introduction

Nowadays the global has witnessed an exponential growth in wireless communication. The growth of mobile networks coupled with intense competition has sharpened operators focus on deployment logistics, security, and cost. One of the most critical challenges is how to power the telecommunication networks, taking into consideration the most economical way, providing the fact of the increasing rate of the fuel cost all over the world [1].

As the wide spread the stronger the mobile network is, mobile communications operators measure their success by the coverage, quality, and the increased capacity of their network. To insure the coverage aspect comes the focus on rural remote areas that must be provided with perfect mobile communication services, because remote sites access is often difficult and the connection to a central electricity grid is rarely possible. A standalone power system is required in those remote rural areas and is generally a convention energy source such as diesel generators. Such a system must be cost effective, simple to maintain, and reliable. Considering those claims, the use of conventional diesel fuel power systems is questionable and an unwise choice.

The use of renewable energy sources for remote telecommunication systems has become more popular recently due to technological advancements and lower costs day after day, compared to the economically exhausted conventional energy generation methods. Renewable resources such as the sun offer valuable energy and reducing overall operating costs of system infrastructure [2].

Palestinian mobile network operators face the same global challenge, of accessing the rural areas in such a way to improve their network coverage and quality, in order to get their customers satisfaction. Providing the fact that Palestine has a large number of remote small villages that lack electricity and the probability of connecting them with the high voltage grid in the near future is very poor due to financial and political situation [3]. Although, Palestine has a high solar energy potential, where the daily average of solar radiation intensity on horizontal surface is 5.4 kWh/m^2, while the total annual sunshine hours amounts to about 3000 [4]. Which encourage starting such a systems of telecommunication and mobile networks powering using solar energy in Palestine.

1.1Objectives

The main goal of this thesis is represented in finding out the possibility of using a PV solar system in powering radio mobile telecommunication stations in remote areas of Palestine. Thesis objectives can be pointed as the following:

- Identifying all types of radio sites and radio communication stations in West Bank which need to be powered by PV system, the radio station unit is known as Radio Base Station (RBS).
- Measuring all needed electrical loads in the station, in order to design the most appropriate PV solar system to cover all energy needs.

- Investigate the optimum PV system for the Palestinian environmental, geographical, commercial, economical and weather conditions.
- Design the PV systems for each radio site depending on the type of the radio station.
- Determine the economic feasibility of powering the radio communication stations by solar energy and compare it to the use of diesel generators instead.

1.2Thesis structure

Chapter two: Solar energy in Palestine

In order to study the possibility of powering radio communication base stations in remote areas using solar energy, the potential of solar energy in Palestine should be investigated first. In this chapter the solar energy situations in Palestine is discussed in terms of numbers and field measurements.

Chapter two: Literature survey and background

This chapter discussed three major axes; starting with the principle of PV modules to know how it work, and then introducing PV systems and their different types, and finally the process of selecting PV systems main components.

Moreover , and since the smartest way to know exactly what should be done in any subject is to start by exploring how other people were able to get it done, so this chapter also spots the light on the global projects which succeeded in providing energy to the telecommunications stations using solar energy. And explains the radio base stations concept from the radio communication and the power consumption perspectives.

Chapter three: Radio base stations in Jawwal Company

This thesis will study the radio sites owned by Jawwal Company as one of the leading radio communication companies in the country. This chapter started by an introduction about the radio sites in Jawwal, and the used radio base stations types. The chapter's second have discusses the load analyses for some different types of radio sites based on the collected data from Jawwal's team.

Chapter four: Case study

In this chapter, the actual work of this thesis will be done. Based on the selected sample of radio in the previous chapter. Designing PV system for each radio site based on its energy consumption. And selecting all the right elements of the PV system based on what is available in the market.

Chapter five: Economic analysis of powering radio base stations using PV system instead of diesel generators

This chapter study the economic feasibility of replacing diesel generators in remote radio sites by PV systems, by the mean of some popular economic measures to compare the two alternatives fairly.

Chapter six: Potential environmental impact of replacing diesel generators by PV systems

For the subject to be well covered from all sides without missing any. The environmental impact of the two alternatives both PV systems and diesel generators powering radio sites will be discussed in this chapter.

CHAPTER TWO

LITERATURE SURVEY AND BACKGROUND

2 Literature Survey and Background

2.1: Solar Energy in Palestine

2.1.1 Introduction

Palestine is located between 34o:20´- 35o:30´ E longitude and 31o: 10´-32o:30´ N latitude. The area of the Arab Palestine is about 27009 square kilometers and it consists of two separated strips [5]; The Gaza Strip is located on the western side of Palestine adjacent to the Mediterranean Sea with 365 km^2 and the West-Bank which extends from the Jordan River to the center of Palestine with 5900 km^2 [6].

Figure 2.1: Palestine location as shown by Google earth [7].

The climate of Palestine for the most part of the year is pleasant. Winter lasts for three months, from mid-December to mid-March [5].

The Palestinian atmosphere is clear and its air is pure. Summer Temperatures reach 35° centigrade and in the winter the temperature may drop to Zero centigrade. The rainy season starts in the second half of autumn (Mid-

October) and continues until the end of April. Heavy rain is limited to fewer than 50 days, with around 70% of the rain falling during November to February. The country is influenced by the Mediterranean Sea breeze that comes around mid-day. Moreover, the country is affected by annual waves of hot, dry, sandy and dust “Khamaseen” winds which originate from the Arabian Desert during the months of April, May and mid-June [5].

The average annual relative humidity is 60% and reaches its highest rates during the months of January and February, humidity levels drop to its lowest in May as well. Night dew may occur in up to 180 days per year [8].

Palestine receives an average of seven hours of sunshine a day during the winter and thirteen hours during the summer [5]. As a consequence, Palestinians use rooftop solar collectors extensively, to capture the solar energy and to replace limited and expensive available energy resource.

2.1.2 Potential of Solar Energy in Palestine

Palestine is located within the global solar belt countries and considered as one of the highest solar energy potential countries in the world [9].

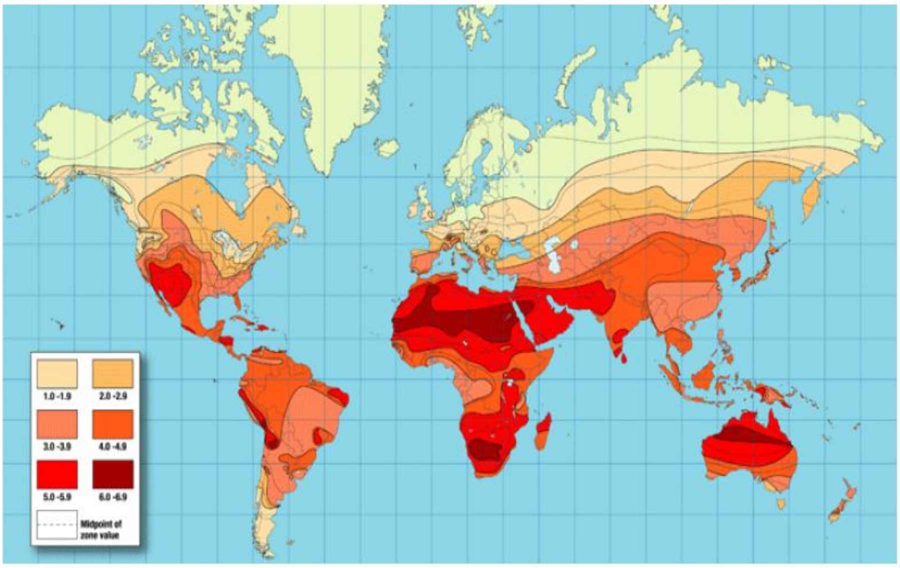

Figure 2.2: World irradiation map.

With around 3000 sunshine hours yearly, and an annual average daily solar radiation intensity of 5.4 kWh/m^2-day [10]

The table below shows the average monthly solar energy measurements in Nablus area [4], given that the measurements were taken place on horizontal surface. And that the reading are in kilo watt hour per meter square and day.

Table 2.1: Average monthly solar energy on horizontal surface for Nablus [4].

Month	(kWh/m^2-day)
January	3
February	3.3
March	4.2
April	5.1
May	6.8
June	8.2
July	8
August	7.8
September	5.8
October	5.2
November	4.6
December	2.8

The lowest solar energy average as shown by the table above is in December. With a value of 2.8 kWh/m^2-day, and the highest value is 8.2 kWh/m^2-day is in June [4].

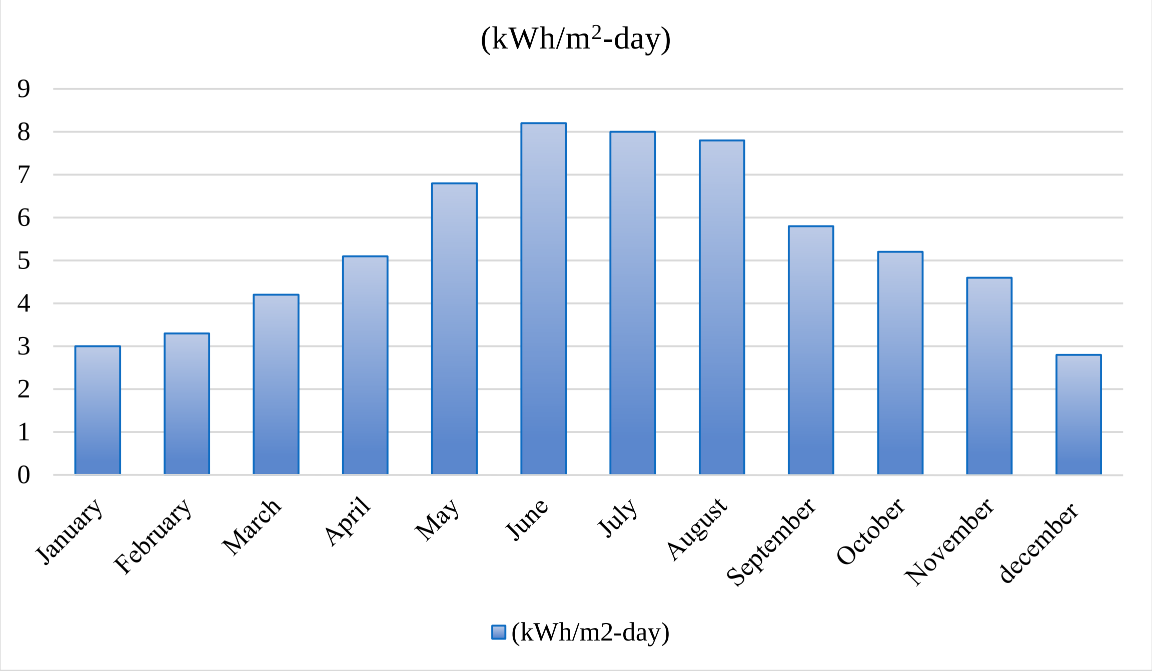

Figure 2.3: Average monthly solar energy on horizontal surface

The number of equivalent hours per day that the solar irradiance is at its peak level of 1 kW/m^2 is known as PSH or Peak Sun Hours, and can be calculated for every month from the data in table above as the following:

The average Peak Sun Hours around month (PSHm):

$PSH_m = E_{sd}/G_o$, where;

Equation 2.1

E_{sd}: the average daily solar radiation intensity for a month.

Go: the peak solar radiation intensity = 1000W/m^2.

So, PSH_m in January = 3000/1000 = 3 hours.

And, PSH: The average Peak Sun Hours around the year is calculated as:

$PSH = sum(PSH_m)/12$ Equation 2.2

PSH= (3+3.3+4.2+5.1+6.8+ 8.2+8+7.8+5.8+5.2+ 4.6+2.8)/12

PSH= 5.4h.

The following table shows the hourly average solar radiation on a horizontal surface of typical summer day in Nablus area [11].

Table 2.2: Hourly average solar radiation of typical summer day (23/7/2012)

Hours	Solar Radiation(W/m²)	Hours	Solar Radiation(W/m²)
1:00	0	13:00	1000
2:00	0	14:00	917
3:00	0	15:00	776
4:00	0	16:00	585
5:00	20	17:00	371
6:00	135	18:00	156
7:00	343	19:00	20
8:00	532	20:00	0
9:00	774	21:00	0
10:00	905	22:00	0
11:00	1019	23:00	0
12:00	1062	0:00	0

These measurements are from the Energy Research Center (ERC) of An-Najah National University. The measurements were performed by horizontally oriented measuring devices, and on a 5-minute Interval basis [11].

From the previous table and figure below its shown that we have enough potential for solar radiation in the interval period from 10 am up to 2 pm, also we can obtain electric energy in morning and evening periods because the solar radiation is greater than 180 W/m² [4].

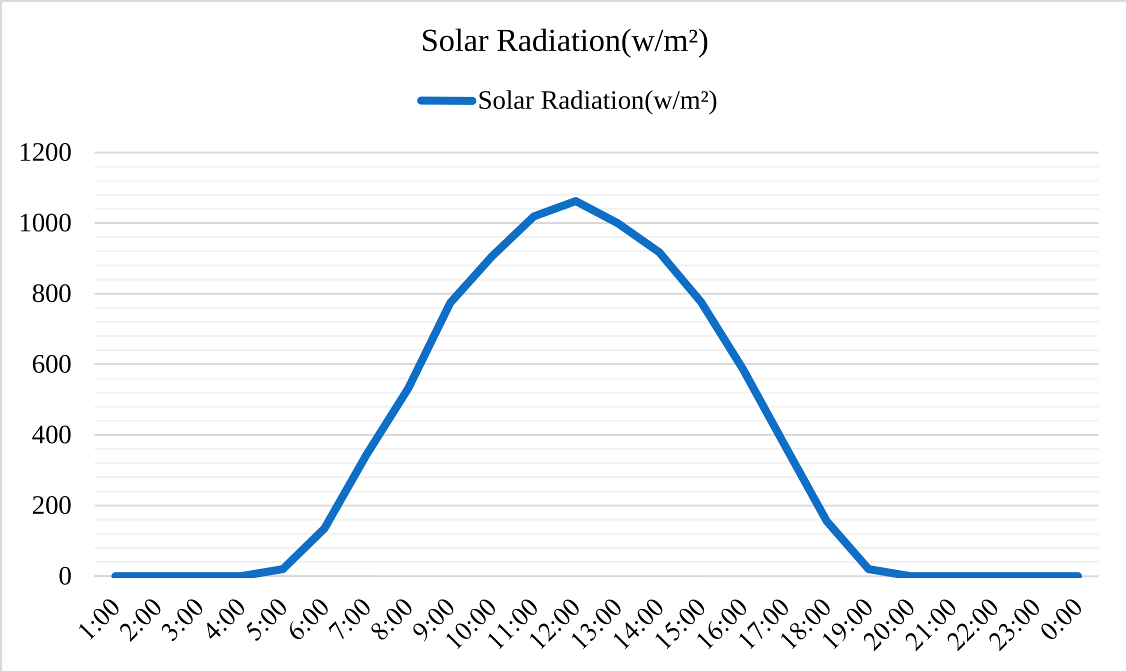

Figure 2.4: Daily solar radiation of typical summer day in Nablus (23/7/2012)

2.1.3 Ambient Temperatures

One of the most important parameters is the ambient temperature, which affects the PV generators efficiency, the relation between efficiency and PV cell temperature is inversed [12], figure (2.5) shows the variation of efficiency with temperature at solar radiation of 1000W/m^2. There is a linear relation between PV cell temperature and the module efficiency. Decreasing temperature results in higher efficiency. So for a desired efficiency of a PV module we can determine what temperature of PV cell is needed, so by changing temperature around the PV module we can affect the efficiency. [13].

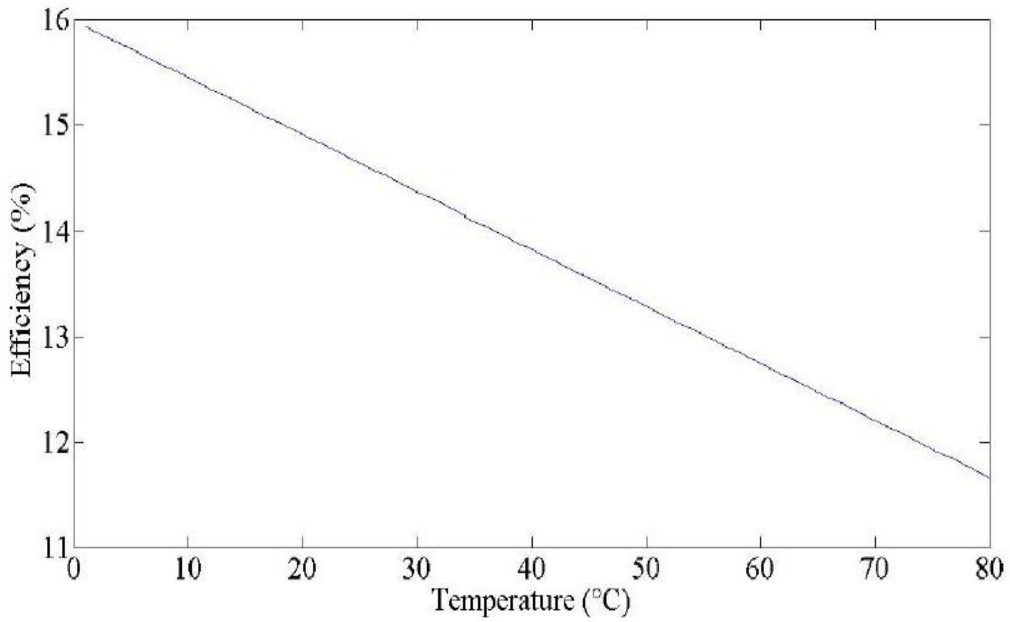

Figure 2.5 : Variation of PV module efficiency with PV cell temperature [13].

Table (2.3) shows the measured data of the ambient temperature for Nablus area [11]. This data is the average of five days measured in June 2012 on a 5-minute interval basis [11].

Table 2.3: The daily ambient temperature 23-7-2012

Hours	Ambient temp.(°C)	Hours	Ambient temp.(°C)
1:00	22	13:00	32
2:00	22	14:00	32
3:00	22	15:00	31
4:00	21	16:00	31
5:00	21	17:00	29
6:00	22	18:00	28
7:00	22	19:00	27
8:00	23	20:00	25
9:00	24	21:00	24
10:00	27	22:00	24
11:00	28	23:00	23
12:00	31	0:00	22

Figure (2.6) shows the daily curve of the ambient temperature drawn from the data table (2.3). It shows that the maximum temperature occurs around the noon time (32°C), and the minimum temperature occurs in the early morning (21°C).

The approximate cell temperature can be calculated depending on the data measured in table (2.2), through the following equation, given the conditions of around 2m/s wind speed and that the calculations are during the day time [4]:

$T_c \approx 0.0256 * G + T_{amb}$, Where; Equation 2.3

T_c: cell temperature

G: solar radiation intensity

T_{amb}: ambient temperature

The following plot shows both the ambient and cell temperatures in the same graph.

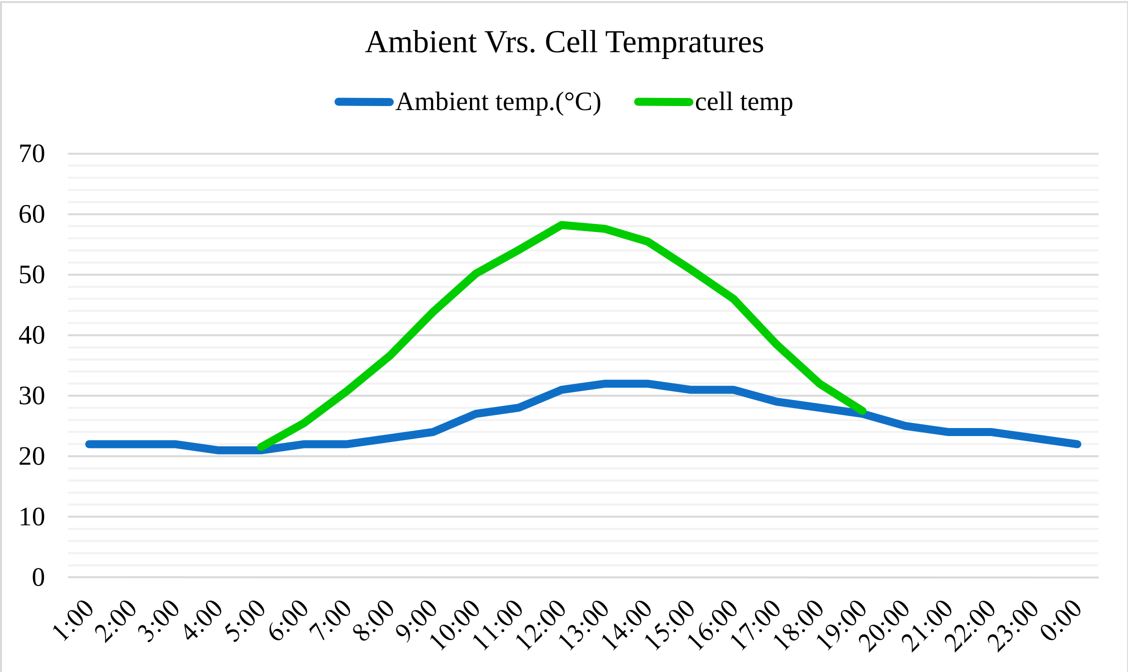

Figure 2.6: The daily ambient and cell temperatures 23-7-2012

2.2: Photovoltaic System Configuration

2.2.1 Introduction

Photovoltaic (PV) technology converts the sun's energy into electricity. The term photo comes from the Greek "phos", which means light. The term volt is a measure of electricity refers to Alessandro Volta (1745- 1827). So the literally meaning of PV is light– electricity [14].

The history of PV goes back to the year 1839, when Becquerel discovered the PV effect [15]. Bell laboratories produced the first solar cell in 1954, the efficiency of this cell was about 5%, and the cost was not a major issue, because the first cells were designed for space applications [15].

PV offers the highest versatility among renewable energy technologies, one advantage is the modularity. All desired generator sizes can be realized from milliwatt range for the supply of pocket calculator to megawatt range for the public electricity supply [15].

The figure below shows how the PV module production developed and increased since 1985.

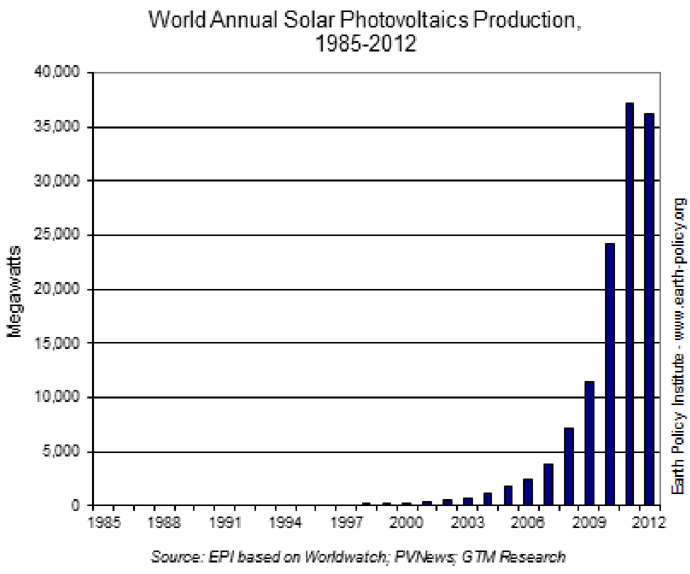

Figure 2.7: world annual PV production 1985-2012

2.2.2 PV Modules Principal

The PV generator is obtained by connecting PV modules in serial and/or parallel configurations. At the same time, modules are made by connecting photovoltaic solar cells, which are connected in series and parallel, to obtain higher current and voltage. To protect the cells against mechanical stress, weathering and humidity, the cells are embedded in a transparent material that also isolates the cells electrically. In most cases, glass is used but depending on the process it is possible to use acrylic plastic, metal or plastic sheeting [16].

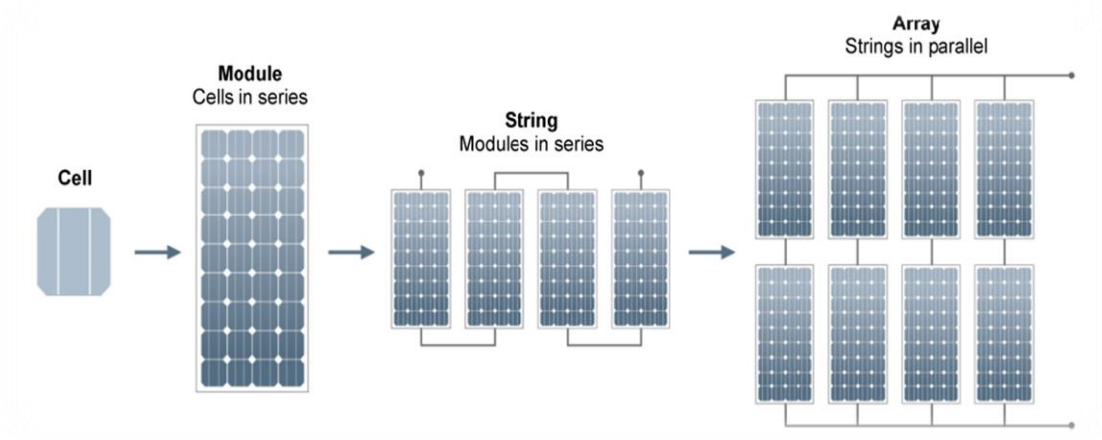

Figure 2.8: Cell, Module and Array.

Solar cells included in PV modules convert directly the solar radiation into electrical energy. In the conversion process, the incident energy of the light creates mobile charged particles in some materials, known like semiconductors, which are separated by the device structure and produce electrical current. This current can be used to power an electric circuit.

The most commonly used photovoltaic cell material is silicon (Si), one of the most abundant elements on earth. The first commercially available cells were monocrystalline silicon in which all the silicon atoms are perfectly aligned building an organized crystal. In order to reduce costs, new manufacturing techniques were developed which in turn gave birth to the polycrystalline solar cells. This type of material contains many crystals and the atoms are aligned in different directions [17].

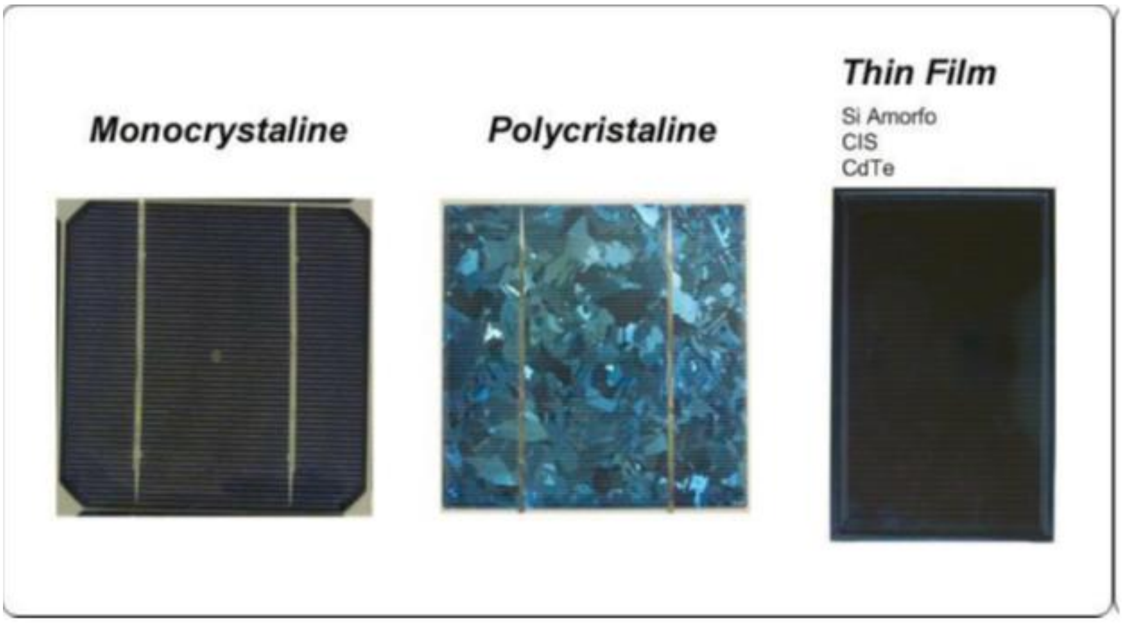

Figure 2.9: Different types of PV cells.

The main characteristics of different commercially available PV cell types are [17]:

Table 2.4: characteristics of different PV cell types

Characteristic/Type	Mono-crystalline silicon	Poly-crystalline silicon	Amorphous silicon (non-crystalline) "thin film"
Open circuit Voltage (V)	0.6-0.62 V	0.55-0.58 V	0.65-0.78 V
Short circuit current (A/cm^2)	$3.4A/100cm^2$	$2.6\text{-}3.1A/100cm^2$	$1\text{-}2\ A/100cm^2$
Efficiency (%)	10-15 %	8-13 %	4.5-8 %
Color	Dark blue	blue	Dark green, black

2.2.3 Current-Voltage Curve for PV Cell at STC

2.2.3.1 Standard test conditions (STC)

A set of uniform conditions which are specified for determining the electrical data with which the solar cell characteristic I-V curve is then calculated the one which enables the differentiation between PV cells and modules [4].

These STC as they are known, relate to the IEC 60904/DIN EN 60904 standards:

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

2.2.3.2 Current – voltage (I-V) curve for PV cell

The relationship between the PV cell current and voltage known as I-V curve. The main characteristics of this I-V curve for any PV cell can be summarized as:

- The maximum power point (MPP) value: which 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).
- 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 mark.

- 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. [17]

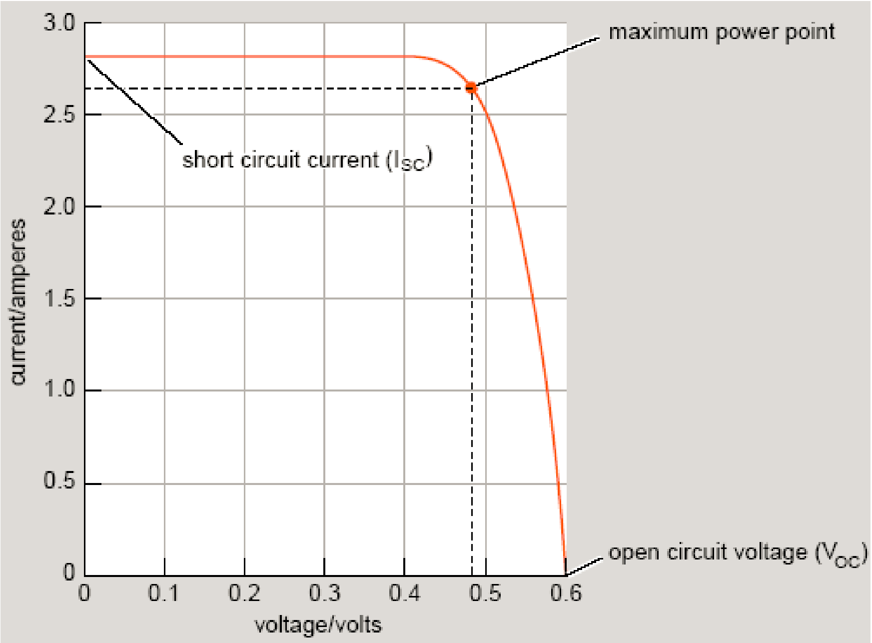

Figure 2.10: (I-V) characteristics of a typical silicon PV cell under standard test conditions

2.2.4 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 the following equation (2.1) [18].

$I_{S.C}$ (G) = ($I_{S.C}$ rated@1000 W/m^2) × (G/G_{STC}), Equation 2.4

Where; $I_{S.C}$**:** Short circuit current.

G: The actual radiation.

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

The figure below shows the effect of radiation variation at PV module consisting of 36 cells of mono crystalline silicon [Siemens, SR50] at constant temperature [18].

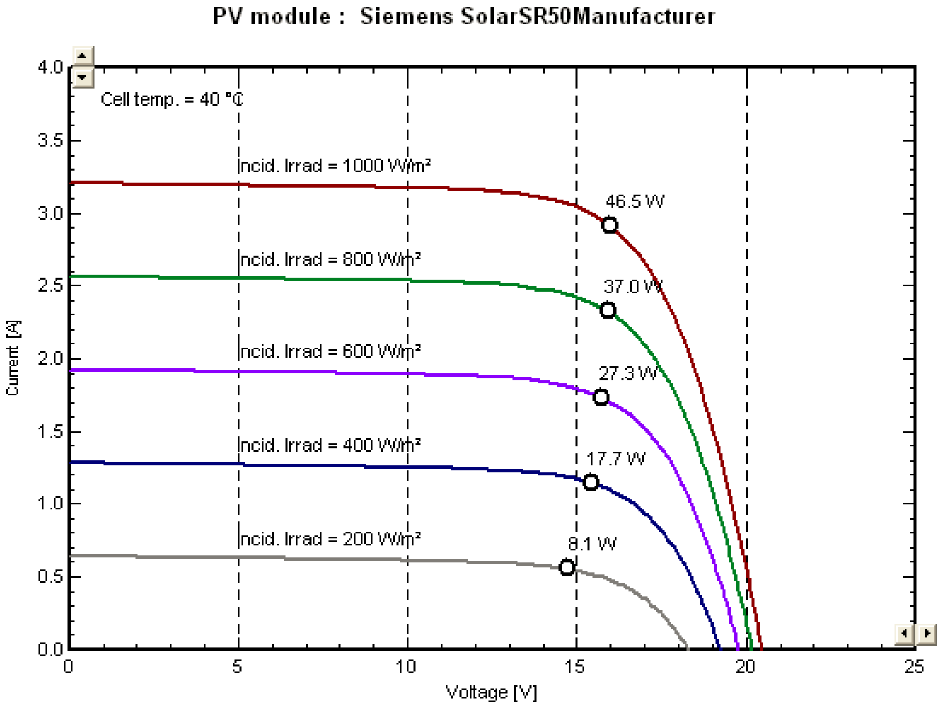

Figure 2.11: PV module (I-V) curve with variation of solar radiation and constant temperature

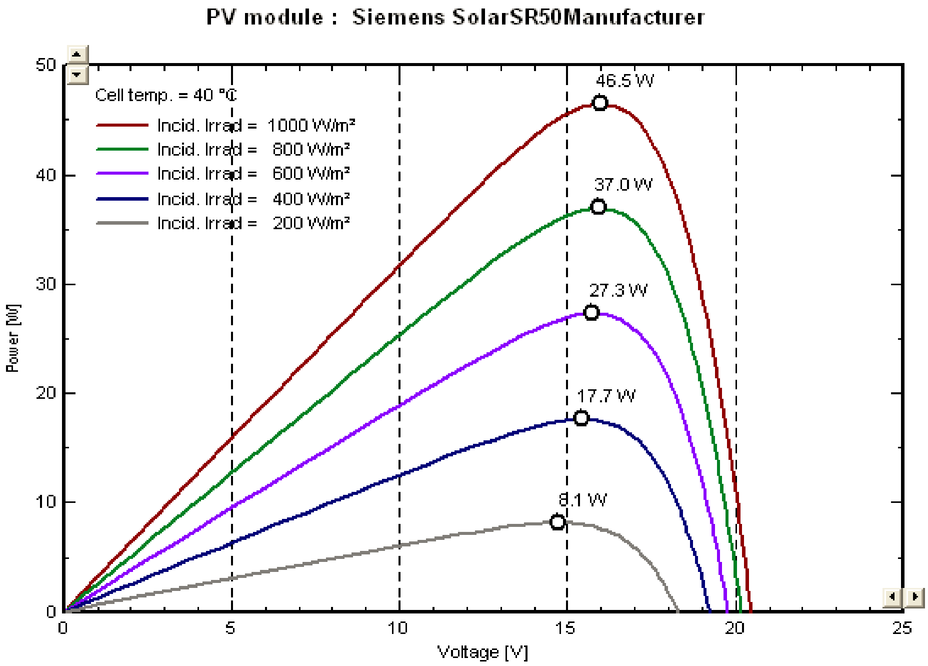

Figure 2.12: PV module (P-V) curve with variation of solar radiation and constant temperature

2.2.5 Effect of Temperature on PV Performance

Solar cells vary under temperature changes; the change in temperature will affect the power output from the cells. The voltage is highly dependent on the temperature and an increase in temperature will decrease the voltage. Each solar module will have manufacturing standards; the normal operating cell temperature (NOCT) should be among these standards. The NOCT is the temperature the 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 quite accurately with the linear approximation that

$$Tc = Ta + ((NOCT-20)/0.8) \times G \qquad \text{Equation 2.5}$$

The combined effects of irradiance and ambient temperature on cell performance merit careful consideration. Since the open circuit voltage of a silicon cell decreases by 2.3 mV/^{o}C, the open circuit voltage of a module will decrease by 2.3n mV/^{o}C, where n is the number of series cells in the module. Hence, for example, if a 36-cell module has a NOCT of 40^{o}C with VOC = 19.40 V, when G = 0.8 kW/m^2, then the cell temperature will rise to 55^{o}C when the ambient temperature rises to 30^{o}C and G increases to 1 kW/m^2. This 15^{o}C increase in cell temperature will result in a decrease of the open circuit voltage to 18.16 V, a 6% decrease. Furthermore, excessive temperature elevation may cause the cell to fail prematurely [19].

Figure 3.7 shows the effect of temperature variation at PV module consisting of 36 cells of mono crystalline silicon [Siemens, SR50] at constant radiation [18].

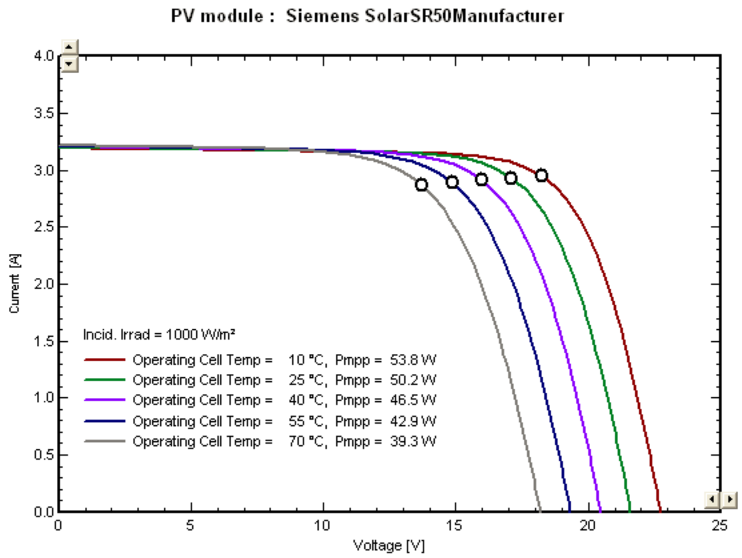

Figure 2.13: PV (I-V) curve with variation of temperature and constant radiation

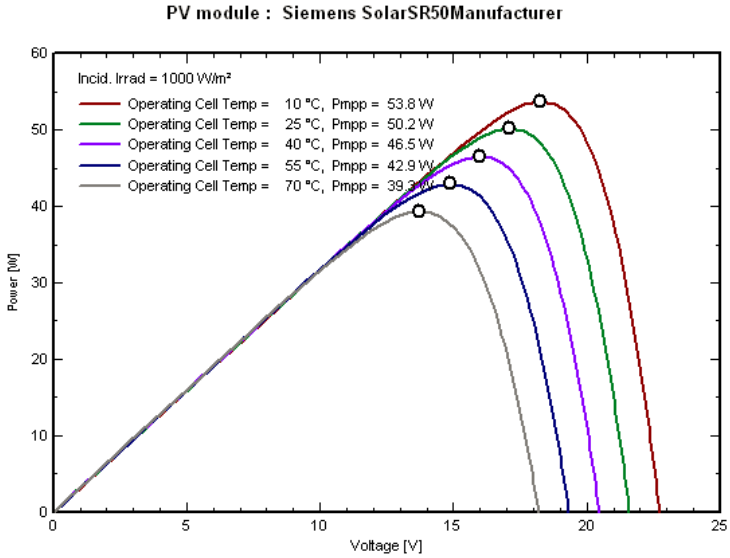

Figure 2.14: PV (P-V) curve with variation of temperature and constant radiation

2.2.6 Types of PV System:

There are two major types of PV system, and it depends on the connection of the system if it's connected to the main grid or it stands alone without any connection, these types are:

- Stand-alone systems.
- Grid-tied systems.

The figure below shows the main components of any PV system [20]

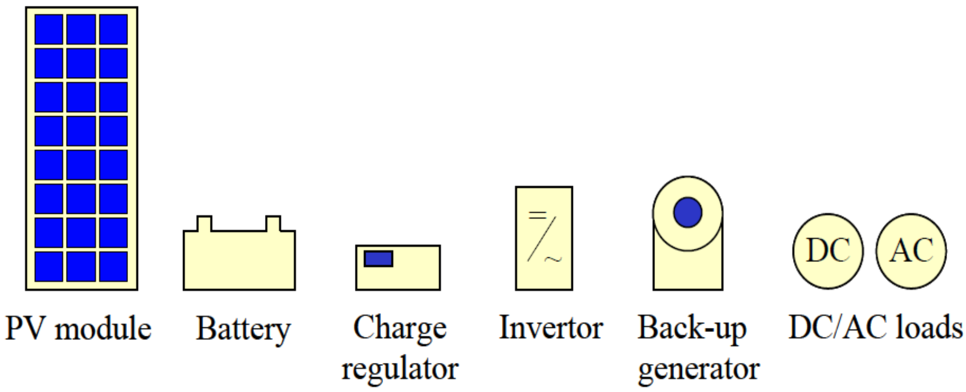

Figure 2.15: The components of a PV system.

2.2.6.1 Stand-alone systems

These systems are most common in remote locations without the utility grid service, stand-alone solar electric systems can work anywhere since they are working independently from the grid to provide loads with electricity. Types of stand-alone systems can be listed as the following:

1) Stand-alone DC system without storage.

   It's the simplest type, where the DC output of a PV module is directly connected to a DC load. The critical part of designing a well performing direct coupled system is the matching of impedance of the electrical load to the maximum power output of the PV module. It can be used to operate pumping machine where water is pumped in the day to reservoir for using at night [21], the figure below shows DC system without storage.

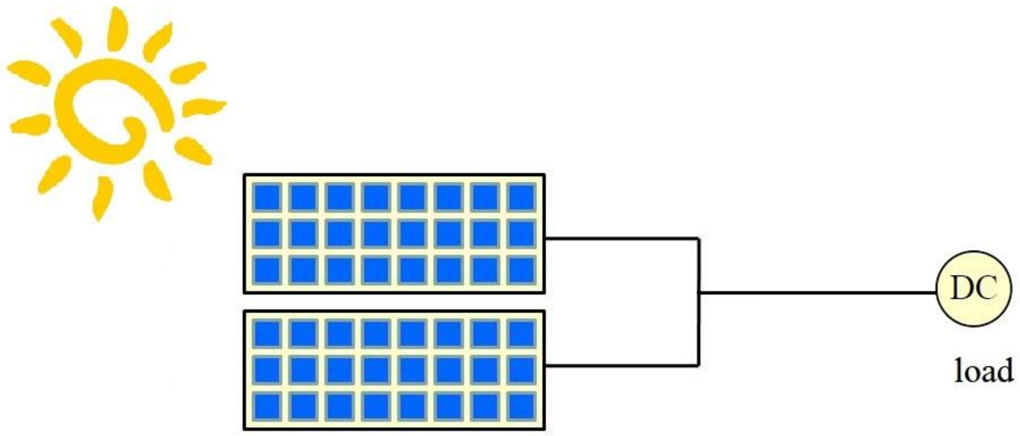

Figure 2.16: DC System without storage

This system has the following limitations:

- It can only be used in the day to supply load as there is no battery for storing energy.

- It cannot be used for AC load

2) Stand-alone AC system without storage.

   This is another type of stand-alone system, it is the type that incorporate inverter unit for conversion of DC voltage to AC at appropriate voltage level [21].

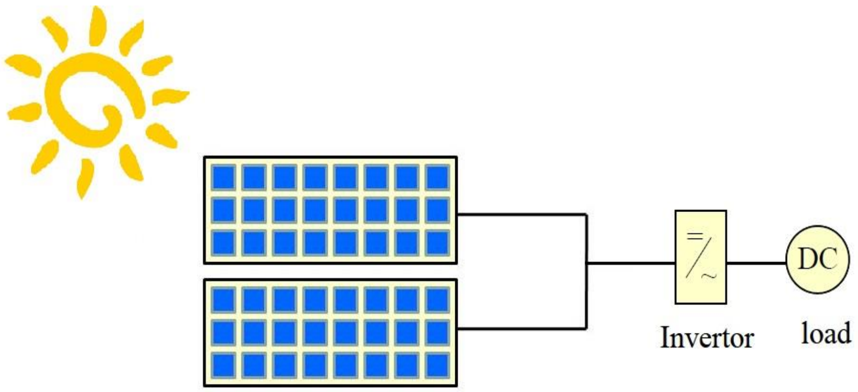

Figure 2.17: AC system without storage

The limitation of this system is:

- The lack of storage unit, so it will not supply load at night.

3) Stand-alone system with DC output and battery.

   The figure below shows the block diagram of a typical stand-alone PV system. A solar PV array, battery, and charge regulator are the three primary components of the PV system. The solar array generates DC power for the load and charges the battery, which serves as the energy storage device that powers the load when there is no output from the array. The charge regulator /controller regulates the output of the PV array and ensures proper charging of the battery, thus protecting it from abuse [21].

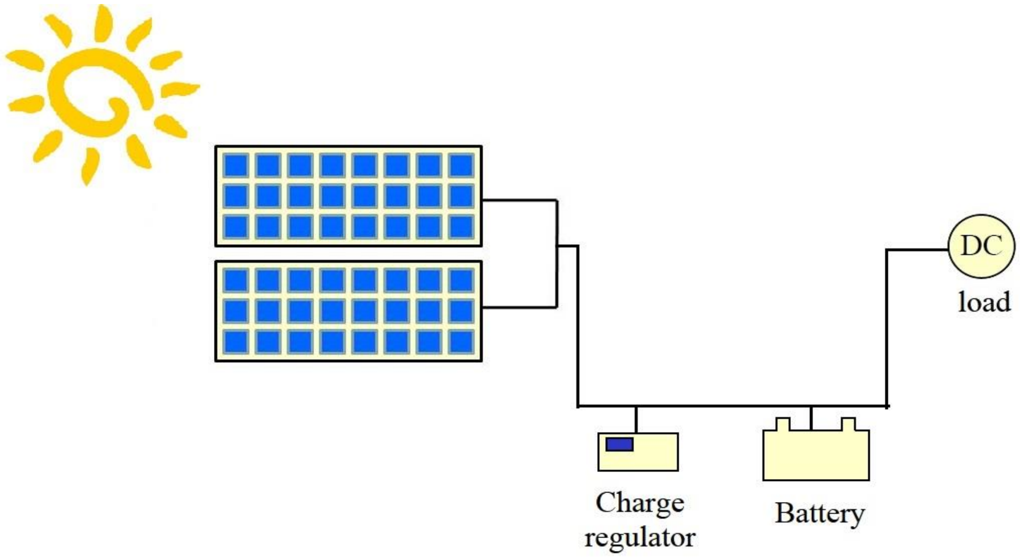

Figure 2.18: Stand-alone system with DC output and battery

4) Stand-alone system with battery and DC and AC output.

Figure (3.13) shows the stand-alone system with battery for storage and both types of output loads DC and AC [21].

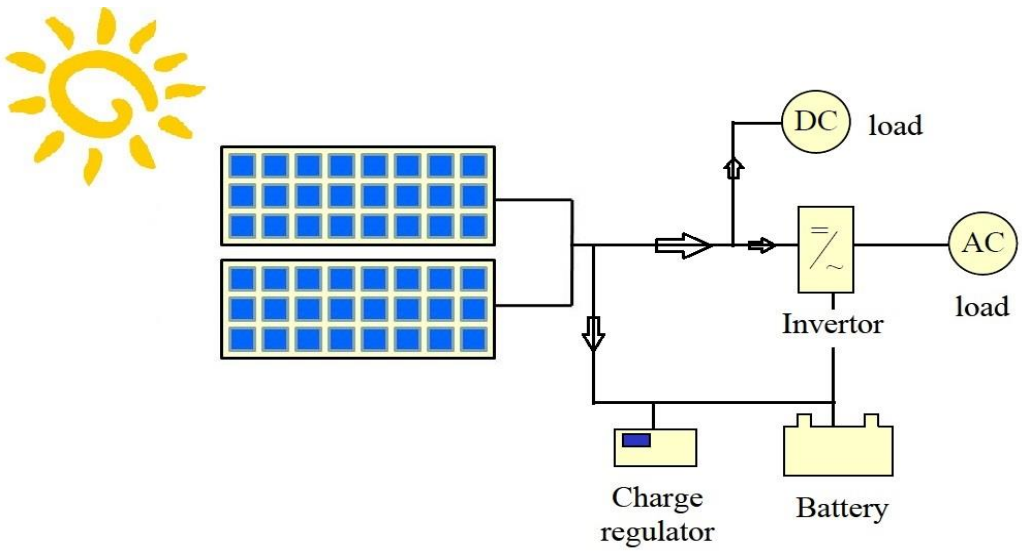

Figure 2.19: Stand-alone system with battery and DC and AC output.

5) Stand-alone system with battery and without DC output.

This system is only for AC loads and there is no DC loads. We can use it for one phase and three phases; it depends on the type of the inverter [21].

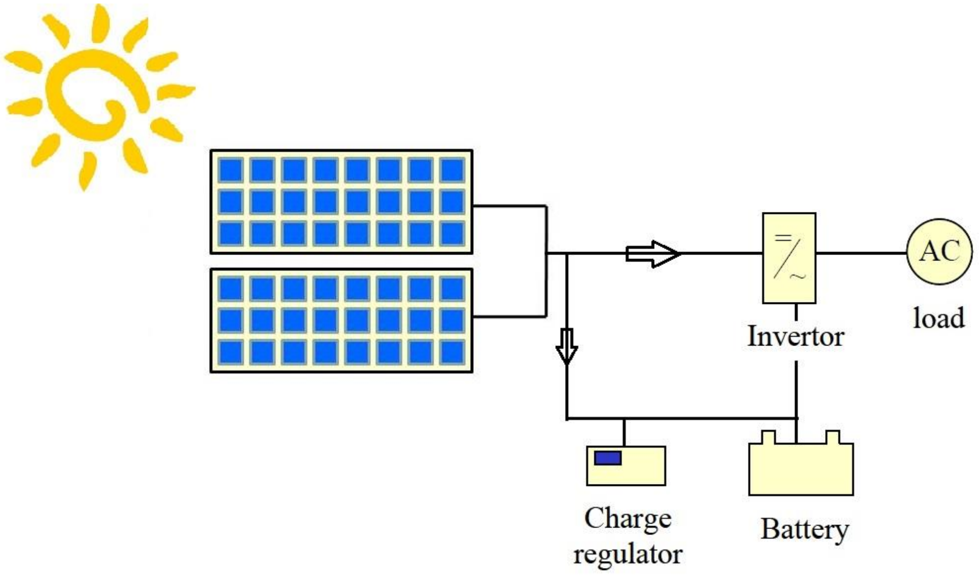

Figure 2.20: Stand-alone system with battery and without DC output.

6) Stand-alone system with engine generator as back-up (hybrid system) [21].

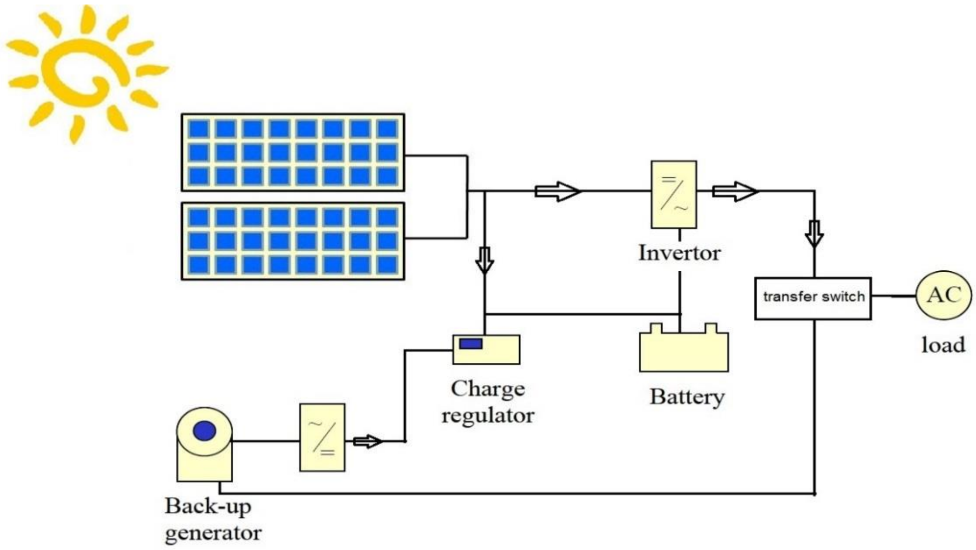

Figure 2.21: Stand-alone system with engine generator as back-up.

2.2.6.2 Grid-tied PV systems

Grid-tied systems are designed to operate in parallel with and interconnected with the electric utility grid. Below are the block diagrams of grid-tied systems.

1) Grid-tied system without battery [21].

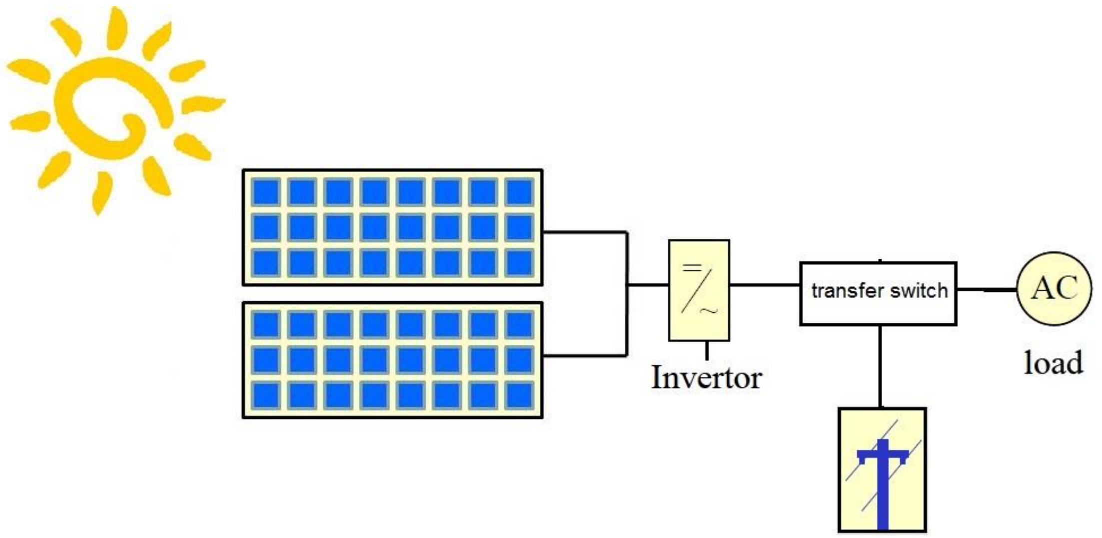

Figure 2.22: Grid-tied system with no battery

2) Grid-tied system with batteries for storing charges [21].

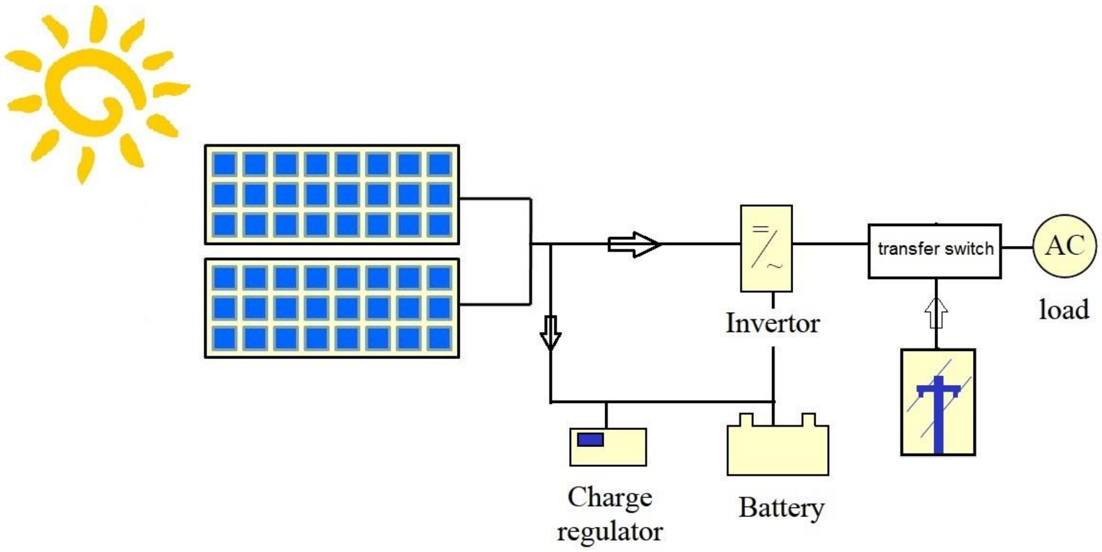

Figure 2.23: Grid-tied system with batteries for storing charges

3) Grid-tied system with utility connected to charge battery [21].

   Grid-tied system can also be connected in a way that utility supply will be charging battery in the period of low light intensity. It has the same features as stand-alone system with engine generator back-up. In the case of long cloudy days and utility outage, there is likely to be blackout.

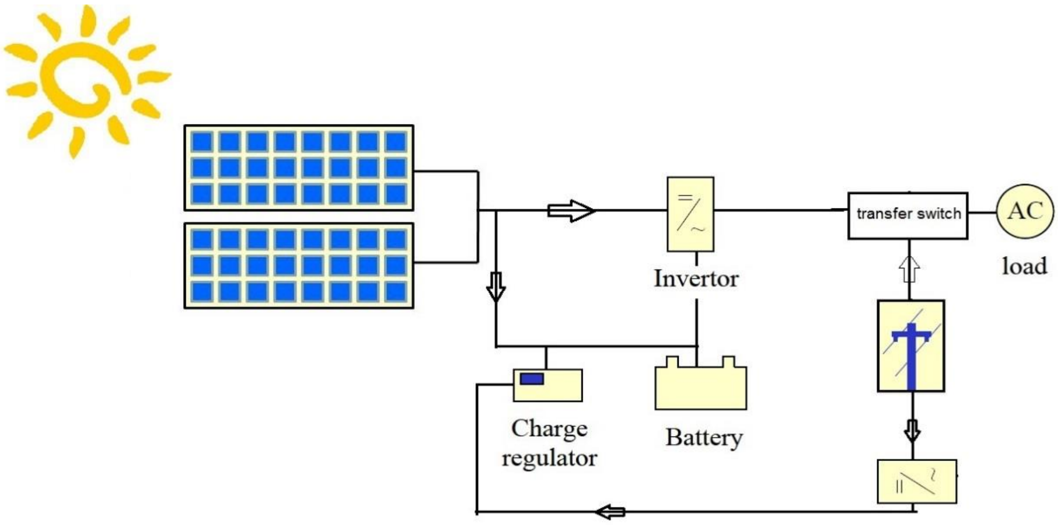

Figure 2.24: Grid-tied system with utility connected to charge battery.

2.2.7 The Selection of Photovoltaic System Elements

A complete system includes different components that should be Selected taking into consideration the individual needs, site location, climate and expectations. The functional and operational requirements will determine which components the system will include such as the DC-AC power inverter, battery bank, system and battery controller/regulator, auxiliary energy sources and any other specified electrical loads.

PV system main elements are:

- Photovoltaic modules

- Charge controller
- Battery
- Inverter
- Load

2.2.8 PV sizing

Selecting the right capacity of the PV modules depends on the following set of calculations [22], the following equations represents the mathematical model for designing any PV system:

E_{PV}: Energy needed from the PV module per day

$E_{PV} = Ed / (\eta_{inverter} * \eta_{charger})$

Equation 2.6

P_P: Peak power rating needed for PV modules

$Pp = (E_{PV} * K)/ PSH$

Equation 2.7

The number of PV modules for the system

No. of modules = Pp/ P of one module

Equation 2.8

No. of modules in series = V_{PV}/ V of one module

Equation 2.9

No. of strings = No. of modules / No. of modules in series

Equation 2.10

A_{PV} = No. modules / A of one module

Equation 2.11

Where;

Ed: Energy consumption per day

$\eta_{inverter}$: Efficiency of the inverter

$\eta_{charger}$: Efficiency of charge regulator

K: safety factor

V_{PV}: Voltage of PV generator

A_{PV}: Area total of PV generator

2.2.9 Inverter sizing

An inverter is a basic component of any independent power system that produces AC power. Inverters convert DC power from PV module or stored in batteries into AC power to run conventional appliances. Another application of the inverters is in the case of uninterruptible power supply where the inverter with the aid of 12V DC battery is able to generate up to 220V AC that can be used to power most of the house and office appliances depending on their power rating. For stand-alone systems, the inverter must be large enough to handle the total amount of Watts that will be using at one time. The inverter size should be 25-30% bigger than total Watts of appliances. In case of appliance type, motor or compressor, then inverter size should be minimum three times of the capacity of those appliances and must be added to the inverter capacity to handle high starting current of these appliances [22]. For grid tie systems or grid connected systems, the input rating of the inverter should be same as PV array rating to allow for safe and efficient operation [22].

Select the right capacity of the Inverter

For selection the inverter, necessary determine the following parameters.

V input, has to be matched with battery block voltage.

Power of inverter ≥ total required power.

Equation 2.12

The efficiency must be not less than 90 %.

2.2.10 Battery block sizing

Storage is one of the key factors in any design, and normally its considerably large, that's why the reliable life cycle of the battery is so important.

The selection of the capacity of batteries in Ah (Amper hour), which are necessary to cover the load demands for the desired period of autonomy days, can be calculated as the following [23].

$Ah = (autonomy * E_d)/ (DOD * \eta_B * V_B * \eta_{inv})$

Equation 2.13

The capacity of batteries in Wh can be calculated as the following:

$C_{Wh} = C_{Ah} * V_B$ Equation 2.14

Where; C_{Ah}: Amper hour capacity

E_d: Energy consumption per day

η_B: Battery efficiency

DOD: Depth of discharge

V_B: Battery voltage

2.2.11 Charge controller/regulator sizing

It's a DC/DC converter, used to regulate the output current of PV generator going to the inverter, and to protect the battery block against deep discharge and over charge, input/output rating of CR are fixed by the output of the PV array and V_B [22].

The selection the charge controller is necessary to determine the following parameters:

- $V_{in\ Charge\ regulator}$ max= $V_{O.C}$ of PV generator @ STC
- $P_{Charge\ regulator}$ nominal = $P_{P.V}$ generator peak = V_{mpp} * I_{mpp}
- $V_{Charge\ regulator}$ out nominal = V_B nominal of the block battery
- The efficiency must be not less than 85 %.

2.3: SOLAR ENERGY AND TELECOMMUNICATIONS

2.3.1 Introduction

The considerable problems deriving from the growth of energetic consumptions and from the relevant environmental "emergency" due to the emissions of greenhouse gases GHG, push the world to find out new solutions and new technologies for the production of primary energy fit for fulfilling the urging and growing energetic demands.

The global climate change, which is due to increased CO_2 and other greenhouse gases concentration levels in atmosphere, is considered one of the most important global emergency that requires immediate and effective policies. The CO_2 emissions are mostly due to the use of fossil fuels as energy source. Thus in the future the use of fossil fuels has to be decreased.

This can be obtained by improving energy efficiency and by using large scale renewable energy sources. This is also true in the telecommunication applications, which has seen, in the last years, a remarkable increase in the number of installations present on the whole world, sometimes located in hardly reachable area and the relevant growth of energetic consumptions, because of growing interest about new and reliable services in mobility calls with an increase of the BTS (base transceiver stations) operation hours and traffic management, in order to guarantee the quality of the service anywhere and anytime [24].

The reduction of the energetic consumptions of a Telecommunications Power Systems represents one of the critical factors of the telecommunications technologies both to allow a sizeable saving of economic resources to the mobile communications system management and to realize "sustainable" development actions.

Diesel generators are used widely in powering telecom towers especially those located in the remote areas. The usage of diesel generators can lead to many series problems starting from the high CO_2 emissions, and the increasing energy cost and the difficulties of maintenance which can be expensive and time consuming [8].

So, improving the energy efficiency of telecom networks is not just a necessary contribution towards the fight against global warming, but with the rapidly rising prices of energy, it is becoming also a real financial opportunity.

The aspects in which Green telecommunication can be achieved can be explained as the below:

- Telecom Networks: greening telecom networks would refer to minimizing consumption of energy through use of energy efficient technology, using renewable energy sources and ecofriendly consumables.
- Manufacturing: The greening process would involve using ecofriendly components, energy efficient manufacturing equipment, electronic and mechanical waste recycling and disposal, reduction in use of hazardous substances like chromium, lead and mercury and reduction of harmful radio emission.
- Design of green central office buildings: optimization of energy power consumption and thermal emission, minimization of greenhouse gas emission.
- Waste disposal: disposal of mobile phones, network equipment etc., in an environment-friendly manner so that any toxic material used during production does not get channelized into the atmosphere or underground water.

2.3.2 Solar Energy in Telecommunications Worldwide

❖ Bharti Infratel's GreenTowers P7 Project

The telecom industry in India has more than 300,000 towers with an average tenancy of 1.5 operators per tower. Bharti Infratel's pioneering GreenTowers P7 Initiative is a comprehensive energy-efficiency and alternate-energy program, which aimed at reducing the carbon footprint through lower and optimized diesel usage [25]. These initiative achievements:

1. Alternate energy sources; like solar, fuel cells etc. are clean energy solutions which are good alternatives to conventional sources of energy. This has already been deployed at around 1200+ sites and has saved more than 35,500 MT of CO_2.
2. Energy efficiency measures; like Integrated Power Management System (IPMS) and variable speed DC generators (DCDG). These have been implemented across 3500 sites and have also significantly reduced diesel consumption by 3.5 million liters, and thereby a reduction of 9800 MT of CO2.
3. Demand side management; through the use of Free Cooling Units (FCU) etc., instead of air conditioners, which substantially reduces the electrical load requirement and the need to run Diesel Generator in absence of grid power. This has already been implemented at 3400+ sites [25]

- Jordan Telecom Company

Jordan telecom Implemented solar energy project for telecommunication tower in Karak area in a hybrid system that contains solar panels, wind turbine and diesel engine generator.

Also there are 15 projects for telecom sites with standalone solar systems are installed and support GSM telecoms equip. Jordan Telecom are installing solar systems for outdoor sites where there is no need for AC units and the average load is 300W to 1400W including the consumption of fans [26].

- Ericsson and Orange in Africa

  Orange Guinea Conakry and Ericsson in STOCKHOLM, were deploying more than 100 base stations fully powered by solar energy, connecting remote parts of rural Africa. Using Ericsson's energy-efficient base stations, a hybrid diesel-battery solution and solar panels, Orange is increasing mobile coverage in rural and urban areas, while taking concrete steps towards its target of reducing CO_2 emissions by 20 % by 2020. This enables remote areas without an established power grid to get access mobile communications [27].

- Telkomsel, Indonesia: Sustainable power

  New Telkomsel, Indonesia, is the market leader in Indonesia with a 54 % share in the country’s telecommunications market.

  Ericsson supplies a third of the operator's network and, with a growing reputation in energy efficient network expansion projects, was the perfect partner to support its growth. By continuously expanding its coverage, Telkomsel increases subscriber numbers and ensures its market position, but the remote diesel powered sites traditionally required to do this, take a lot of maintenance and this can substantially increase OPEX.

  Ericsson offered a 100 percent solar-driven site which was easy to install and kept maintenance costs to a minimum. Solar site, including RBS 2111 base station, MINI-LINK™ and power solution. The deployment has been a success and it is anticipated that it could lower OPEX by up to 40 % [28].

2.3.3 Wireless Network Energy Consumption

The typical mobile wireless network can be viewed as composed by three different sections [29]:

1) The Mobile Switching Center (MSC) which is a switch used for call control and processing, the Home Location Register (HLR) as the main database of permanent subscriber information for a mobile network, it contains pertinent user information, including address, account status, and preferences. And the Base Station Controller (BSC) that takes care of switching, and controls the radio base stations, this section known as the core of mobile communication network.
2) Radio Base Station (RBS), which takes care of the frequency interface between network and mobile terminals, which represents the radio section in the network.
3) Mobile switch or terminals (MS), which is the subscriber’s part, normally limited to the handheld device or what is called the mobile handset.

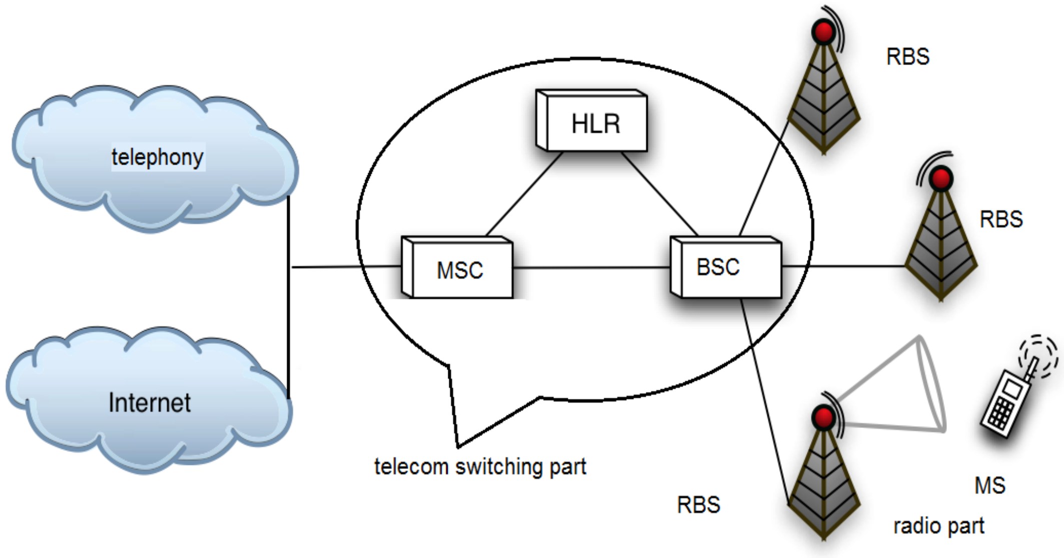

Figure 2.25: GSM (global system of mobile) network architecture [29]

It is estimated that over 90% of the wireless network energy consumption is part of the operators operating expenses [24]. The key elements are the radio base stations because of the number of base stations is relative high with relative high energy consumption. On the other hand as the number of core network elements is low, the total energy consumption due to core network is relative low. Finally the energy consumption of mobile terminals is very low due to the mobile nature. With these premises the ways to decrease energy consumptions of cellular network and thus to reduce cost and CO2 emissions are:

- Minimizing RBS energy consumption.
- Use of renewable energy sources.

Moreover could also be considered a minimization of number of RBS sites in order to reduce energy consumption: in this case the network design play an important role to implement a telecom network with correct capacity and minimum number of sites at optimum locations.

2.3.4 Radio base stations (RBS)

Radio Base stations enable mobile communications as mobile phones require a network of base stations in order to function. The base station antennas transmit and receive RF (radio frequency) signals, or radio waves, to and from mobile phones near the base station. Without these radio waves mobile communications would not be possible. Radio waves have been used for communication for more than 100 years [30].

The base station antennas are usually placed on rooftops, in masts or on building walls. Antennas are sometimes also installed in shopping malls, airports, offices, and other places with many mobile phone users. Indoor antennas are usually placed on walls or on ceilings [30].

As the number of mobile phone users in a community grows, more base stations are therefore needed. For that reason, more antennas are needed in crowded locations like a shopping mall where there are many mobile phone users. However, the shorter the distance between RBS antennas, the lower the output power of each antenna.

In Ericsson's GSM (Global System of Mobile) systems the Base Transceiver Station (BTS) is included as part of a product called Radio Base Station (RBS). The RBS also contains extra functionality which enables the support of several GSM-defined BTSs [29].

RBS model analysis

The model of a typical Radio Base Station is shown in the next figure [31]. Analyzing the proposed scheme it results that the system takes 10.3 kW of electricity to produce only 120 watts of transmitted radio signals and to process the incoming signals from the subscriber.

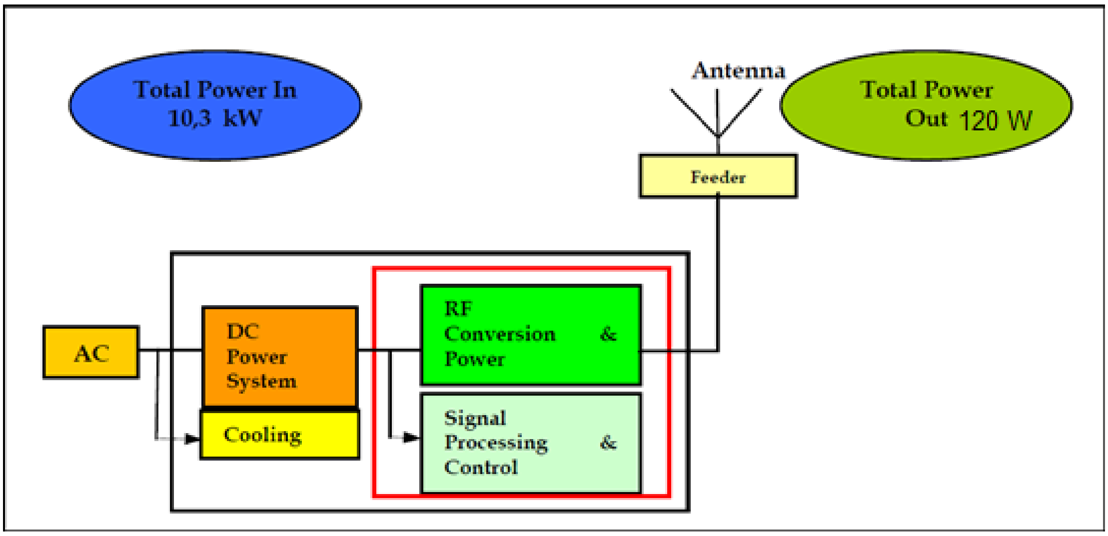

Figure 2.26 : RBS block diagram

Figure (2.27) shows the energy allocation per function within the RBS ([32]. More than 60% of the power is consumed by the radio equipment and amplifiers, 11% is consumed by the DC power system and 25% by the cooling equipment, an air conditioning unit, typical of many such sites. The Radio Equipment and the Cooling are the two major sections where the highest energy savings potential resides [32].

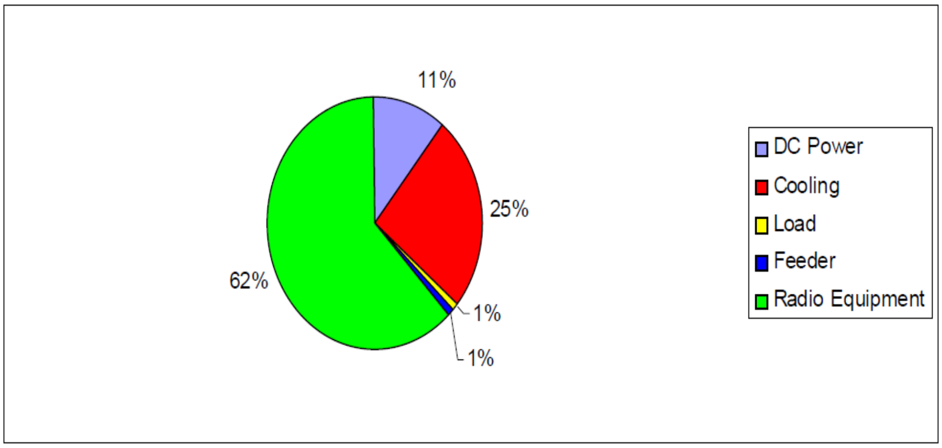

Figure 2.27: Percent BTS Energy per function

A very important thing to consider regarding the energy saving is the cascade effect that represents in aggregate a benefit of 28 times: for example, saving 1W in the feeder cables saves 17.3 watts of modulation and amplification losses, 3.3W of rectification losses and 7.1W of associated cooling energy [32].

CHAPTER THREE

RADIO BASE STATIONS IN JAWWAL COMPANY

3 . Radio Base Stations in Jawwal Company

3.1 Introduction

The Palestinian Cellular Communications company “Jawwal”, is the leading Palestinian mobile communication provider for communication services in the country; working with the GSM technology which stands for Global System of Mobile Jawwal’s network consists of more than 1400 radio sites spread in the Palestinian lands both Gaza and West Bank. Each radio site in the network provide communication services to the customer in the surrounding area. These radio sites are controlled by a set of main switches known as MSC’s (Mobile Services Switching Center) and a group of sub-switches known as BSC’s (Base Station Controller) [33].

3.2 Radio Sites

The radio sites in Jawwal express a group of common components which are:

- Antenna: which is the electrical device that converts electric power into radio waves and vice versa.
- Radio Base Station (RBS) : the main radio component in the site as discussed in the last chapter
- Transmission equipment: which connects between the network nodes like between the BSC and the RBS, and other RBS’s or outer networks such as the microwave links [33]
- Backup battery system: which represents the standby system in case of having any problem with the main power supplier of the site.

- External alarms system: which guarantees the remote control over the site in case of any appeared alarms or faults.

Jawwal Sites may be categorized, depending on the location of the RBS, to Indoor sites in which the RBS is located inside called “shelter” and Outdoor sites in which the RBS is at the outside.

Figure 3.1: Radio Site the RBS is in the shelter

Figure 3.2: Jawwal deferent sites

Radio sites are usually very similar in terms of design, equipment, and principle of work, and also electrical loads. In each site there is a small well isolated room 4m^2 area containing the sites elements, electrical, AC distribution boards, racks, and DC power system [33].

Regarding the electrical loads in each site are almost the same, the differences may occurs because of the variable air conditioner required.

The high sensitivity of the Telecom equipment requires a stable source of electricity, which is a 48V DC source, each RBS has stable power system, and AC to DC inverter, two backup battery systems, each battery system contains 4 batteries in series with 6V for each battery and rectifier. The largest electrical loads is air conditioner which operates for many hours daily in summer and winter to ensure the optimum temperature for the telecomm equipment to be between17C° -20C° [33].

3.3 Jawwal's RBS Radio Base Stations Examples

3.3.1 Ericsson RBS 2206

The RBS 2206 is an indoor macro base station with up to 12 radio units. The cabinet has the same footprint and is only marginally higher than the old RBS 2202 but has doubled capacity due to the new double capacity transceivers and combiners [34].

3.3.2 Ericsson RBS 2216

The RBS 2216 is a high-capacity indoor base station. It is used for indoor applications, with up to six Double Radio Units (DRU). The RBS 2216 is designed to be transported as a fully assembled cabinet to the site. All units in the cabinet are easily accessible from the front of the cabinet, which means that the cabinets can be mounted side by side or with their backs against a wall [35].

Figure 3.4: RBS 2206

Figure 3.3: RBS 2216

3.3.3 RBS 2308 and RBS2302

The two types are used for outdoor solutions, they have light weights and can be fitted easily as the pictures below [36].

Figure 3.6: RBS 2308

Figure 3.5: RBS 2302

3.3.4 Ericsson RBS 6102

Ericsson RBS 6102 is a multi-standard high-capacity outdoor base station. It provides a complete site in a single cabinet, supporting large radio configurations in single or multi standard radio applications.

Figure 3.7: RBS 6102

The cabinet includes radio, transport network equipment, power system as well as battery back-up and climate system. The base station can be used in the whole radio network where coverage and capacity are essential for a successful network rollout or expansion. Typical sites are metropolitan rooftop sites, ground level sites and rural outdoor sites [37].

3.4 Jawwal's Sites Power Supplies

The powering of radio sites in Jawwal network depends on three main cases which will be explained as the following:

Case A) Main nodes

The term nodes referred to the main radio sites in the network, those sites are connected to a large number of secondary sites so they have to be protected from any interruption for the large effect they have. In Jawwal network there is almost 116 main radio site, provided with electricity through the followings [33]:

a) Main Source is AC power from Grid networks.
b) First Backup System is Diesel Generators.
c) Second Backup system is Battery Systems.

Case B) Sites serve small areas

Almost the rest of the sites refer to this category around 1300 [33], provided with electricity through the following:

a) Main source is AC power from Grid networks.
b) Backup system is Battery Systems.

Case C) Sites located in remote rural areas

There are two sites in remote rural areas [31], provided with electricity through the following:

a) Main source is Diesel Generators.
b) Backup system is Battery Systems.

3.5 Electrical Consumption and Load Calculation

In this section, the electrical loads analysis will be performed to a group of different sites as an example from the targeted network, this will include; 1) sites that are mainly supplied by the grid network, 2) remote sites that depends on Diesel generators to be supplied by energy.

3.5.1 Grid network supplied sites

The load calculations for a sample of sites depending on the data measured by the power technical department in Jawwal, the analysis will be performed for some sites from different RBS types and deferent geographical location in the West Bank [38].

Table 3.1: Jawwal radio sites examples

Site / RBS location	Indoor		Outdoor	
Location	Ramallah city	Nablus city	Al Ram area	Nablus city
Site name	RAMA41	NABL96	RAH020	NABL39
RBS type	2206	2216	6102	2111

Indoor sites

The load calculations based on the measured data by the power technical department in Jawwal for two selected sites; site name is RAMA41 with 2206 RBS which is located in Ramallah city, and site name NABL96 with 2216 RBS which is located in Nablus city [38], each RBS is placed in a room which called the shelter together with the other elements.

The electrical load for the indoor sites includes; the radio base station (RBS) load, the air conditioning load (AC), the transmission equipment load (TM), and the aviation lamps load where the number of lamps depends on the height of the tower, 4 Lamps if its more than 48 meter height , 2 lamps otherwise [38]. Each site has a different electrical load depending on the type of the RBS as shown by the following two tables.

Table 3.2: Electrical load for the indoor site located in Ramallah City RAMA41 with 2206 RBS

Loads	Load in W	Qty.	Demand factor	Working hours /day	Energy consumption Wh/day
Aviation lamp	4	2	0.5	12	96
Air conditioning	1580	2	0.6	12	37920
RBS	1600	1	1	24	38400
TM equipment	50	1	1	24	1200
	3.5 kW total				77.6 kWh/day

Where; the demand factor is the Ratio of the maximum energy demand during a period to the total load connected to system [38].

Energy consumption per day for RAMA41 is obtained by the summation of all the loads in the table the value of kilowatt hour daily for this site is 77.6 kWh/day.

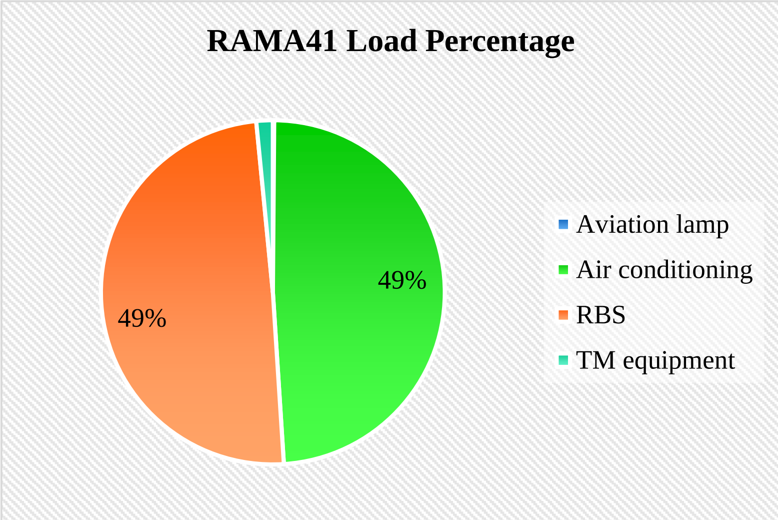

Figure 3.8: Load Percentage for the radio site RAMA41

Table 3.3: Electrical load for the indoor site located in Nablus City NABL96 with 2216 RBS

Loads	Load in W	Qty.	Demand factor	Working hours /day	Energy consumption Wh/day
Aviation lamp	4	2	0.5	12	96
Air conditioning	1580	2	0.6	12	37920
RBS	1800	1	1	24	43200
TM equipment	50	1	1	24	1200
	3.7 kW total				82.4 kWh/day

Energy consumption per day for NABL96 is obtained by the summation of all the loads in the table the value of kilowatt hour daily for this site is 82.4 kWh/day.

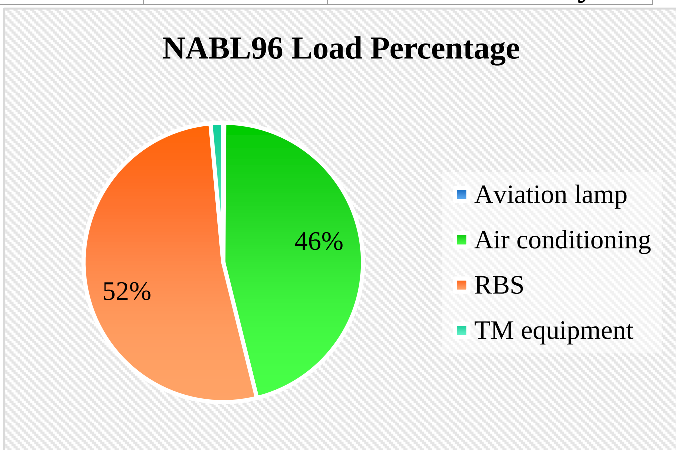

Figure 3.9: Load Percentage for the radio site NABL96

Outdoor sites

The load calculations based on the measured data by the power technical department in Jawwal for two selected sites; site name is RAH020 with 6102 RBS which is located in Al-Ram area, and site name NABL39 with 2111 RBS which is located in Nablus city [38]. The total electrical load for the outdoor sites will be less than the indoor ones, since there is no need for the air conditions that was mandatory in the indoors. On the other hand the outdoor RBS's come with a climate unite attached to them which performs the cooling process. The climate unit system controls the temperature inside the RBS by automatically adjusting the speed of the fans and the output signal to the heater [38]. Also there is the transmission equipment (TM), and the electrical aviation lamp which are common between the indoor and outdoor sites.

Table 3.4: Electrical load for the indoor site located in Nablus City NABL39 with 2111 RBS

Load	Load in W	Qty.	Demand factor	Number of working hours /day	Energy consumption Wh/day
Aviation lamp	4	2	0.5	12	96
Climate unite	700	1	0.8	19	13300
RBS	500	1	1	24	12000
TM equipment	50	1	1	24	1200
	1.1 kW total				26.6kWh/day

Where; the demand factor is the Ratio of the maximum energy demand during a period to the total load connected to system [38].

Energy consumption per day for NABL39 is obtained by the summation of all the loads in the table the value of kilowatt hour daily for this site is 26.59 kWh/day.

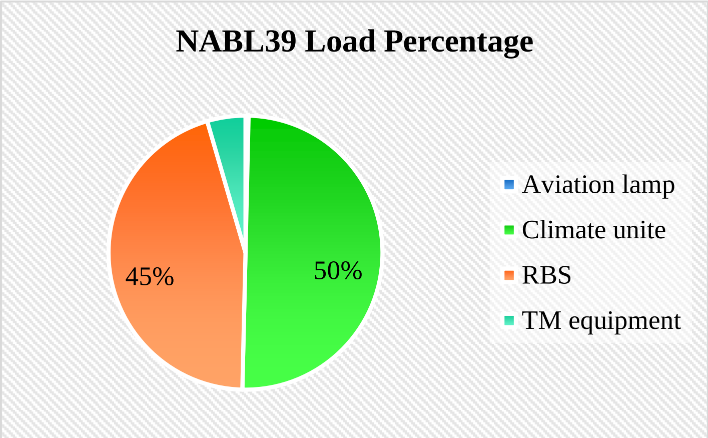

Figure 3.10: Load Percentage for the radio site NABL39

Table 3.5: Electrical load for the indoor site located in Al Ram area RAH020 with 6102 RBS

Load	Load in W	Qty.	Demand factor	Number of working hours /day	Energy consumption Wh/day
Aviation lamp	4	2	0.5	12	96
Climate unite	700	1	0.8	19	13300
RBS	1500	1	1	24	36000
TM equipment	50	1	1	24	1200
	2.1 kW total				50.5kWh/day

Energy consumption per day for RAH020 is obtained by the summation of all the loads in the table, the value of kilowatt hour daily for this site is 50.5 kWh/day.

As we compare the total energy consumption per day for the indoor and the outdoor sites calculated above, it's obvious that the outdoor sites consumes the least.

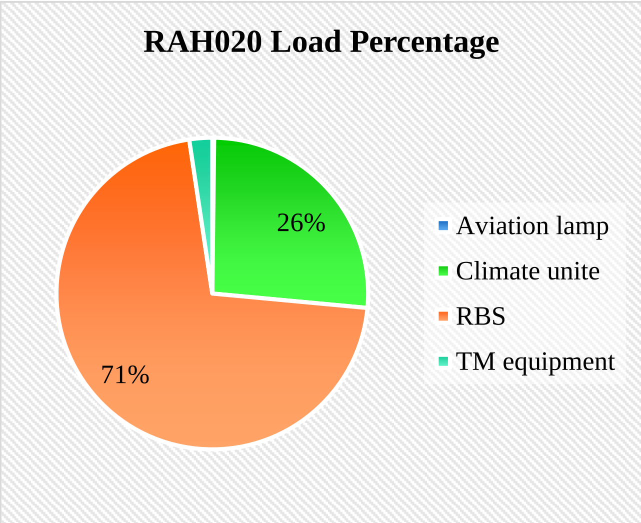

Figure 3.11: Load Percentage for the radio site RAH020

3.5.2 Diesel generator supplied remote sites

In the network of Jawwal, there is only two sites which still don't have a connection with the electrical grid, the sites main source of energy is two diesel generators for each site.

WBR115 radio site located in Al seila Al harethya has two diesel generators working alternatively, every generator works for 12 hours a day, the available fuel tank is 2000 liter, and the consumption per hour is between (2.5-2.7) liters of Diesel. Noting this values with radio site at full load [38].

The other radio site WBR008 located in Za'tara also has two Diesel generators working alternatively, every generator works for 12 hours a day, but with 1.3 liters of Diesel per hour consumption [38]. The table below summarize the situation in both sites, where D.G1 = the first Diesel generator, and D.G2 = the second diesel generator.

Table 3.6: Jawwal remote area sites

Site	Al seila Al harethya	Za'tara
Site name	WBR115	WBR008
RBS type	2206 RBS	6102 RBS
RBS Location	Indoor	Outdoor
Operating hours per day D.G1	12	12
Operating hours per day D.G2	12	12
Diesel consumption daily L/h	2.6	1.3
Yearly diesel consumption D.G1 L	11388	5694
Yearly diesel consumption D.G1 L	11388	5694

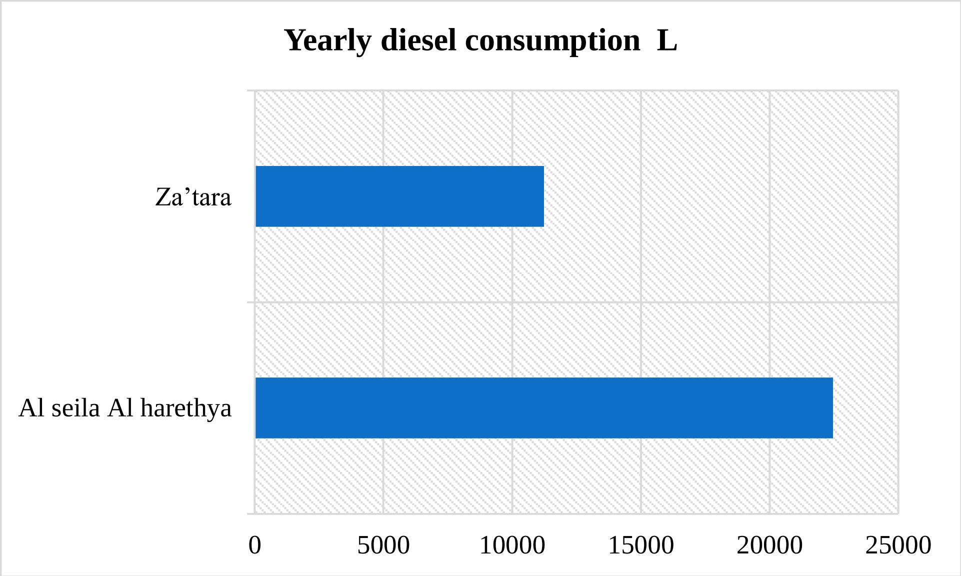

Figure 3.12: Yearly diesel consumption litter/year

The load analysis for the two remote radio sites are listed in the two following tables:

Table 3.7: load calculation for remote indoor Al seila Al harethya site WBR115 with 2206 RBS

Load	Load in W	Qty.	Demand factor	Working hours /day	Energy consumption Wh/day
Aviation lamp	4	2	0.5	12	96
Air conditioning	1580	2	0.6	12	37920
RBS	1600	1	1	24	38400
TM equipment	50	1	1	24	1200
	3.5 kW total				77.6 kWh/day

Energy consumption per day for WBR115 (2206 RBS) is obtained by the summation of all the loads (3.5 kW) in the table, the value of kilowatt hour daily for this site is 77.6 kWh/day [38].

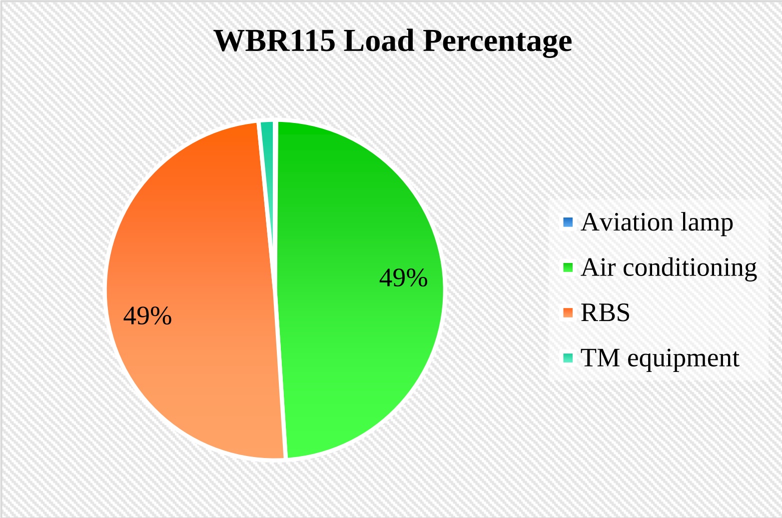

Figure 3.13: Load Percentage for the radio site WBR115

Table 3.8: load calculation for remote outdoor Za'tara site WBR008 with 6102 RBS

Load	Load in W	Qty.	Demand factor	Working hours /day	Energy consumption Wh/day
Aviation lamp	4	2	0.5	12	96
Climate unite	700	1	0.8	19	13300
RBS	1500	1	1	24	36000
TM equipment	50	1	1	24	1200
	2.1 kW total				50.5kWh/day

Energy consumption per day for WBR008 (6120 RBS) is obtained by the summation of all the loads (2.1 kW) in the table the value of kilowatt hour daily for this site is 50.5 Kwh/day [38].

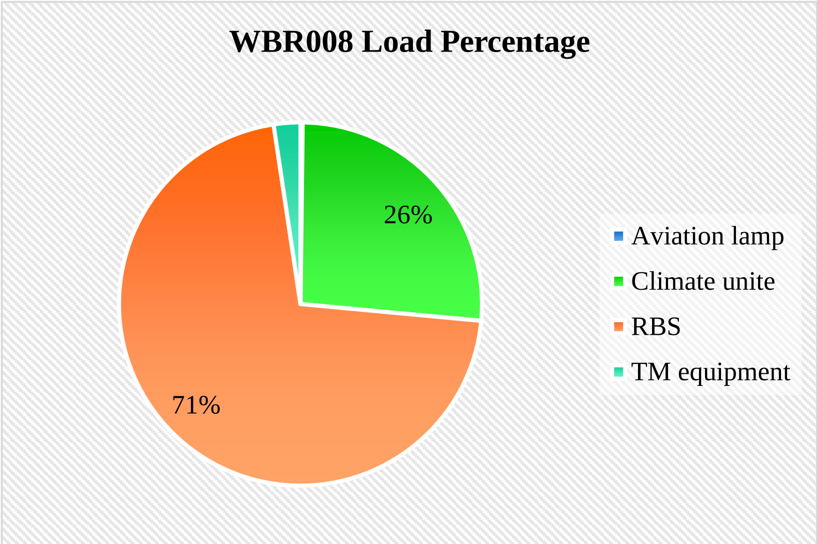

Figure 3.14: Load Percentage for the radio site WBR008

- **Remark**

  As an observation, it's noticeable that there is a huge difference between the load distribution in the indoor and outdoor sites. For the indoor radio sites, the highest percentage of the participation in the total load is shared between the RBS load and the air condition, in an almost fifty fifty percentage. While the load sharing percentage for the outdoor sites is mainly acquired by the load of the RBS.

3.6 Yearly Energy Consumption Summery

In this section, the yearly energy consumption for all radio sites shall be shown, in order to highlight the differences between them. The table below contains the kilo watt hours per year for each site.

Table 3.9: the yearly energy consumption for all radio sites

Site name	RAMA41	NABL96	WBR115	NABL39	RAH020	WBR008
	indoor			Outdoor		
Yearly energy Consumption kWh/year	28324	28324	30076	18432	9709	18432

This figure illustrates the yearly energy consumption in a meaningful graphical way to show the differences clearly.

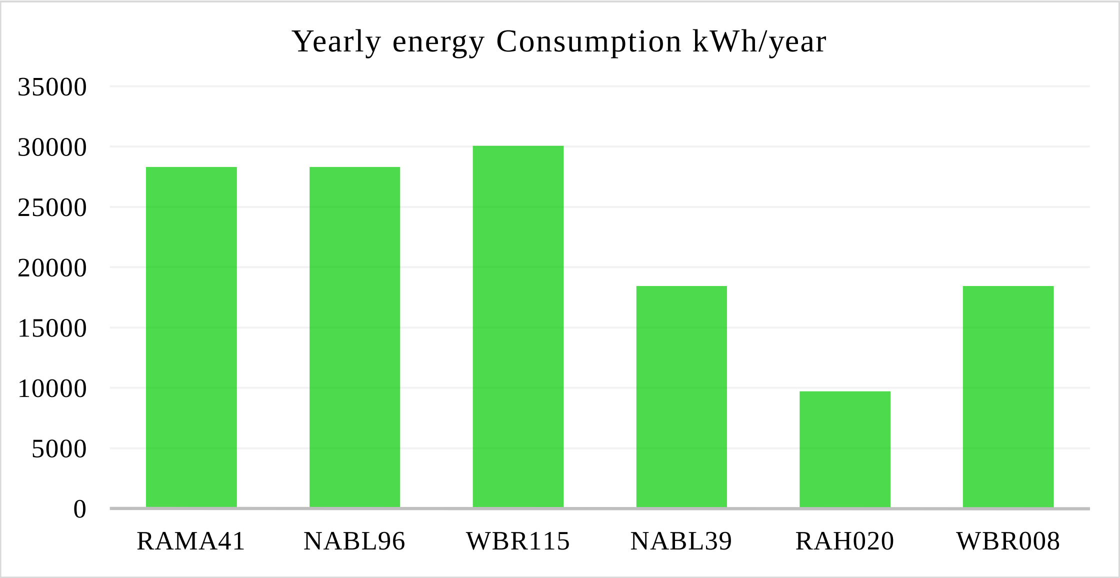

Figure 3.15: Yearly energy consumption kWh/year

Chapter Four

Case Study

4 CASE STUYDY

4.1Introduction

In this chapter, the PV systems will be designed based on the data load analysis of the radio sites. The aim of this study is to design the optimum PV system which is capable of providing energy to the remote radio site instead of the use of diesel generator. Considering the following aspects:

A. There is only two remote sites in JAWWAL's network which work on diesel.
B. Radio base station type are more than those type which were used in the two remote sites.
C. The network of JAWWAL is getting bigger and there will be more remote sites in the future.
D. The more the radio base station types in the study, the more valuable and meaningful it became.

The assumption will be as the following:

All six radio sites including the ones which are connected to grid right now, will be considered as remote sites. The different radio sites, radio base stations, and energy consumption between the six sites, will create a better point of view and a stronger decisions regarding the use of PV systems instead of diesel than if it was just two sites.

The main two categories are indoor and outdoor radio sites. All indoor sites will be handled as the radio remote site (WBR115) located in Al Seileh Al Haretheya regarding diesel consumption. Similarly all outdoor sites will be treated as the radio remote site (WBR008) located in Za’tara regarding diesel consumption.

4.2Radio Sites Load Analysis

The study case will be built on the sample of sites analyzed in chapter four. The six sites and their corresponding load calculations can be summarized in the following table.

Table 4.1: load summery for the selected radio site sample

Number	Site name	RBS location	RBS	Load rated power kW	Energy demand / day kWh/day
1	RAMA41	Indoor	2206	3.5	77.6
2	NABL96	Indoor	2216	3.7	82.4
3	WBR115	Indoor	2206	3.5	77.6
4	NABL39	Outdoor	2111	1.1	26.6
5	RAH020	Outdoor	6102	2.1	50.5
6	WBR008	Outdoor	6102	2.1	50.5

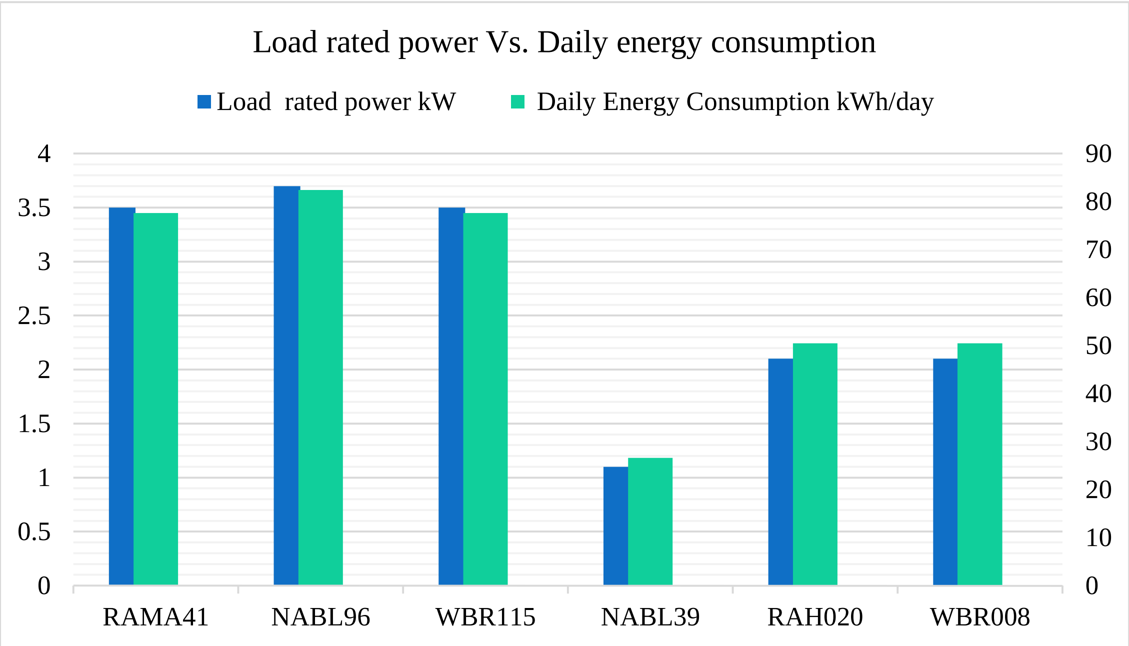

Figure 4.1: Load rated power Vs. Daily energy consumption

4.3 PV System Design for the Remote Sites

4.3.1 The indoor site located at Al Seila Al Harethya

The design of the PV system including the PV generator and the storage battery system will be performed at this section for the site WBR115 which is located at Al Seila Al Harethya with a 2206 RBS type.

In order to determine the PV generator supply size the following data must be given:

- PSH peak sun hours = 5.4
- Safety factor of k= 1.15 [4].

PV generator sizing

The design of PV generator for all sites, will be performed similarly depending on the set of equations previously mentioned. The key elements which will be used for the design are:

- Load rated power =3.5 kW
- Energy consumption per day E_d = 77.6 kWh/day
- The required nominal DC voltage for the system = 48 VDC

1) The selection of the inverter as mentioned in sec. (3.7.2), the inverter size should be 25-30% bigger than total power of the load. The selected inverter for this site which is rated at an output power of 3.5kW is a “Studer” inverter “XTH 6000-48” with a rated input voltage of 48V DC, apparent

Figure 4.2: Studer XTH 6000-48

output power of 5000VA, and an efficiency of 96%. The data sheet is found in Appendix A-1.

2) The selection of a suitable charge regulator is the next step, where “BlueSolar charge controller MPPT 150/70” is used. The nominal output voltage is 48 V, the maximum input voltage is 150 volt PV open circuit voltage is 150 V, the maximum solar array input power is 4000W and the efficiency at full load is 97.5%. The data sheet can be found in Appendix A-2.

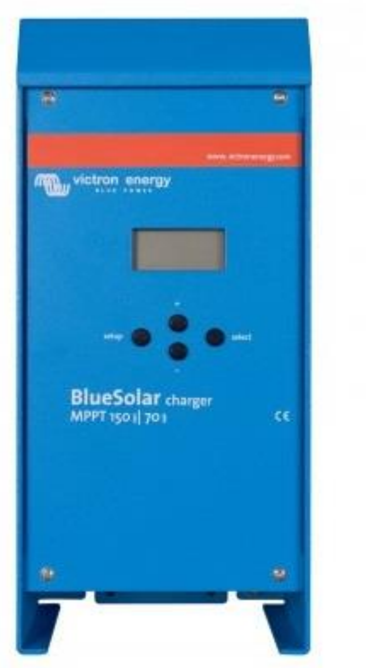

Figure 4.3: BlueSolar charge controller MPPT 150/70

Calculate the PV generator peak power

$E_{P.V} = E_d / \eta_{inv} * \eta_{C.R}$

$E_{P.V} = 77.6/0.96*0.975 = 82.90$ kWh/day

P_{PV} generator power peak = $E_{P.V}$ * K/ PSH

P_{PVG}= 82.9 * 1.15 / 5.4 = 17.65 kW_p

3) The selection of the proper PV modules. The selected PV module is "SCHOTT MONO 180" which is a crystalline module with MONO cells. The number of cells connected in series is (6*12) = 72 cells, and the dimensions are (1.620 * 810) = 1.3 m^2 area, rated at 180 W_P (P_{mpp}), 36.2 VDC (V_{mpp}), and 4.97A (I_{mpp}). The open circuit voltage $V_{O.C}$ is 44.8 V and the short circuit current $I_{S.C}$ is 5.40A. The efficiency of the module is 13.7%, all specifications are found in Appendix A-3.

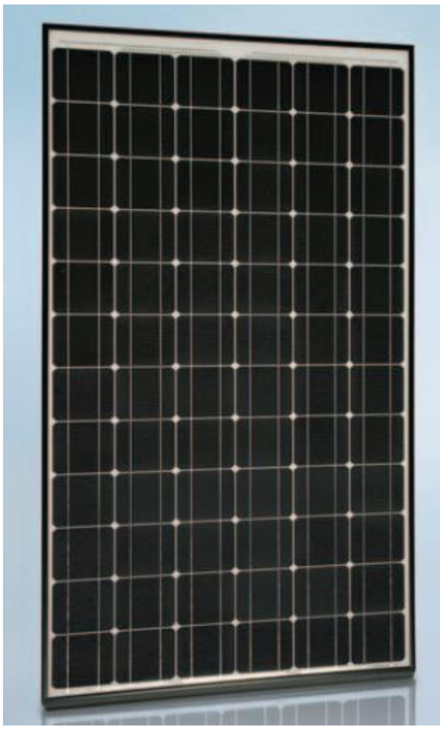

Figure 4.4: SCHOTT MONO 180

Calculate the number of modules

The system nominal system DC voltage is 48V, thus the PV generator will consist of parallel PV strings each contains 2 Schott Modules connected in series.

Rated power per module is 180W_p.

No. of modules = P_{PVG} /P of one module

No. of modules= 17.7*1000/180 = 98.0 modules.

The number of modules will be selected as 98 modules so it can be divided in 2 modules in series.

No. of strings = 98/2= 49 strings

Based on the ratings of the selected charge regulator (C.R), the max input power of one C.R per array on the 48V DC is 4000 Watt, the number of strings per array will be 7.

The selected No. of arrays will be 7.

Calculate the PV generator Area

Total minimum area needed for PV generator = No. modules * area for one module

A_{PV}=98*1.3m^2= 128.6 m^2

Calculate the PV generator open circuit voltage and short circuit current

$V_{O.C}$ of module = 44.8 V

$I_{S.C}$ of module = 5.40 A

$V_{O.C}$ actual of the PV generator = 2* 44.8 = 89.6 VDC

$I_{S.C}$ actual of the PV generator = 5.40 *49= 264.6 A

4) The selection of a suitable circuit breaker C.B is very important at this stage, in order to ensure the protection for all precious components of the system. The placement of the C.B will be at each array of modules, and so for this PV system with six arrays, six Circuit breakers are needed. The selected C.B is “C60H-DC” “miniature circuit breaker - C60H - 1 pole - 50 A” manufactured by Schneider Electric with 50A rated current. The sizing of the C.B is as follows

$I_{C.B} = k * I_{max\ array}$ Equation 4.1

Where, k = factor of safety = 1.2 [4],

$I_{max\ array}$ = the maximum current of the PV array.

$I_{max\ array}$ = No. strings per array * $I_{S.C\ module}$

$I_{S.C\ module}$ = 5.40 A

Number strings per array = 5 strings

$I_{rating\ array}$ = 7*5.40 = 37.8A

$I_{C.B}$ =1.2* 37.8= 45.36 A

The selected DC C.B rating current should be 50 A considering the breakers standards in the market, the chosen one is 50A Appendix A-4.

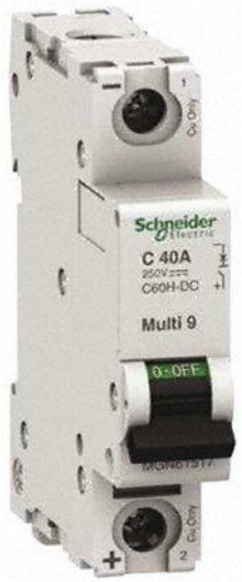

Figure 4.6: circuit breaker - C60H-DC

5) Battery block sizing, the storage capacity for this system is considerably large that’s why the selected type should be a reliable, strong, and high quality block battery. The “OPzS solar.power” single cell battery are vented stationary batteries with liquid electrolyte (diluted sulphuric acid). Due to the tubular plates technology “OPzS solar.power” batteries offer an extreme high cycling expectancy. The excellent cycling behavior of “HOPPECKE OPzS solar.power” tubular plate batteries is based on the around protection of positive mass by using of gauntlets. “HOPPECKE OPzS solar.power” batteries are optimal for application in sectors with high

Figure 4.7: HOPPECKE OPzS solar.power

charge and discharge operation load like solar or off-grid applications, in partial during Particle State of change operations, with 80% depth of discharge DOD, and 90% efficiency Appendix A-5.

Calculate the watt hour capacity for the block battery

Capacity in Amper hour CAH = Ed / DOD* η_{inv}* η_{Batt}*V_{system}

CAH = 77.6*10^3/0.80*0.96*0.90*48

CAH = 2338.93 Ah

The calculations will be for two autonomy days, so:

CAh 2 Days = 2* 2338.9 = 4677.8 Ah

The selected battery cells for this site will be “11 OPzS solar.power 1670, 2V”, with C10/1.80 V and Amper hour capacity of 1255.8 Ah at 2V.

The number of battery strings is 4677.8 /1255.8 = 3.75, so 4 strings

The number of cells per string = 48/2= 24 battery cell

The watt hour capacity of the battery bank will be = 4*1255.8 *48=241114 Wh

The following table shows the main selected components for the PV system:

Table 4.2: PV system components for WBR115 radio site

WBR115	Model	Ratings per unit
PV module	SCHOTT MONO 180	180 W_P
Inverter	XTH 6000-48	5000 VA
Charge regulator	MPPT 150/70	4000 W per array
Circuit breaker	C60H-DC	50A
Battery bank	11 OPzS solar.power 1670	1670 Ah/2V

By the obtained calculation results, the PV system of the radio site which is located in Al Seila Al Harethya area is ready to be sketched, showing all components of the system. The table below represents the summery of all calculated items and components which characterize this PV system.

Table 4.3: The radio site WBR115 PV system components summery

Component	Al Seila Al Harethya
Site name	WBR115
RBS location	Indoor
Load Rated power kW	3.5
E_d kWh/day	77.6
E_{PV} kWh/day	82.91
P_{PVG} kW_P	17.65
No. calculated PV modules	98.0
No. actual PV modules	98
No. PV modules in series	2
No. strings	49
No. arrays	7
$A_{P.V}$ generator m^2	128.6
$V_{OC.PVG}$ Volts	89.6
$I_{SC.PVG}$ Amperes	264.6
Amper hour capacity C_{Ah} 2 days Ah	4677.8
Watt hour capacity C_{AW} Wh	241114
No. Battery strings	4
No. Batteries in series	24
No. Batteries	96
No. of C.B's	7

4.3.2 The outdoor site located at Za'tara area

The design of the PV system including the PV generator and the storage battery system will be performed at this section for the site WBR008 which is located at Za'tara with 6102 RBS type.

The same way of calculations which was performed in the previous section for WBR115 will be followed in this section.

The main given data for this site are:

- Load rated power =2.1 kW
- Energy consumption per day E_d = 50.5 kWh/day
- The needed DC voltage for the system = 48 VDC

Thereby, the main selected components can be listed as below:

Table 4.4: PV system components for WBR008 radio site

WBR008	Model	Ratings per unit
PV module	SCHOTT MONO 180	180 W_P
Inverter	SI2324, 2348	2300 VA
Charge regulator	MPPT 150/70	4000 W per array
Circuit breaker	C60H-DC	32A
Battery bank	9 OPzS solar.power 1370	1026 Ah/2V

Depending on the load characteristics for this radio site the selection of the elements of the PV system was performed as follows:

1) Selecting the suitable inverter depending on 2.1 kW rated load power and the needed 48 DC voltage. The selected inverter is "SI2324, 2348" with a maximum efficiency (η_{inv}) equals 95% and 2300 kVA. The data sheet can be found in Appendix A-6.

Figure 4.8: SI2324, 2348 inverter

2) The charge regulator is the next selected item, using the same charger of the pervious section (6.3.1)," BlueSolar charge controller MPPT 150/70" with a Maximum PV open circuit voltage of 150V, a

Maximum solar array input power of 4000W at 48V, and an efficiency at full load and 97.5%, the data sheet can be found in Appendix A-2.

3) The type of PV module is the same one used in sec. (6.3.1) “SCHOTT MONO 180”. A MONO crystalline module, the number of cells connected in series is (6*12) = 72 cells, and the dimensions are (1.620 * 810) = 1.3 m^2 area, rated at 180 W_P (P_{mpp}), 36.2 VDC (V_{mpp}), and 4.97A (I_{mpp}). The open circuit voltage $V_{O.C}$ is 44.8 V and the short circuit current $I_{S.C}$ is 5.40A. The efficiency of the module is 13.7%, all specifications are found in Appendix A-3.
4) The selection of the C.B circuit breakers, as per sec. (5.3.1), four “C60H-DC” “miniature circuit breaker - C60H - 1 pole - 32 A” circuit breakers each one for an array (Appendix A-7).
5) The selected battery cells from the same “HOPPECKE OPzS solar.power” used in sec. (6.3.1) but with deferent size “9 OPzS solar.power 1370, 2V”, with C10/1.80 V Ah of 1026.0 Ah Appendix A-5.

PV system of the radio site located in Za’tara area is ready now to be sketched, showing all the components of the system. The table below represents the summery of all calculated items and components which characterize this PV system.

Table 4.5: The radio site WBR008 PV system components summery

component	Za'tara
Site name	WBR008
RBS location	Outdoor
Load rated power kW	2.1
E_d kWh/day	50.5
E_{PV} kWh/day	54.52
P_{PVG} kW_P	11.61
No. calculated PV modules	64
No. actual PV modules	64
No. PV modules in series	2
No. strings	32
No. arrays	8
$A_{P.V}$ generator m^2	83.9
$V_{OC.PVG}$ Volts	89.6
$I_{SC.PVG}$ Amperes	172.8
Amper hour capacity C_{Ah} 2 days Ah	3076
Watt hour capacity C_{AW} Wh	147744
No. Battery strings	3
No. Batteries in series	24
No. Batteries	72
No. of C.B's	8

4.3.3 Remote sites PV system design comparison

After finishing the designs of the two PV systems for the two remote sites, it comes a need to compare between the two systems, the components and the effect of the RBS location on the final system (indoor vs. outdoor). The following table will highlight those differences:

Table 4.6: PV systems summery for two sites

component	Al Seila Al Harethya	Za'tara
Site name	WBR115	WBR008
RBS location	Indoor	Outdoor
Load rated power kW	3.5	2.1
E_d kWh/day	77.6	50.5
E_{PV} kWh/day	82.9	54.52
P_{PVG} kW_P	17.65	11.61
No. calculated PV modules	98.0	64
No. actual PV modules	98	64
No. PV modules in series	2	2
No. strings	49	32
No. arrays	7	8
$A_{P.V}$ generator m^2	128.6	83.9
$V_{OC.PVG}$ Volts	89.6	89.6
$I_{SC.PVG}$ Amperes	264.6	172.8
C_{Ah} 2 days Ah	4677.8	3076
Watt hour capacity C_{AW} Wh	241114	147744
No. Battery strings	4	3
No. Batteries in series	24	24
No. Batteries	96	72
No. of C.B's	7	8

4.4PV System Design for the Assumed Remote Sites

4.4.1 Indoor sites

The same calculations will be applied to the indoor sites which assumed to be in remote areas. The first site is located in Ramallah city and named RAMA41, the second one is located in Nablus city and named NABL96. The selected elements for designing the PV systems for both sites can be summarized by the two following tables:

Table 4.7: PV system components for RAMA41 radio site

	Model	Ratings per unit
PV module	SCHOTT MONO 180	180 W_P
Inverter	XTH 6000-48	5000 VA
Charge regulator	MPPT 150/70	4000 W per array
Circuit breaker	C60H-DC	50A
Battery bank	11 OPzS solar.power 1670	1670 Ah/2V

Table 4.8: PV system components for NABL96 radio site

	Model	Ratings per unit
PV module	SCHOTT MONO 180	180 W_P
Inverter	XTH 6000-48	5000 VA
Charge regulator	MPPT 150/70	4000 W per array
Circuit breaker	C60H-DC	50A
Battery bank	12 OPzS solar.power 1820	1370 Ah/2V

Also the calculations for the PV systems can be summarized as the following table

Table 4.9: PV systems summery for two sites

component	Ramallah	Nablus
Site name	RAMA41	NABL96
RBS location	Indoor	Indoor
Load rated power kW	3.5	3.7
E_d kWh/day	77.6	82.4
E_{PV} kWh/day	83.3	88.03
P_{PVG} kW_P	17.65	18.75
No. calculated PV modules	98.0	105
No. actual PV modules	98	112
No. PV modules in series	2	2
No. strings	49	56
No. arrays	7	8
$A_{P.V}$ generator m^2	128.6	146.5
$V_{OC.PVG}$ Volts	89.6	89.6
$I_{SC.PVG}$ Amperes	264.6	302
C_{Ah} 2 days Ah	4677.8	4967.2
Watt hour capacity C_{AW} Wh	241114	241497
No. Battery strings	4	4
No. Batteries in series	24	24
No. Batteries	96	96
No. of C.B’s	7	8

4.4.2 Outdoor sites

The Outdoor assumed remote sites, PV system designs depends also on the same calculations applied before, the first site is located in Nablus city and named NABL39, the second one is located in Al Ram area and named RAH020, the selected elements for designing the PV systems for both sites can be summarized by the two following tables:

Table 4.10: PV system components for NABL39 radio site

	Model	Ratings per unit
PV module	SCHOTT MONO 180	180 W_P
Inverter	SI 1212,1224, 1248	1200 VA
Charge regulator	MPPT 150/70	4000 W per array
Circuit breaker	C60H-DC	50A
Battery bank	8 OPzS solar.power 1220	915 Ah/2V

Table 4.11: PV system components for RAH020 radio site

	Model	Ratings per unit
PV module	SCHOTT MONO 180	180 W_P
Inverter	SI2324, 2348	2300 VA
Charge regulator	MPPT 150/70	4000 W per array
Circuit breaker	C60H-DC	32A
Battery bank	9 OPzS solar.power 1370	1026 Ah/2V

Table 4.12: PV systems summery for two sites

Component	Nablus	Al Ram
Site name	NABL39	RAH020
RBS location	Outdoor	Outdoor
Load rated power kW	1.1	2.1
E_d kWh/day	26.6	50.5
E_{PV} kWh/day	28.71	54.52
P_{PVG} kW_P	6.11	11.61
No. calculated PV modules	33.9	64
No. actual PV modules	36	64
No. PV modules in series	2	2
No. strings	18	32
No. arrays	3	8
$A_{P.V}$ generator m^2	47.2	83.9
$V_{OC.PVG}$ Volts	89.6	89.6
$I_{SC.PVG}$ Amperes	97.2	172.8
C_{Ah} 2 days Ah	1620	3076
Watt hour capacity C_{AW} Wh	87840	147744
No. Battery strings	2	3
No. Batteries in series	24	24
No. Batteries	48	72
No. of C.B's	3	8

4.5PV Systems Schematic diagram

- PV system block diagram for radio sites WBR115 and RAMA41

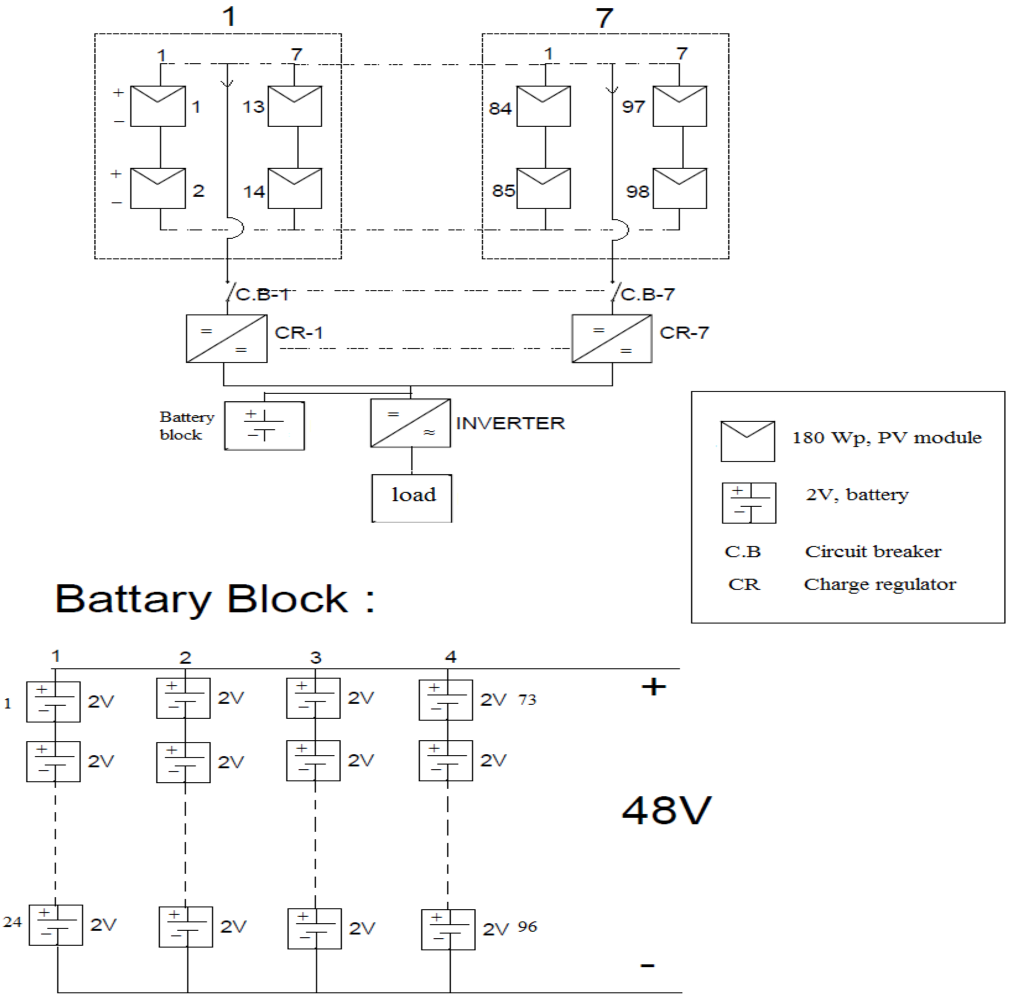

Figure 4.9: PV system block diagram for radio sites WBR115 and RAMA41

- PV system block diagram for radio sites WBR008 and RAH020

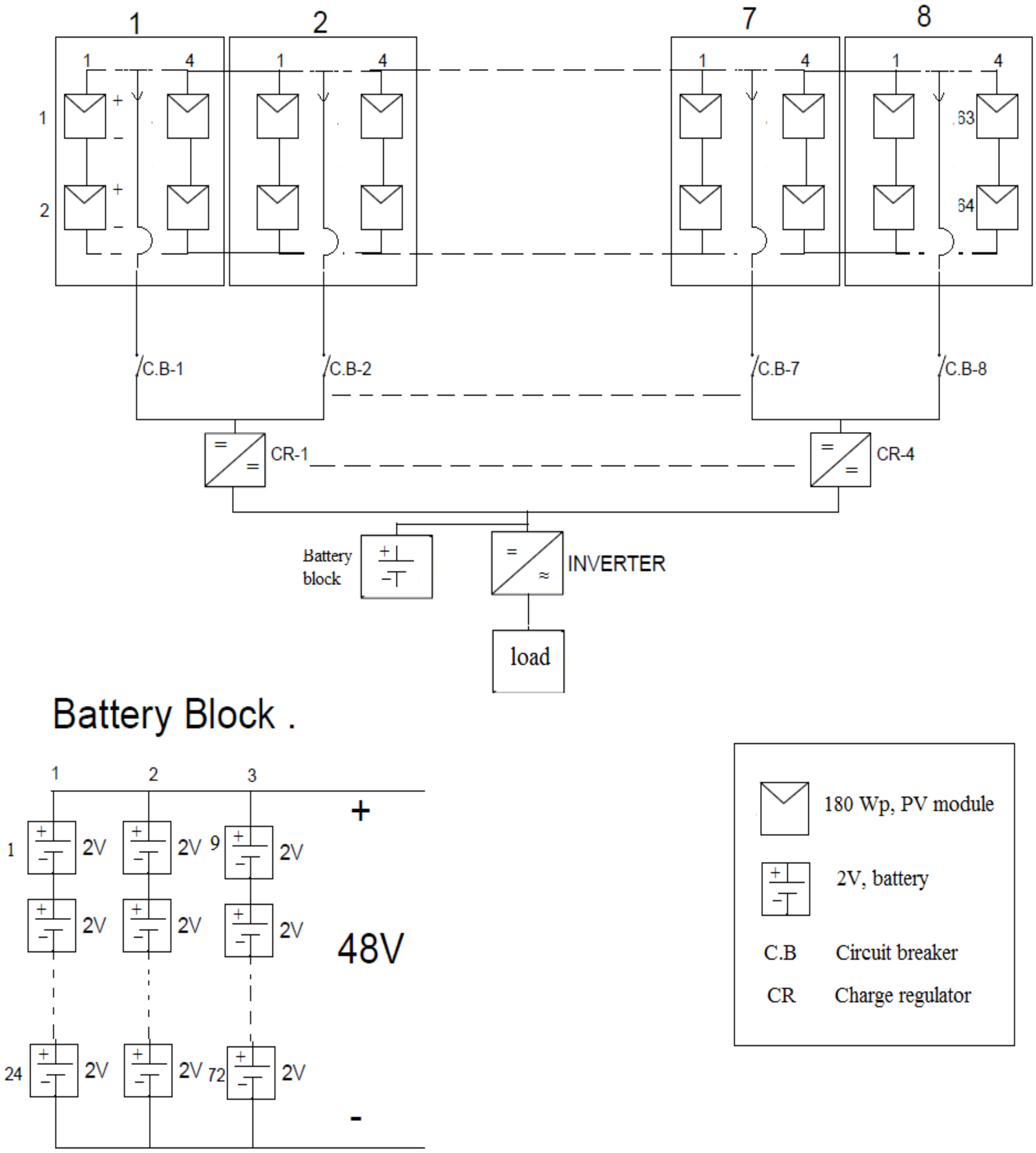

Figure 4.10: PV system block diagram for radio sites WBR008 and RAH020

- PV system block diagram for radio site NABL96

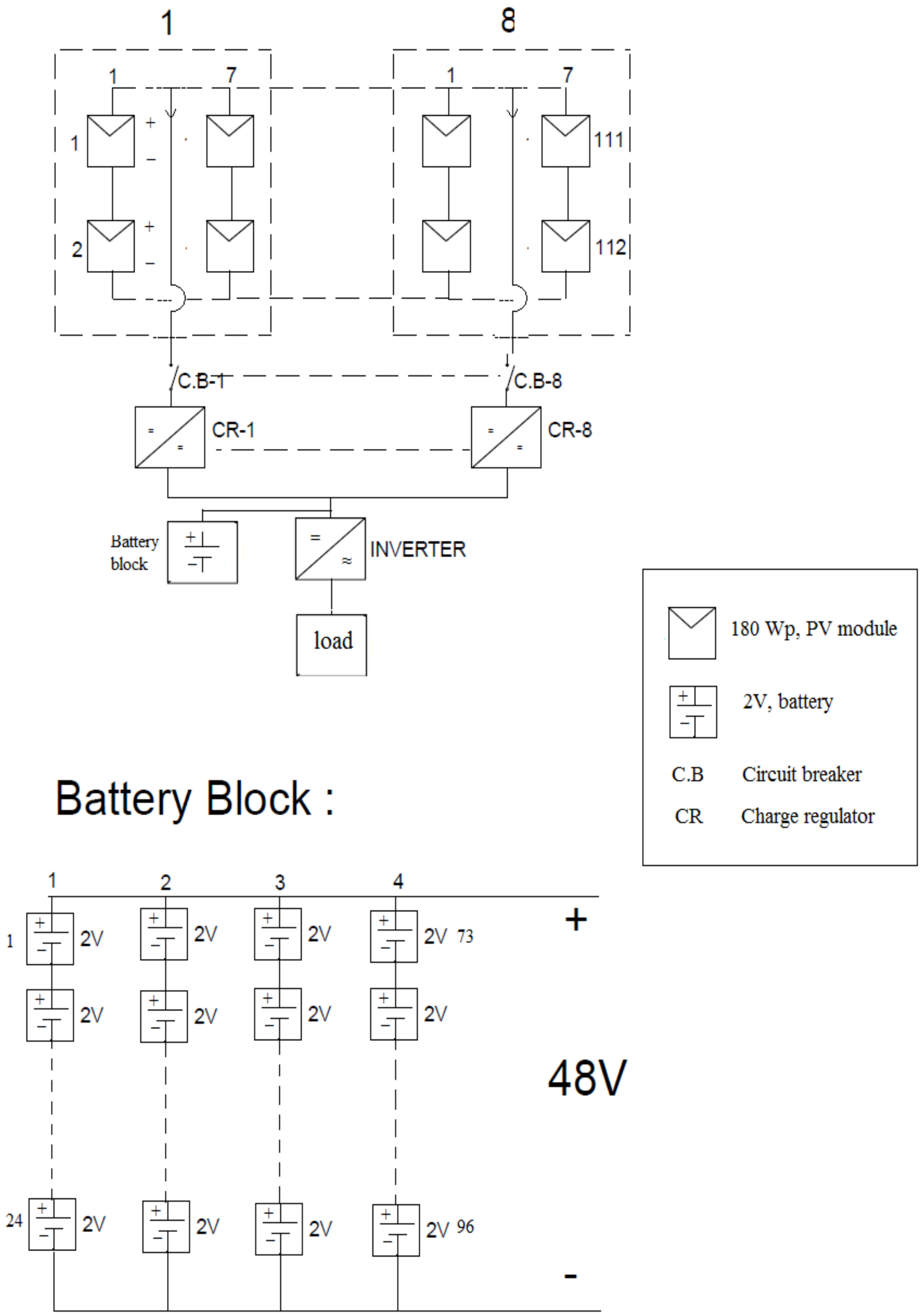

Figure 4.11: PV system block diagram for radio site NABL96

- PV system block diagram for radio site NABL39

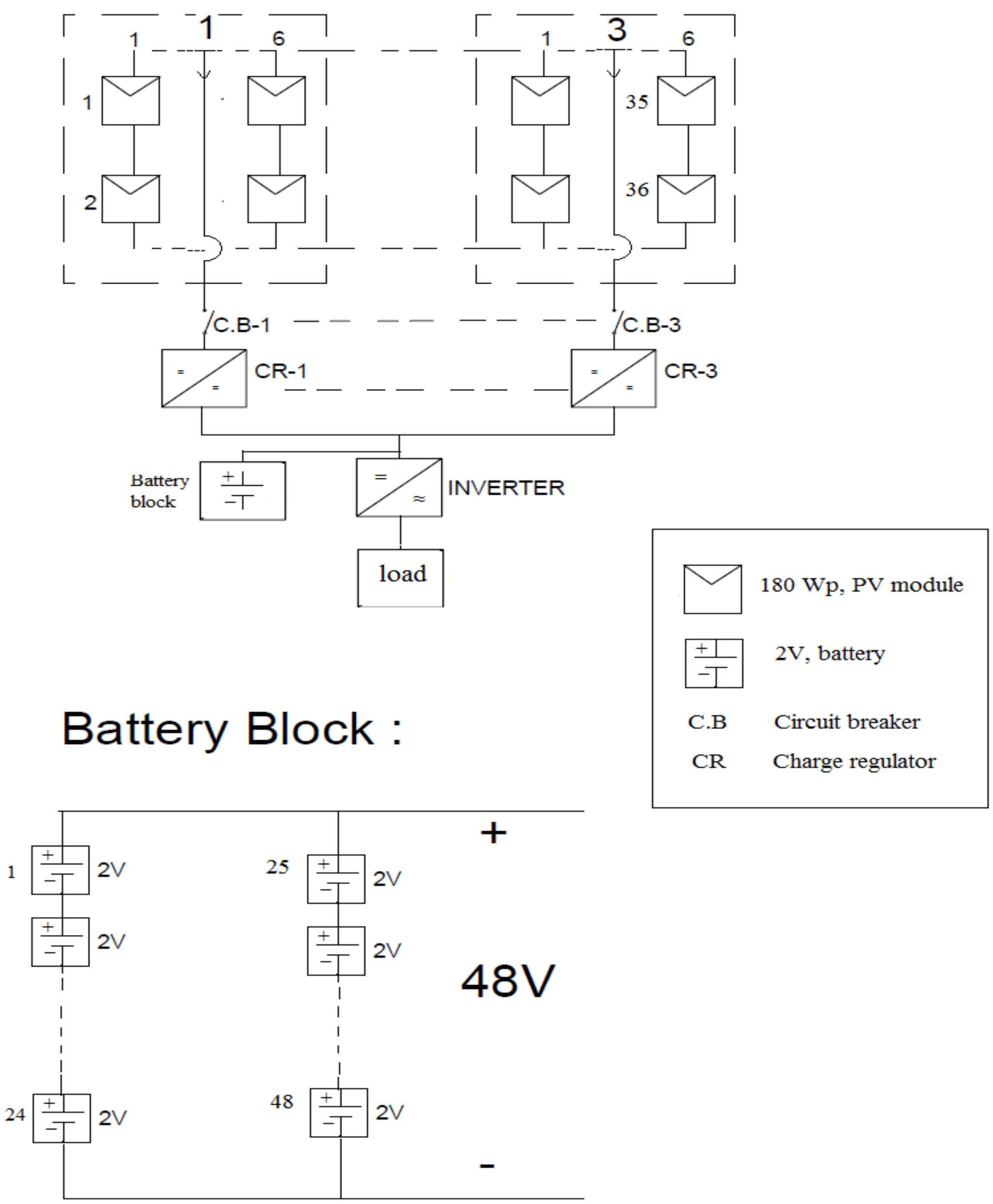

Figure 4.12: PV system block diagram for radio site NABL39

4.6 PV systems optimum installation

The PV modules for each site will be installed facing south in the suitable way for each site. Normally radio sites are located on the roof of a building, house, or what they call it in the telecommunication green field which means on ground.

The shadowing effect of photovoltaics modules have a devastating impact on their performances since any shadow is able to keep down the electricity production on a PV module. The distance between PV modules arrays can be calculated as the following, to avoid shadowing during the daily peak sun hours [39].

$x = a\,[\sin\beta \times \tan(23.5 + L) + \cos\beta]$, Where; Equation 4.2

x: is the minimum distance between the two PV arrays facing south to avoid shading

a: is the length of the PV array its equal 1.620 m in for all radio sites.

β: is the tilt angle of the PV array on a horizontal level.

L: is the latitude of the radio site, its equal 32° in the selected areas Nablus, Ramallah.

The optimum values of the tilt angle β for the solar modules can be given by the three following corrections:

β = L= 32, for Mar, Sep.

β = L – 10= 22, for Apr, May, Jun, Jul, Aug.

β = L + 20 = 52, for Jan, Feb, Oct, Nov, Dec.

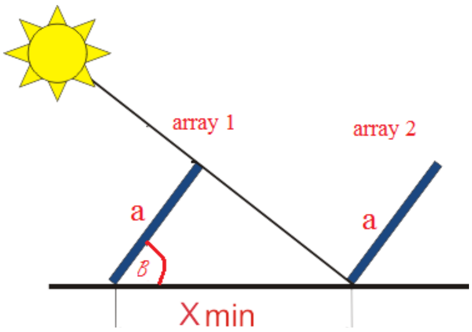

Figure 4.13: Min distance (x)

The assumption which will be used in this study is β = 45°.

So the minimum distance to avoid shadowing at noon is

$x = 1.620[\sin 45^{o} \tan(23.5^{o} + 32) + \cos 45^{o}] = 2.8$ m

CHAPTER FIVE

ECONOMIC ANALYSIS OF POWERING RADIO BASE STATIONS USING PV SYSTEM INSTEAD OF DIESEL GENERATORS

5 Economic Analysis of Powering Radio Base Stations Using PV System Instead of Diesel Generators

5.1 Introduction

Radio communication companies have a strong effect on the local and international markets in any country and globally, they affect their customers' lifestyle and behavior with the well-studied and perfectly directed marketing campaigns.

Adopting the green technology culture from such companies considered a big step for any company to promote itself as an environmental friend operator, and as a role model not only for normal individuals but also for the other companies.

For any telecommunication company entering the green field there will be common questions to be asked; what economic benefits will I get back? How can I select the right alternative? And this will be the challenge for any suggested design.

To overcome this challenge and choose a suitable alternative, the key factor at this stage is the economical factor, giving the fact that we didn't miss any other essential factor such as the environment, social, political, ethical, health, safety, and sustainability, they are all of high importance.

A feasibility study aims to objectively and rationally uncover the strengths and weaknesses of an existing business or proposed venture, opportunities and threats present in the environment, the resources required to carry through, and ultimately the prospects for success.

The economic model will include yearly cash flows, the present value of system costs, incomes and annual costs. In addition, the analysis has been designed to allow economical comparison of using PV system instead of diesel generators.

5.2Diesel Generators Economic Analysis

5.2.1 Fixed and running costs of using diesel generators

To make a good economic comparison between the use of diesel generators verses the use of PV solar system, each case should be economically analyzed. In this section the fixed capital cost and the operational annual cost of using two diesel generators to provide energy for the two remote sites in Jawwal's network will be analyzed. As mentioned in sec. (4.5.2), the two remote sites in Jawwal's network are working with two diesel generators each, the following table shows the given data which characterize each site as given by the technical power team of Jawwal, keeping in mind that the main difference between those two sites is the location of the RBS which is indoor for Al Seila Al Harethya site and outdoor for Za'tara site.

Table 5.1: Diesel generators data for both remote sites

Site	Al seila Al harethya	Za'tara
Site name	WBR115	WBR008
RBS type	2206 RBS	6102 RBS
RBS Location	Indoor	Outdoor
Operating hours per day D.G1	12	12
Operating hours per day D.G2	12	12
Diesel consumption daily L/h	2.6	1.3
Yearly Diesel consumption D.G1 L	11388	5694
Yearly Diesel consumption D.G2 L	11388	5694

The nominal data and the fixed cost which is known as the CAPEX or the capital cost of the diesel generators can be summarized by the following table.

Table 5.2: The specifications of the used diesel generators per remote site including the CAPEX.

Location	No. of Diesel generators	Diesel Generator Name	Diesel Generator Capacity	Diesel Generator Capital cost
Al Seila Al Harethya	2	LISTER- LPW4	15 KVA	7750 USD
Za'tara	2	LISTER- LPW4	15 KVA	7750 USD

Moreover, the running cost which is known as the "OPEX" for both sites can be summarized as the table below. Note that the values per site are for both diesel generators summed up together.

Table 5.3: The running cost OPEX for using diesel generators in the two remote sites

	Al Seila Al Harethya	Za'tara
Yearly Diesel consumption cost USD	29608.8	14804.4
Yearly Maintenance cost (oils and filters) USD	3050	3050
Yearly Urgent maintenance cost USD	300	300
Yearly transportation cost USD	400	300
Total annual cost USD	33358.8	18454.4

The calculations for the cost of diesel are based on the price of one liter which costs 5.28 NIS. Assuming that 1 USD equals 4 NIS, the cost of one liter of diesel will equals 1.3 USD.

5.2.2 Energy unit cost from diesel generators

The calculations of the cost per unit (kWh), can be performed using the following equation [40]

Cost/kWh= fixed cost/kWh + running cost/kWh

Equation 5.1

Considering a depreciation factor (D.F) of 0.1

The needed data can be summarized by the following table:

Table 5.4: Data for calculating the cost per kWh

	Al Seila Al Harethya	Za'tara
Site name	WBR115	WBR008
RBS location	Indoor	Outdoor
CAPEX cost USD	15500	15500
Annual OPEX cost USD	33358.8	18454.4
Annual energy consumption kWh	28324	18432.5

Calculation of fixed cost per kWh

- Al Seila Al Harethya site

Cost /kWh = CAPEX*D.F/Annual energy consumption

USD/kWh=15500*0.1/28324= 0.05 USD/kWh

- Za'tara site

USD/kWh=15500*0.1/18432.5= 0.08 USD/kWh

Calculation of running cost per kWh

- Al Seila Al Harethya site

Cost /kWh = Annual OPEX/Annual energy consumption

USD/kWh=32953/28324= 1.17 USD/kWh

- Za'tara site

USD/kWh=18351/18432.5= 1 USD/kWh

Cost of unit per kWh

The cost per unit for the two sites can be shown in the following table after the summation of both fixed cost per kWh and running cost per kWh

- Al Seila Al Harethya = 0.05+01.17 =1.2 USD/kWh
- Za'tara = 0.08+1= 1.08 USD/kWh

Table 5.5: cost per kWh for both sites

	Al Seila Al Harethya	Za'tara
RBS location	Indoor	Outdoor
Cost per unit $/kWh	1.2	1.08

- **Remark**

  The comparison between using diesel generators or PV system for providing energy to the radio sites will depend on the above cost per unit values. The economic evaluation for all the indoor sites in this study will be built on 1.2 USD per kWh as the cost of the energy unit from diesel. On the other hand, the economic evaluation for all the outdoor sites in this study will be built on 1.08 USD per kWh as the cost of the energy unit from diesel.

The sites are listed as shown by the smart graphic blow:

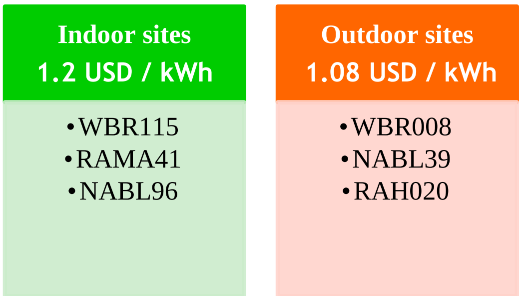

Figure 5.1: Indoor vs. Outdoor sites list with the corresponding cost per kWh

5.3 PV systems Economic Analysis

5.3.1 Fixed and running costs of using PV systems

5.3.1.1 Fixed and running costs of using PV system for Al Seila Al Harethya (WBR115)

The fixed cost "CAPEX" or the capital cost of the designed PV systems for Al Seila Al Harethya radio site can be summarized by the following table.

Table 5.6: CAPEX and OPEX of WBR115 radio site

Component	Qty.	Unit price USD	Life Time year	Total Price USD
PV module (180W_P)	98*180=17640	0.7/ Wp	20	12348
Batteries (1670 Ah/2V)	96	630.65	10	60542
Charge Regulator 4 kW	7	832.8	20	5829.6
Circuit breaker 32A	7	34.9	20	244.3
Inverter 5 kVA	1	4948.8	20	4948.8
Support structure	17.6kW	150USD/1kW	20	2640
Wiring and cabling	17.6kW	30USD/1kW	20	528
Total CAPEX cost USD			87080.7	
Operating and maintenance USD/year	= 3% from capital cost		2612.4	
Salvage value USD	= 3.5% from capital cost		3047.8	

- The calculations of the price of PV modules was performed such that each watt peak costs 0.7 USD. So for the 98 modules each of 180 Watt which is 18000 total Watt peak multiplied by 0.7 USD the price is 12600 dollar.
- The operation and maintenance cost per year was considered as 3% from the capital investment cost (CAPEX).
- The salvage value is between (2-5%) from the capital investment cost (CAPEX), so it has been considered 3.5%.
- The same calculations will be applied for all radio sites as follows.

5.3.1.2 Fixed and running costs of using PV system for Ramallah city site (RAMA41)

Table 5.7: CAPEX and OPEX of RAMA41 radio site

Component	Qty.	Unit price USD	Life Time year	Total Price USD
PV module (180WP)	98*180=17640	0.7/ WP	20	12348
Batteries (1670 Ah/2V)	96	630.65	10	60542
Charge Regulator 4 kW	7	832.8	20	5829.6
Circuit breaker 32A	7	34.9	20	244.3
Inverter 5 kVA	1	4948.8	20	4948.8
Support structure	17.6kW	150USD/1kW	20	2640
Wiring and cabling	17.6kW	30USD/1kW	20	528
Total CAPEX cost USD			87080.7	
Operating and maintenance USD/year	= 3% from capital cost		2612.4	
Salvage value USD	= 3.5% from capital cost		3047.8	

5.3.1.3 Fixed and running costs of using PV system for Nablus city site (NABL96)

Table 5.8: CAPEX and OPEX of NABL96 radio site

Component	Qty.	Unit price USD	Life Time year	Total Price USD
PV module (180W)	112*180=20160	0.7/Wp	20	14112
Batteries (1370Ah/2V)	96	677.68	10	65057
Charge Regulator 4 kW	8	832.8	20	6662.4
Circuit breaker 32A	8	34.9	20	279.2
Inverter 5 kVA	1	4948.8	20	4948.8
Support structure	20kW	150USD/1kW	20	3000
Wiring and cabling	20kW	30USD/1kW	20	600
Total CAPEX cost USD			94659.4	
Operating and maintenance USD/year	= 3% from capital cost		2839.7	
Salvage value USD	= 3.5% from capital cost		3313.0	

5.3.1.4 Fixed and running costs of using PV system for Za'tara site (WBR008)

The fixed cost “CAPEX” or the capital cost of the designed PV systems for Za’tara radio site can be summarized by the following table.

Table 5.9: CAPEX and OPEX of WBR008 radio site

Component	Qty.	Unit price USD	Life Time year	Total Price USD
PV module (180W)	64*180= 11520	0.7/Wp	20	8064
Batteries (1026 Ah/2V)	72	531.2	10	38246
Charge Regulator 4 kW	4	832.8	20	3331.2
Circuit breaker 32A	8	25.4	20	203.2
Inverter 2.3 kVA	1	2435.5	20	2435.5
Support structure	11.5kW	150USD/1kW	20	1725
Wiring and cabling	11.5kW	30USD/1kW	20	345
Total CAPEX cost USD			54349.9	
Operating and maintenance cost/year USD	= 3% from capital cost		1630.4	
Salvage value USD	= 3.5% from capital cost		1902.2	

5.3.1.5 Fixed and running costs of using PV system for Nablus city site (NABL39)

Table 5.10: CAPEX and OPEX of NABL39 radio site

Component	Qty.	Unit price USD	Life time year	Total price USD
PV module (180W)	36*180=6480	0.7/Wp	20	4536
Batteries (915 Ah/2V)	48	482.4	10	23155
Charge Regulator 4 kW	3	832.8	20	2498
Circuit breaker 32A	3	34.9	20	104.7
Inverter 1.2 kVA	1	2006.8	20	2006.8
Support structure	6.4kW	150USD/1kW	20	960
Wiring and cabling	6.4kW	30USD/1kW	20	192
Total CAPEX cost USD			33452.5	
Operating and maintenance cost/year USD	= 3% from capital cost		1003.5	
Salvage value USD	= 3.5% from capital cost		1170.83	

5.3.1.6 Fixed and running costs of using PV system for Al Ram area site (RAH020)

Table 5.11: CAPEX and OPEX of RAH020 radio site

Component	Qty.	Unit price USD	Life time year	Total price USD
PV module (180W)	64*180= 11520	0.7/Wp	20	8064
Batteries (1026 Ah/2V)	72	531.2	10	38246
Charge Regulator 4 kW	4	832.8	20	3331.2
Circuit breaker 32A	8	25.4	20	203.2
Inverter 2.3 kVA	1	2435.5	20	2435.5
Support structure	11.5kW	150USD/1kW	20	1725
Wiring and cabling	11.5kW	30USD/1kW	20	345
Total CAPEX cost USD			54349.9	
Operating and maintenance cost/year USD	= 3% from capital cost		1630.4	
Salvage value USD	= 3.5% from capital cost		1902.2	

5.3.2 Unit energy cost from PV system

Calculating the cost of energy unit in USD/kWh, the following equation must be solved [40].

Unit cost ($/kWh) = life cycle cost / yearly energy consumption

Equation 5.2

Where the life cycle cost (LCC) is calculated in the annual worth (AW)

LCC (AW) = $C_{\text{Investment}} + C_{\text{O\&M}} + C_{\text{battery replacement}} - C_{\text{salvage value}}$

Equation 5.3

Where, C= cost

7% assumed interest rate

Life time of the project = 20 years

$C_{\text{O\&M}}$ = operating and maintenance annual cost

The needed data to calculate the unit energy cost for each radio site is summarized by the table below.

Table 5.12: cash flow summery and annual energy consumption per radio site

Site name	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
RBS location	Indoor	Indoor	Indoor	Outdoor	Outdoor	Outdoor
Yearly energy consumption kWh/year	28324	28324	30076	18432.5	9709	18432.5
Investment COPEX	87080.7	87080.7	94659.4	54349.9	33452.5	54349.9
Annual cost OPEX	2612.4	2612.4	2839.7	1630.4	1003.5	1630.4
Battery replacement	60542	60542	65057	38246	23155	38246
Salvage value	3047.8	3047.8	3313.0	1902.2	1170.8	1902.2

Unit energy cost for Al Seila Al Harethya site (WBR115)

LCC (AW) = $C_{\text{Investment}} + C_{\text{O\&M}} + C_{\text{battery replacement}} – C_{\text{salvage value}}$

LCC= 87080.7*(A/P,7%,20) + 2612.4+ 60542* (P/F,7%,10)(A/P,7%,20)-3047.8*(A/F,7%,20) = 13663.4 USD

Unit cost ($/kWh) = 13663.4 USD / 87080.7 $\text{kWh}_{/\text{year}}$ = 0.48 $/kWh

Using the compound interest tables (Appendix B) the values of the flowing factors are:

(A/P,7%,20) = 0.0944, (P/F,7%,10)(A/P,7%,20) = 0.5083 *0.0944, (A/F,7%,20) = 0.0244.

Table 5.13: LCC cost and unit energy cost for radio sites PV systems

	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
LCC cost	16077.9	16077.9	17517.62	10163.82	6242.6	10163.82
Unit cost USD/kWh	0.48	0.48	0.49	0.46	0.54	0.46

5.3.3 Unit energy cost comparison

The comparison between unit energy costs in USD per kWh is finally clear between the two alternatives, the Diesel generator scenario verses the PV system one. The following table show the cost per energy unit for the two alternatives:

Table 5.14: Cost per energy unit comparison from Diesel generators and PV system

	Radio site	USD/kWh from Diesel	USD/kWh from PV
Indoor radio sites	WBR115	1.2	0.48
	RAMA41	1.2	0.48
	NABL96	1.2	0.49
Outdoor radio sites	WBR008	1.08	0.46
	NABL39	1.08	0.54
	RAH020	1.08	0.46

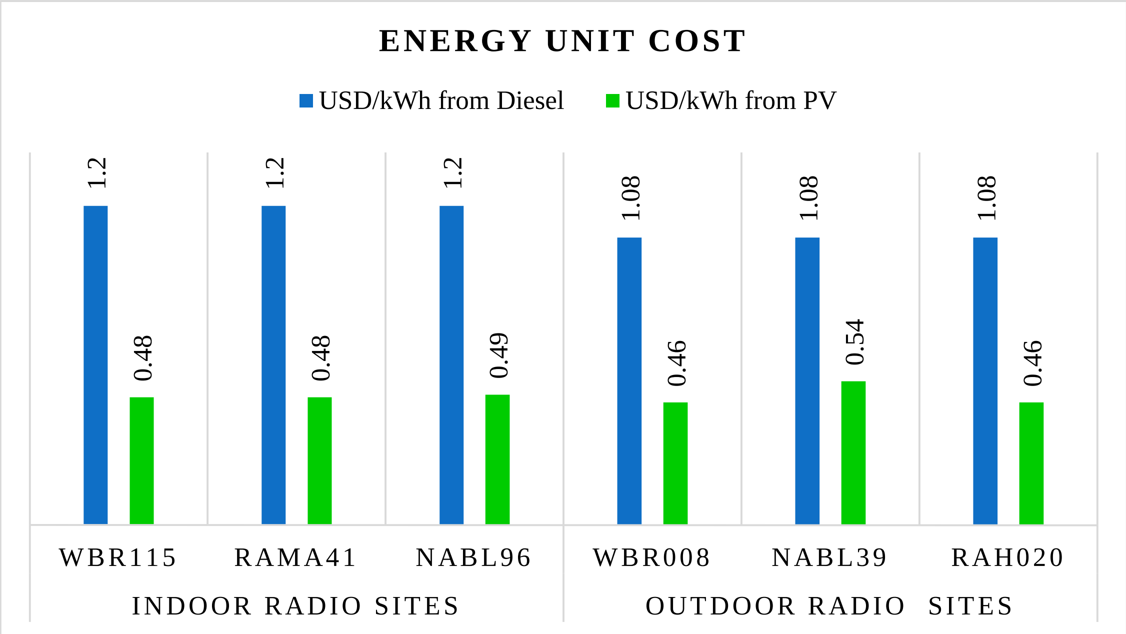

Figure 5.2: Energy unit cost comparison

It's clear that the cost of one kWh produced by PV system is the lower tan that produced by diesel generator for all radio sits. So it's for sure the best alternative to provide radio sites with energy considering the long life time of the system which is capable of returning the relatively large investment cost of the PV system.

5.3.4 Total energy consumption cost comparison

To compare between the total cost of energy consumption generated by diesel generators and the energy generated by the PV system for every site in the study.

Table 5.15: Unit energy cost generated by both diesel and PV

Site name	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
RBS location	Indoor	Indoor	Indoor	Outdoor	Outdoor	Outdoor
Yearly energy consumption kWh/year	28324	28324	30076	18432.5	9709	18432.5
Energy unit from diesel USD	1.2	1.2	1.2	1.08	1.08	1.08
Energy unit from PV USD	0.48	0.48	0.49	0.46	0.54	0.46

Table 5.16: Yearly energy consumption cost comparison USD

	Site name	Yearly Energy Consumption kWh/day	Yearly energy cost from Diesel USD	Yearly energy cost from PV USD
Indoor Sites	WBR115	28324	33988.8	13595.5
	RAMA41	28324	33988.8	13595.5
	NABL96	30076	36091.2	14737.2
Outdoor sites	WBR008	18432.5	19907.1	8478.9
	NABL39	9709	10485.72	5242.8
	RAH020	18432.5	19907.1	8478.9

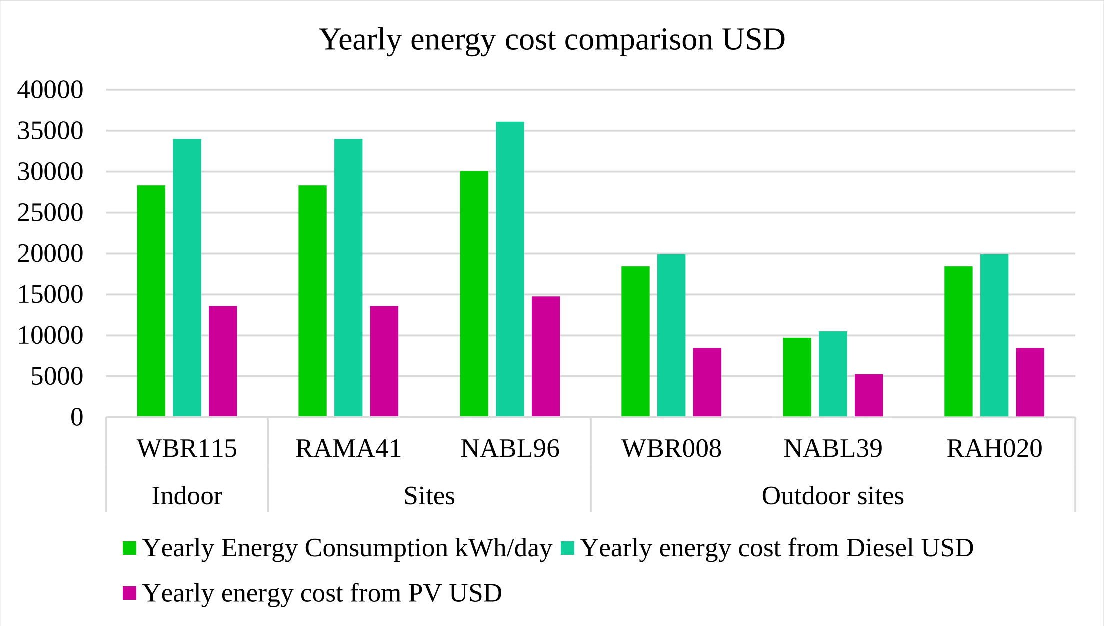

Figure 5.3: Yearly energy cost comparison USD

5.3.5 Energy consumption cost comparison with the utility grid cost

Energy consumption cost is a very strong economic indicator, considering the fact that the world is witnessing a significant increase in fuel prices. After comparing the energy consumption price from diesel and PV generator, it would be meaningful to discuss utility grid energy consumption cost for the on grid radio sites. Such a comparison will make better indication.

Given that the cost per kWh from the local utility is between (0.6 – 0.7) NIS, (0.18 – 0.15) USD. The average will be consider 0.165 dollar per kWh

Table 5.17: Unit energy cost generated by diesel, PV and utility grid

Site name	RAMA41	NABL96	NABL39	RAH020
RBS location	Indoor	Indoor	Outdoor	Outdoor
Yearly energy consumption kWh/year	27936	29664	9576	18180
Energy unit from diesel USD	1.2	1.2	1.08	1.08
Energy unit from PV USD	0.48	0.49	0.54	0.46
Energy unit from grid USD	0.165	0.165	0.165	0.165

Table 5.18: Yearly energy consumption cost comparison USD

	Site name	yearly energy cost from Diesel USD	yearly energy cost from PV USD	yearly energy cost from grid USD
Indoor Sites	RAMA41	33988.8	13595.5	4673.4
	NABL96	36091.2	14737.2	4962.5
Outdoor sites	NABL39	10485.7	5242.8	1601.9
	RAH020	19907.1	8478.9	3041.3

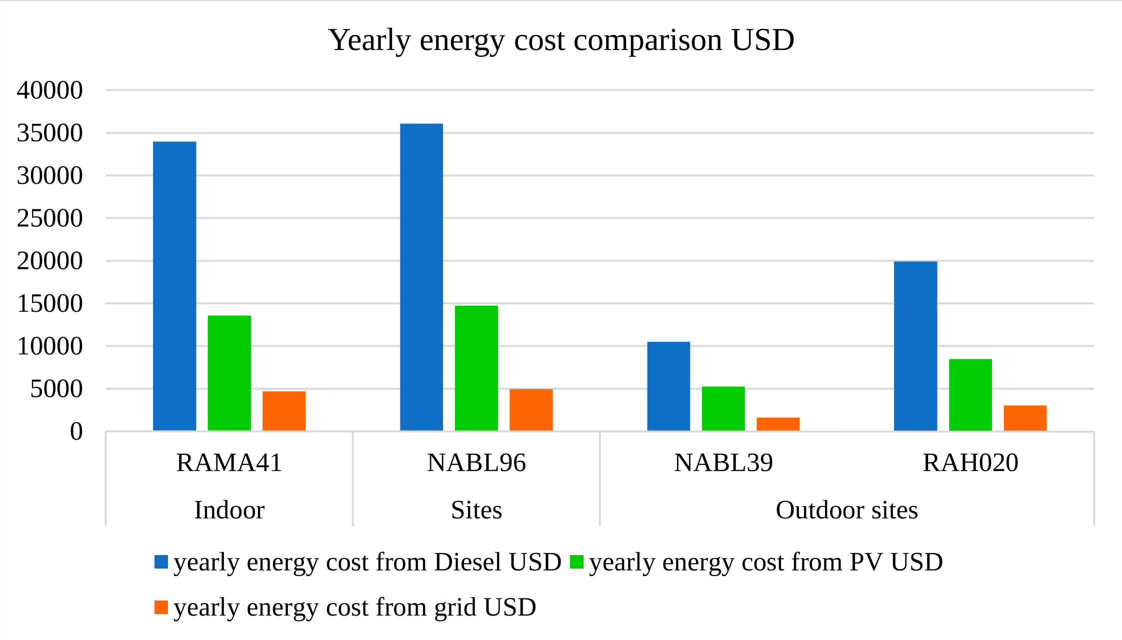

Figure 5.4: Yearly energy cost comparison USD for on grid sites

It's clearly shown that, the cost of energy provided by the utility grid is lower than both diesel and PV sources.

5.3.6 Annual saving of using PV systems instead of diesel generator

To summarize the annual saving in money from using PV systems instead of diesel generators. The table below shows the difference between energy yearly consumption costs which represents the desired annual saving [40].

Table 5.19: Annual saving for all radio sites

	Site name	Yearly Energy Consumption kWh/day	Yearly energy cost from Diesel USD	Yearly energy cost from PV USD	Yearly Energy cost saving USD
Indoor Sites	WBR115	28324	33988.8	13595.5	20393.3
	RAMA41	28324	33988.8	13595.5	20393.3
	NABL96	30076	36091.2	14737.2	21354
Outdoor sites	WBR008	18432.5	19907.1	8478.9	11428.2
	NABL39	9709	10485.7	5242.8	5242.9
	RAH020	18432.5	19907.1	8478.9	11428.2

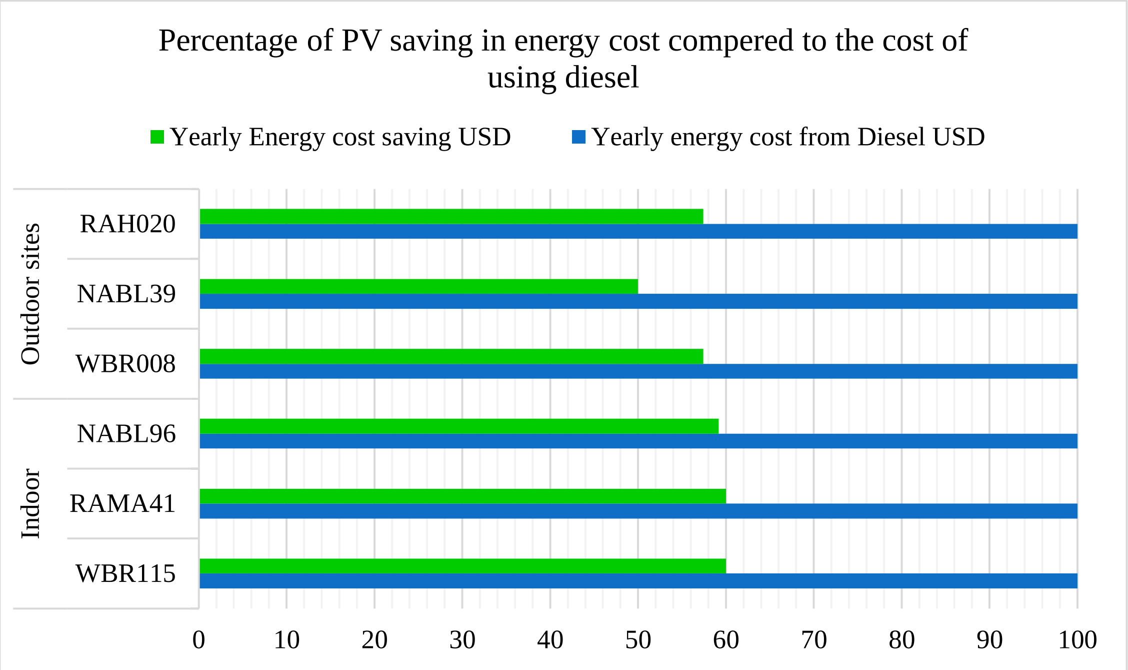

Figure 5.5: Percentage of PV saving in energy cost compered to using diesel

5.3.7 Degradation on annual saving due to efficiency

The degradation in energy saving over the life time of the PV system which is 20 years will occur due to the degradation in the efficiency of the modules with 0.5% degradation per year.

The six radio sites are plotted together in the figure below, which illustrates the degradation on the annual saving over PV system life time.

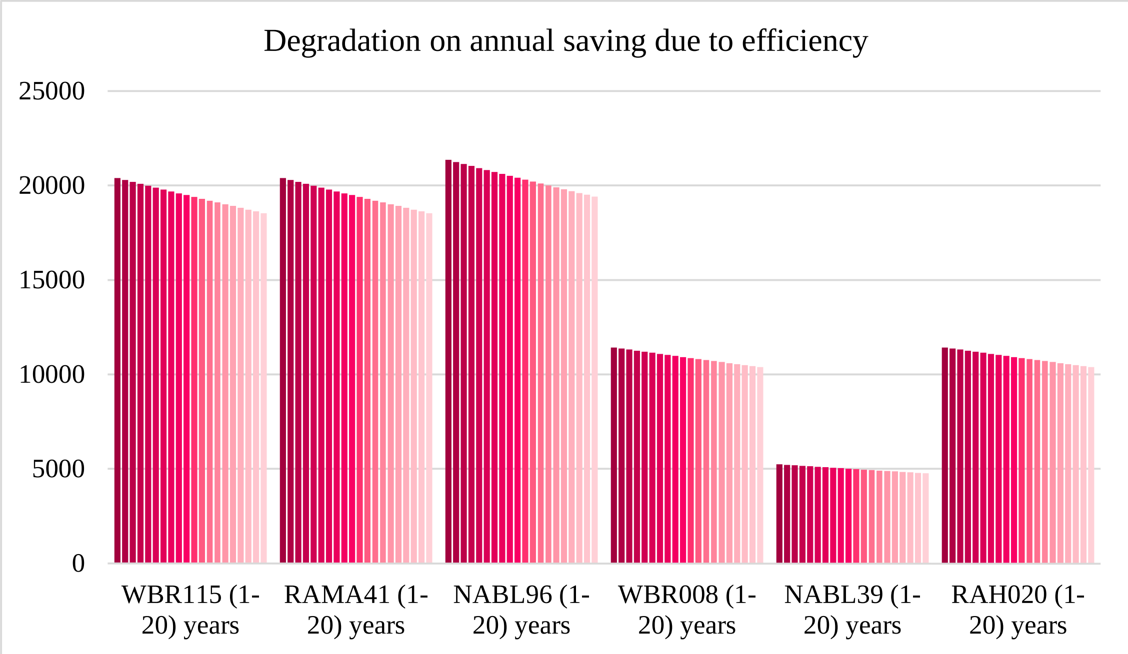

Figure 5.6: Degradation on annual saving for all radio sites

5.4Cash Flow Analysis for PV Systems

Cash flow is the net amount of cash and cash-equivalents moving into and out of a business. Positive cash flow indicates that a company's liquid assets are increasing, enabling it to settle debts, reinvest in its business, return money to shareholders, pay expenses and provide a buffer against future financial challenges. Negative cash flow indicates that a company's liquid assets are decreasing. Net cash flow is distinguished from net income, which includes accounts receivable and other items for which payment has not actually been received. Cash flow is used to assess the quality of a company's income, that is, how liquid it is, which can indicate whether the company is positioned to remain solvent [41].

In this section, all the data required for plotting a meaningful cash flow are available, the incomes and the outcomes to the cash flow can be listed in the table blow

Table 5.20: Cash flow incomes and outcomes for the indoor sites

	Cash flow	Al Seila Al Harethya (WBR115)	Ramallah City (RAMA41)	Nablus City (NABL96)
The cash outflow (Total money out)	CAPEX cost	87080.7	87080.7	94659.4
	OPEX cost	2612.4	2612.4	2839.7
	Battery replacement	60542	60542	65057
The cash inflow (Total money in)	Annual saving	Fig	Fig	Fig
	Salvage value	3047.8	3047.8	3313.0

Table 5.21: Cash flow incomes and outcomes for the outdoor sites

		Za'tara (WBR008)	Nablus City (NABL39)	Al Ram area (RAH020)
The cash outflow (Total money out)	CAPEX cost	54349.9	33452.5	54349.9
	OPEX cost	1630.4	1003.5	1630.4
	Battery replacement	38246	23155	38246
The cash inflow (Total money in)	Annual saving	Fig (5.6)	Fig (5.6)	Fig (5.6)
	Salvage value	1902.2	1170.8	1902.2

5.4.1 Cash flow plot for Al Seila Al Harethya (WBR115) radio site

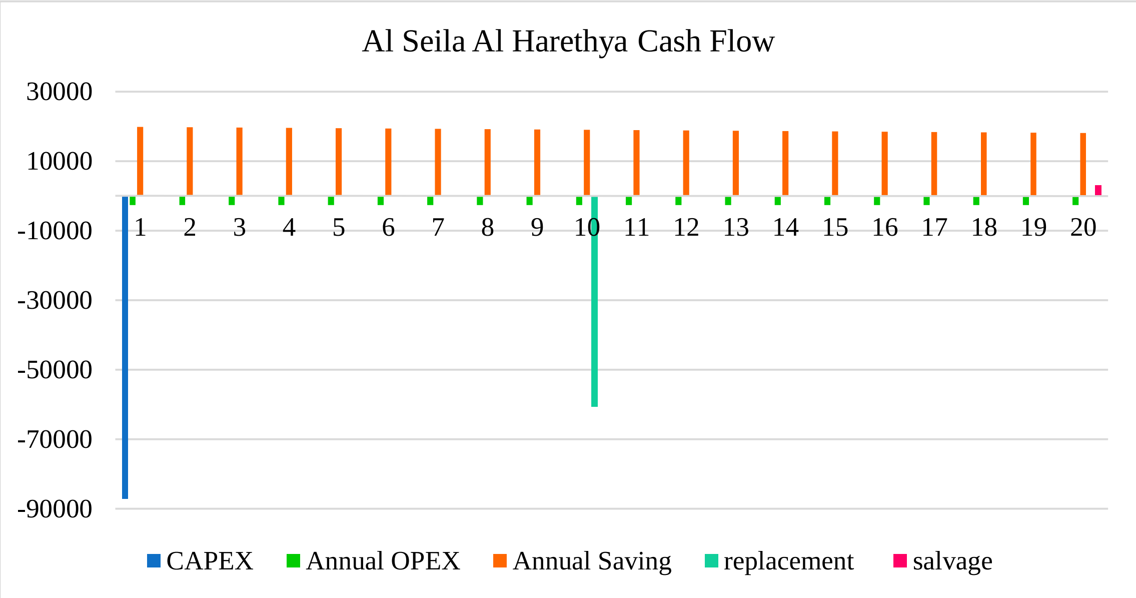

Figure 5.7: Cash flow for WBR115 site

5.4.2 Cash flow plot for Ramallah city (RAMA41) radio site

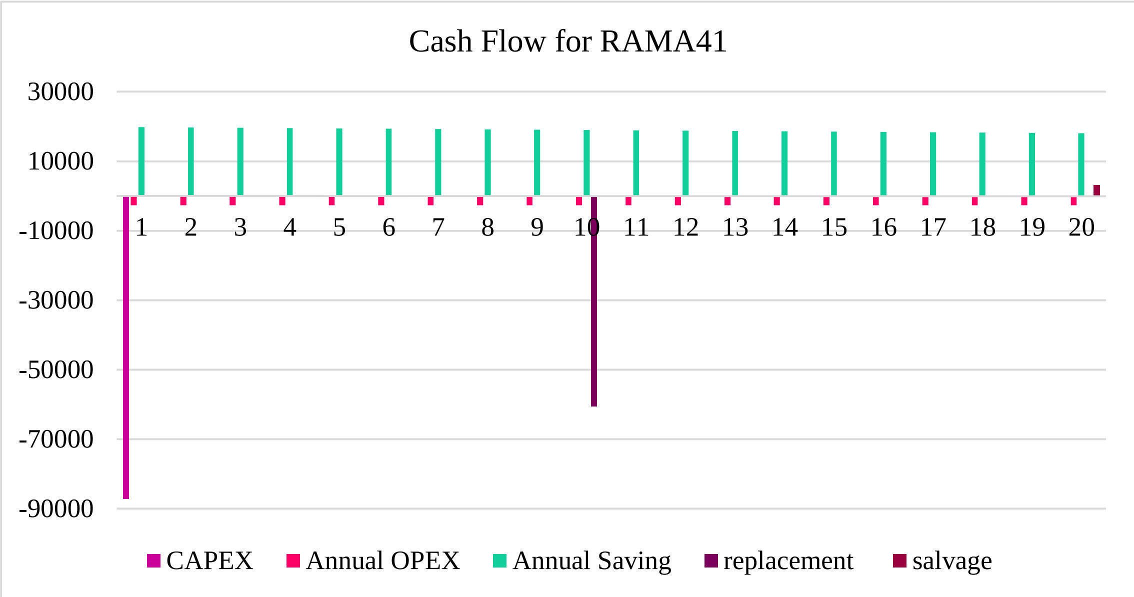

Figure 5.8: Cash flow for RAMA41 site

5.4.3 Cash flow plot for Nablus city (NABL96) radio site

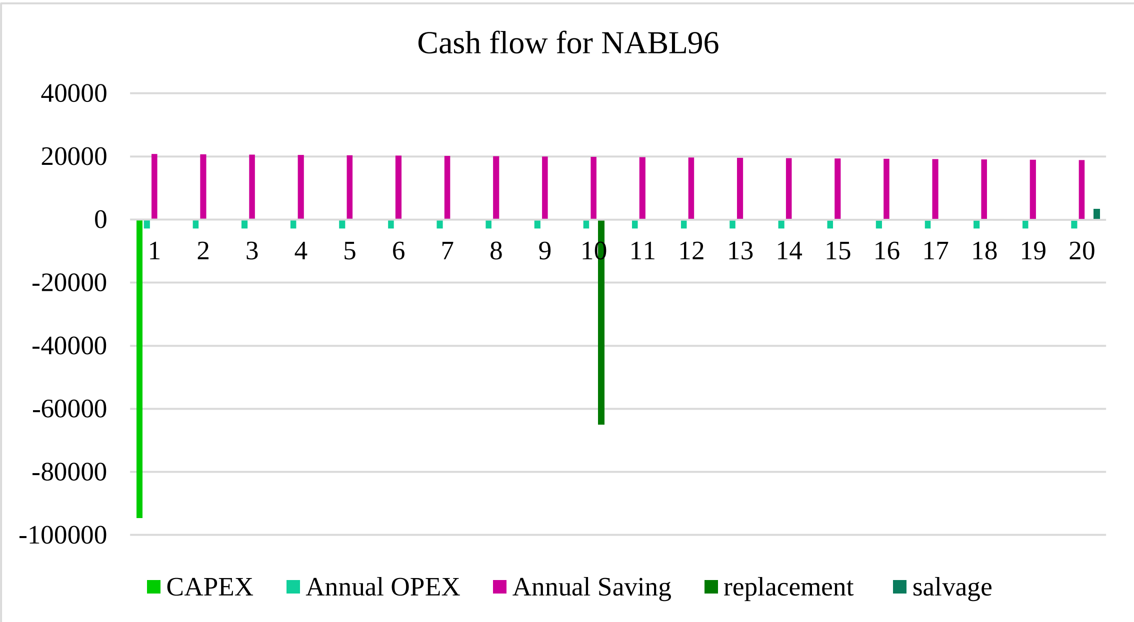

Figure 5.9: Cash flow for NABL96 site

5.4.4 Cash flow plot for Za'tara (WBR008) radio site

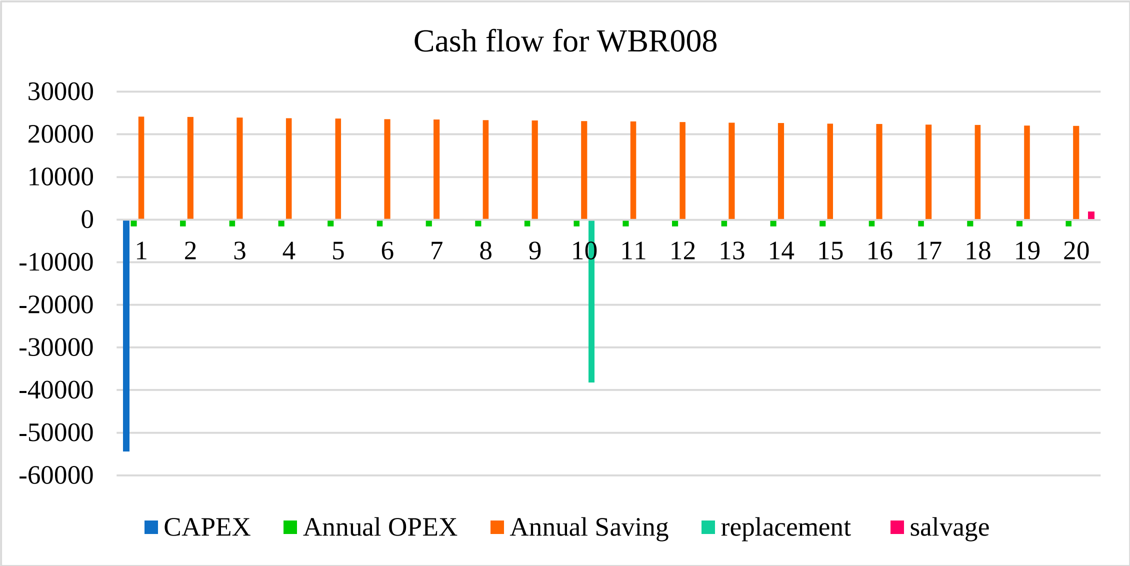

Figure 5.10: Cash flow for WBR008 site

5.4.5 Cash flow plot for Nablus city (NABL39) radio site

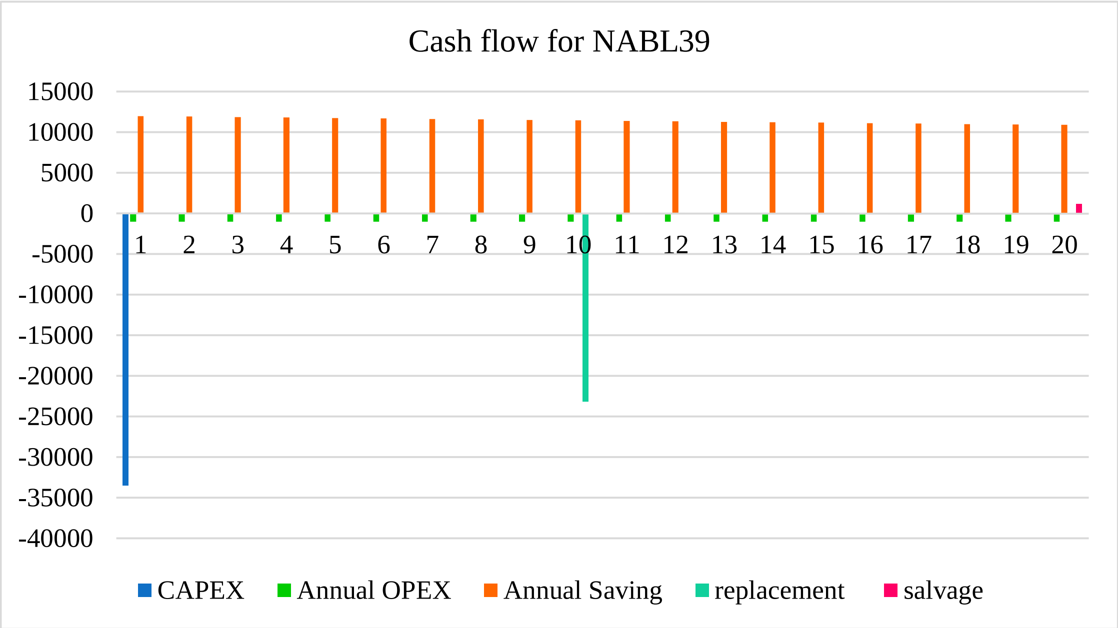

Figure 5.11: Cash flow for NABL39 site

5.4.6 Cash flow plot for Al Ram area site (RAH020)

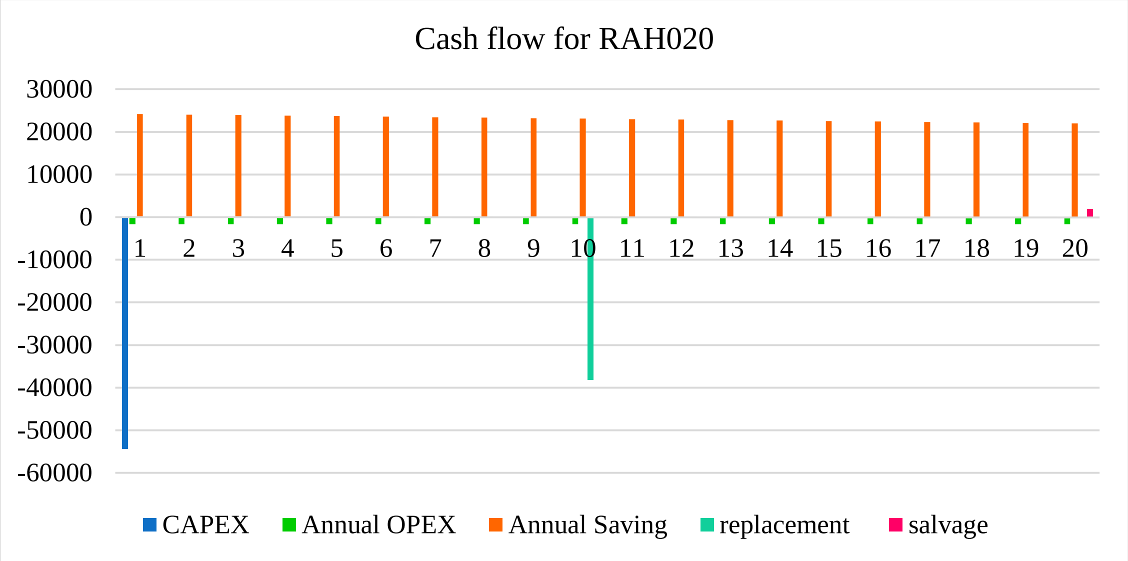

Figure 5.12: Cash flow for RAH020 site

5.5Payback Period of PV Systems

The time it will take to pay back known as payback period, is the single most popular method of project screening. If a company makes investment decisions solely on the basis of the payback period, it considers only those projects with a payback period shorter than the maximum acceptable payback period. However, because of shortcomings of the payback screening method, it is rarely used as the only decision criterion. However it gives a good indication [41].

The conventional payback period given a uniform stream of annual inflow or outflow, is calculated by easily dividing the initial cash investment by the annual cash flow [41] . However in this study and for all radio sites the annual savings are not a fixed value, due to the degradation effect of the PV modules efficiency.

So when the expected cash flows vary from year to year, the payback period must be determined by adding the expected cash flows for each year until the sum is equal to or greater than zero. After applying the cumulative cash flow payback method to all radio sites, the following figure was the result, which illustrated the cumulative cash flow verses the number of years (life of the PV system).

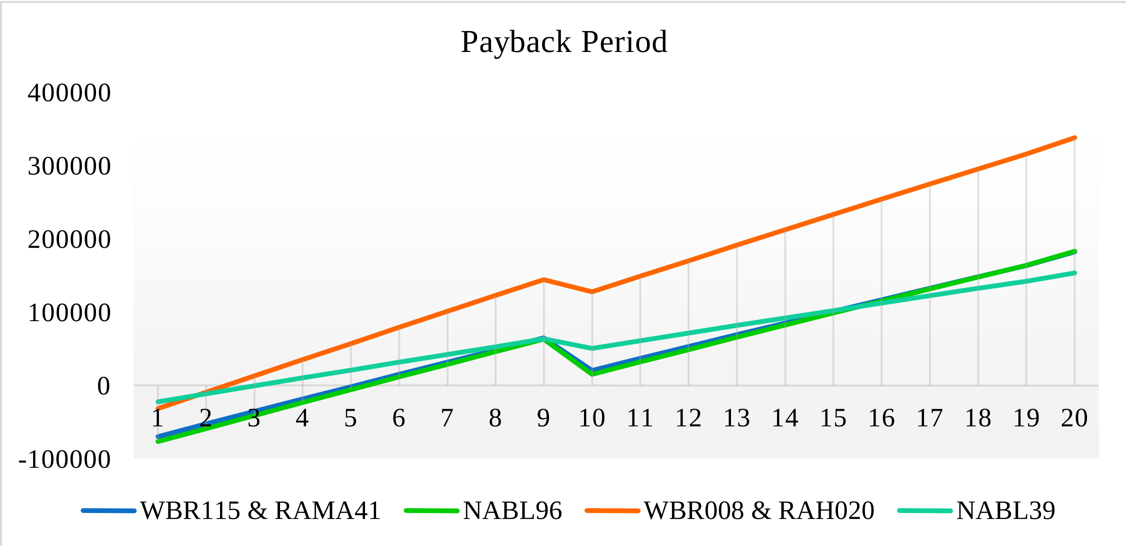

Figure 5.13: Payback period for all radio sites

The necessary time that the system will return its money back, as calculated by the popular payback period method, is shown the following table for all radio sites operated PV systems:

Table 5.22: Payback period for PV systems in each radio site

Site name	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
RBS location	Indoor	Indoor	Indoor	Outdoor	Outdoor	Outdoor
Payback period (years)	7	7	7	3	4	3

As shown by the figure and the table above, the payback period is so attractive for the investment in PV solar systems with maximum of three years to get the initial money back.

5.6Net Present Value (NPV) of PV Systems

Until the 1950s, the payback method was widely used as key for making investment decisions. However, businesspeople began to search for methods to improve project evaluations. The result was the development of discounted cash flow techniques (DCFs) [41], which take into account the time value of money. One of the DCFs is the Net-present-worth (NPW), or what is called the Net-present-value (NPV) method. A capital investment problem is essentially a problem of determining whether the anticipated cash inflows from a proposed project are sufficient to attract investors to invest funds in the project.

Under the NPV or NPW criterion, the present worth of all cash inflows is compared against the present worth of all cash outflows associated with an investment project. The difference between the present worth of these cash flows, referred to as the net present worth (NPW), net present value (NPV) determines whether the project is an acceptable investment. When two or more projects are under consideration, NPW analysis further allows us to select the best project by comparing their NPW figures.

The basic procedure for applying this method can be summarized:

- Determine the interest rate that the company wishes to earn on its investments. This interest rate is often referred to as either a required rate of return or a minimum attractive rate of return (MARR) [41]. Usually, selection of the MARR is a policy decision made by top management. And it's going to be assumed7% in this study.

- Determine the life time of the project.
- Determine the cash inflow over the life time.
- Estimate the cash outflow over the life time.

Calculate the net cash flows each by the subtraction of the two flows as magnitude values.

Project Evaluation

A positive NPV or NPW means that the equivalent worth of the inflows is greater than the equivalent worth of outflows, so the project makes a profit. Therefore, if the PW (i) is positive for a single project, the project should be accepted; if the PW (i) is negative, the project should be rejected the decision rule is [41]:

If NPV (i) > 0, accept the investment

If NPV (i) = 0, remain indifferent

If NPV (i) < 0, reject the investment

When it comes to compare Multiple Alternatives, Compute the NPV (i) for each alternative and select the one with the largest NPV (i).

PV systems NPV procedure

Present worth $PW_{\text{Out flow}} = P_{\text{investment cost}} + A_{\text{annual cost}}\,(P/A,7\%,20) + B_{\text{attery replacement}}\,(P/F,7\%,10)$

Present worth $PW_{\text{In flow}} = F_{\text{Salvage value}}$ (P/F,7%,20) + $F_{\text{year1 saving}}$ (P/F,7%,1) + $F_{\text{year2 saving}}$ (P/F,7%,2) + … + $F_{\text{year 20 saving}}$ (P/F,7%,20)

Where the factors (P/A,7%,20)= 10.594

(P/F,7%,10)= 0.5083

(P/F,7%,20)= 0.2584

The following table explains all the inflow and out flow cashes, plus the net present value for PV systems of all the radio sites in this study:

Table 5.23: NPV table for PV systems of all radio sites

	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
Inflow cash	203679	203679	213153	247459	122824	247459
Outflow cash	145530	145530	157813	91064	55854	91064
The NPV = Inflow cash - Outflow cash						
NPV	58148	58148	55340	156396	66970	156396

- **Remark**

  It was shown clearly that all the PV system of the radio sites have a positive value of NPV which make them a good investment for any company.

CHAPTER SIX

POTENTIAL ENVIRONMENTAL IMPACT OF REPLACING DIESEL GENERATOS BY PV SYSTEMS

6 Potential environmental impact of replacing diesel generatos by PV systems

6.1 Introduction

Every energy generation method may affect the environment in many ways whether it was direct or indirect. And clearly the conventional energy generating sources and technologies are the main criminal in this perspective. The damage can affect the environment physically such as the waste of the natural resources like water , chemically such as air pollution, biological such as the genetic damage from ionizing radiation, ecologically such as the big global problem of climate change, and Aesthetically as well.

Renewable technologies and methods of generating energy are substantially safer offering a solution to many environmental and social problems associated with fossil and nuclear fuels. Solar energy technologies represented by PV systems provide obvious environmental advantages in comparison to the conventional energy sources such as the diesel generation method. Their main advantage is related to the reduced CO2 emissions, yet there are still some environmental impacts associated with the used technologies and methods of generating energy.

Regarding the use of solar PV systems in providing energy for radio sites, instead of using the diesel generation energy method, it’s super important to know the environmental effects and consequences which may occur respectively. Keeping in mind that radio telecommunications companies have a very affective influence in the local and global markets, which enables them to create a whole new vision of adopting the green technologies and the environmental friendly marketing campaigns.

This chapter will discuss the environmental impacts of PV solar systems in comparison with the energy generation using diesel conventional generating method.

6.2Environmental Impacts from Photovoltaic Power Generation

Photovoltaics (PV) are generally categorized of interesting environmental impact, generating no noise or chemical pollutants during their use. Solar energy PV systems are of the most viable renewable energy technologies for use in an urban environment. It is also an attractive option for use in beautiful natural scenery areas and National Parks, where the avoidance of pylons and wires is of high advantage. Yet one should mention other more specified perspectives regarding the environmental impact of using PV systems, as what will be discussed consecutively in this section. The chosen way of reviewing this subject doesn't depend on classifying the impacts into positive and negative, or advantages and disadvantages, since each impact may reflect both positivity and negativity based on the way it's been treated.

6.2.1 Land use

The impact of land use on natural ecosystems is highly dependent on specific factors such as the topography, type, and features of land covered by the PV system, in addition to how far they are from areas of natural beauty or sensitive ecosystems and biodiversity. The land use effect is most likely to occur during construction stage by construction activities, such as earth movements and by transport movements. Furthermore, an application of a PV system in once-cultivable land is possible to damage soil productive areas. Plus the social disagreements and displeasure "sentimental bind" which may occur due to PV farms constructions [42].

6.2.2 Accidental discharges of pollutants

PV systems tends to emit no gaseous or liquid pollutants nor radioactive substances during their normal operation. "In the case of Contact image sensor (CIS) and Cadmium Telluride (CdTe) thin film modules, which include small quantities of toxic substances, there is a potential slight risk that a fire in an array might cause small amounts of these chemicals to be released into the environment [43]". In large scale PV plants, a release of these hazardous materials might occur as a result of abnormal plant operations which may pose a small risk to public and occupational health. Thus, emergency preparations and readiness must be on alert to take the right response in case of an accidental fire or exposure to heat. Moreover emissions to soil and groundwater may occur inadequate storage of materials [44].

6.2.3 Visual effects

Visual violation is mainly dependent on the type of the scheme and the surroundings of the PV systems. It is obvious that, if we apply a PV system near an area of natural beauty, the visual impact would be significantly high. While integrating modules into the facade of buildings, may be positive aesthetic impact on modern buildings in comparison to historic buildings or buildings with cultural value.

Integrated PV electrification schemes, which help to regenerate rural areas and user associations have successfully overcome the problems of managing and maintaining remote schemes by establishing mechanisms for collecting user payments, arranging regular maintenance, obtaining finance and providing advice on energy efficient appliances [45]. This explains the double impact effect, every environmental impact might be treated in a way of good benefit.

6.2.4 Depletion of natural resources

"The production of current generation PV's is rather energy intensive (especially the poly crystalline and the mono crystalline modules) and large quantities of bulk materials are needed. Also, also limited quantities of the toxic Cd. In general the Cd emissions attributed to CdTe production amount to 0.001% of Cd used (corresponding to 0.01 g/GWh). Furthermore Cd is produced as a byproduct of Zn production and can either be put to beneficial uses or discharged into the environment [46]".

6.2.5 Air pollution

Concerning the life cycle assessment, the environmental performance of the system depends heavily on the energy efficiency of the system manufacturing and especially electricity production. "The emissions associated with transport of the modules are insignificant in comparison with those associated with manufacture". Transport emissions were still only (0.1– 1)% of manufacturing related emissions. In the case of poly and mono crystalline modules, the estimated emissions are [47]:

- 2.757–3.845 kg CO_2/kWp
- 5.049– 5.524 kg SO_2/kWp
- 4.507–5.273 kg NO_x/kWp

In urban environment, up to date PV systems, which are architecturally incorporated into buildings, are capable of providing a direct supply of clean electricity that is well matched to the demand of the building, and also contribute to day lighting, and the control of shading and ventilation. Also, PV panels can be used instead of mirrors directly into the facade of a building. PV systems also help to create a supportive environment within which to encourage other means of energy saving by the building promoters, owners and users. PV energy services are particularly obvious where only low levels of power are needed, such as in remote electrification applications, and where the users might benefit directly from the very high reliability of having their own PV generator.

6.2.6 Noise intrusion

As with all types of construction activity obviously, there will be certain level of noise. Manufacturers had to be encouraged to produce systems that cause lower noise levels and that are easily recyclable. On the other hand, the availability of a considerable chance of employment opportunities during the construction phase especially for large scale systems during the operational phase is of great benefit.

6.2.7 Waste management

In the case of standalone systems [48], the effects on health of chemical substances included in the batteries must be studied. A life cycle analysis of batteries for standalone PV systems indicates that the batteries are responsible for most of the environmental impacts, due to their relatively short life span and their heavy metal content. In addition to the large amount of energy and raw materials which is required for their production [49].

6.3 Diesel Generation Carbon Dioxide Emissions environmental impact

One of the main greenhouse gases, carbon dioxide, CO2, is a colorless, odorless gas that is naturally emitted from the earth's surface, as well as through the human function, respiration, and the plant function, photosynthesis. Carbon dioxide is released during exhalation and is used by plants as a necessary component for photosynthesis, which yields glucose, a carbohydrate that must be consumed by humans in order to have energy.

Carbon dioxide is also emitted through the combustion or burning of fossil fuels such as coal, oil, and natural gas. Combustion occurs when vehicles are driven as well as when power plants and industrial plants are utilized, which is known as burning and is considered the greatest source of carbon dioxide emissions globally.

Typically, fossil fuels are burnt for electricity generation in homes and buildings, industrial uses, as well as transportation. Petroleum such as gasoline and diesel are the largest share of domestic energy demands. Second is coal, followed by natural gas (EPA, 2006 emission standards).

In addition to the carbon dioxide emissions that result from industrial processes, deforestation is a serious environmental threat in terms of carbon dioxide emissions. Carbon is naturally removed from the atmosphere to be stored in oceans and the soil surrounding the roots of many plants. Areas where carbon is stored are otherwise known as carbon “sinks.” Forested areas are large carbon sinks because enormous amounts of carbon dioxide are naturally stored in the soil, a result of photosynthesis. That’s why logging is not encouraged since when a large group of trees is removed at once, either deliberately by logging or accidently in a forest fire, it is titled as deforestation. When this occurs, carbon dioxide is released from the soil at rates that are damaging to the environment because there are no longer any trees to contain the carbon dioxide.

6.3.1 CO_2 Emissions from radio sites powered by diesel generators

In order to measure the carbon dioxide emissions from the use of Diesel in generation energy for the radio sites in this study, the carbon content must be considered with the calorific value of the carbon, the amount of energy produced from it and the chemical process and properties of the carbon combustion.

Working on the same assumption of this study, considering all indoor sites have the same diesel consumption of the remote site Al Seila Al Harethya (WBR115), and all the outdoor sites consume the same consumption as the remote site Za'tara (WBR008).

Table 6.1: Diesel consumption annually for all radio sites in litter

Site name	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
RBS location	Indoor	Indoor	Indoor	Outdoor	Outdoor	Outdoor
Diesel consumption annually L	22776	22776	22776	11388	11388	11388

Given the following data about Diesel [50]:

Diesel Equivalent Weight (density) = 0.832 kg/L

Diesel Calorific Value = 42.8 MJ/kg = 11.7kWh/kg = 10.184 kWh/liter

Amount of diesel in kg = volume * density

Equation 6.1

Table 6.2: Annual amount of diesel in kg per radio site

Site name	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
RBS location	Indoor	Indoor	Indoor	Outdoor	Outdoor	Outdoor
Diesel consumption annually L	22776	22776	22776	11388	11388	11388
Amount of diesel in kg	18949.6	18949.6	18949.6	9474.8	9474.8	9474.8

The equation of combustion of Diesel is [50].

$$4C_{12}H_{23} + 71O_2 \rightarrow 48\ CO_2 + 46H_2O$$

Equation 6.2

From the previous equation we can calculate the carbon content in the Diesel as:

C: 12 kg/kmol

H: 1 kg/kmol

$C_{12}H_{23}$ = 12*12 + 23*1 = 167 kg of diesel

Carbon content in diesel = C (kg)/ Diesel (kg)
Equation 6.3

Carbon content in diesel = 144/167 = 0.8623 = 86.23%

The carbon dioxide emitted from combustion of Diesel is [50]:

4kmole of $C_{12}H_{23}$ → 48 kmol CO_2

4*167 of $C_{12}H_{23}$ = 668kg of Diesel

48 kmol CO_2 = 48*(12 + 32) = 2112 kg of CO_2
Equation 6.4

668 kg of Diesel = 2112 kg of CO_2 emission

Therefore,

1 kg of diesel emits 3.16 kg of CO_2

1 kilogram of diesel = 1.202 liters → 1 liter of Diesel emits 2.63 kg CO_2

And amount of emitted CO_2 = (amount of diesel in kg*2112) / 668
Equation 6.5

Table 6.3: Annual amount of CO_2 emissions per radio site

Site name	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
RBS location	Indoor	Indoor	Indoor	Outdoor	Outdoor	Outdoor
Diesel consumption annually L	22776.00	22776.00	22776.00	11388.00	11388.00	11388.00
Amount of diesel in kg	18949.63	18949.63	18949.63	9474.82	9474.82	9474.82
Amount of emitted CO2 in kg	44338.73	44338.73	44338.73	22169.37	22169.37	22169.37

6.3.2 Reduced CO_2 Emissions from radio sites powered by PV systems

Replacing the diesel generators with PV systems will logically contribute in reducing the amounts of CO_2 [8]. To calculate the annual reduction in CO_2 emission for each site after using PV solar system, we the flowing equation is required

CO_2 emissions reduction = $E_{PV\ yearly}$ kWh * Emissions $_{CO2}$ kg/kWh

Equation 6.6

Emissions of CO_2 kg/kWh = Amount $_{CO2}$ kg / Energy $_{consumption}$ kWh

Equation 6.7

Table 6.4: Amount of CO_2 in kg per kWh for all radio sites

Site name	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
RBS location	Indoor	Indoor	Indoor	Outdoor	Outdoor	Outdoor
Amount of emitted CO2 in kg	44338.73	44338.73	44338.73	22169.37	22169.37	22169.37
Yearly energy consumption kWh/year	28324	28324	30076	18432.5	9709	18432.5
CO2 kg/kWh	1.57	1.57	1.47	1.20	2.28	1.20

So, the following table shows the final numbers of the reduction in CO_2 emissions caused by the use of PV systems instead of diesel generators.

Table 6.5: Reduced CO_2 emissions for all radio sites

Site name	WBR115	RAMA41	NABL96	WBR008	NABL39	RAH020
RBS location	Indoor	Indoor	Indoor	Outdoor	Outdoor	Outdoor
Energy PV output (KWh)	30405	30405	34160	19900	10479	19900
Reduced CO_2 emission kg	47596.36	47596.36	50359.46	23934.38	23927.57	23934.38

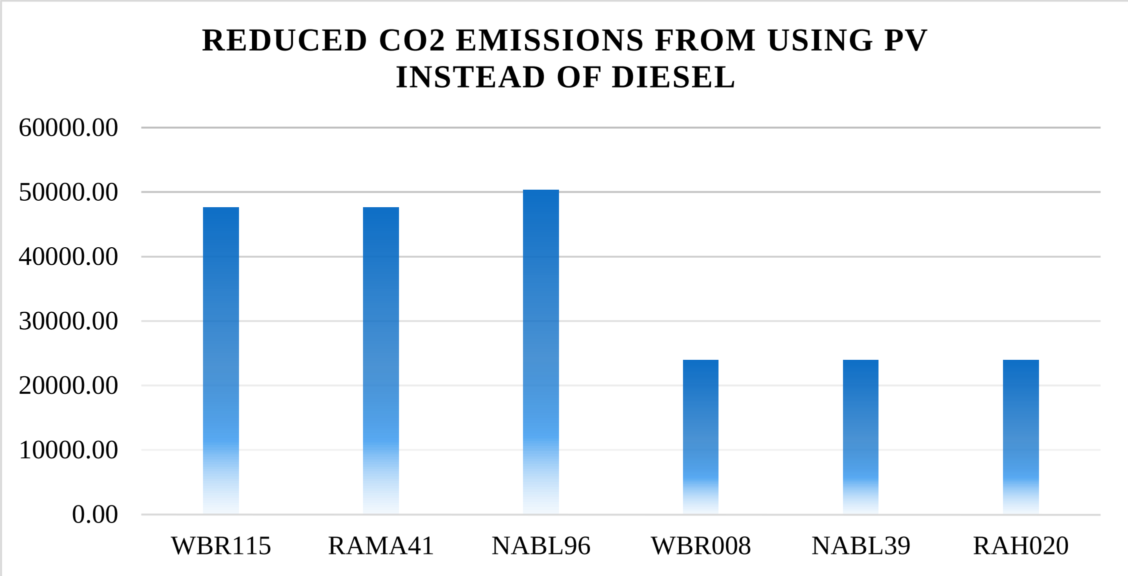

Figure 6.1: Reduced CO_2 emissions from using PV instead of diesel

Remark

Note the very high amount of CO_2 emissions generated from each radio site yearly due to use of diesel generators. Which will contribute in all the negative impacts on the environment. While the benefit of using solar energy PV systems which save the environment from that huge amount of CO_2 emissions.

CHAPTER SEVEN

CONCLUSIONS & RECOMMENDATIONS

7 Conclusions & recommendations

7.1 Conclusions

The PV power system is technically reliable, economically feasible, and environmentally viable solution, for providing electrical power requirements of in radio communication systems in remote sites, when compared with the diesel generator power system. An optimum PV system design is achieved by sitting the related necessary storage battery block with an autonomy of two days.

The unit energy cost represented in USD per kWh generated from PV system is remarkably less than the cost of kWh produced by diesel generators utilized currently in providing power to remote communication systems. The average cost of energy supplied to indoor and outdoor radio sites amounts to 0.49 USD/kWh for PV system, while it amounts to 1.14 /kWh for diesel generator.

PV systems can be successfully used to provide all radio base stations (RBS) types in remote sites, as separately analyzed and illustrated in this study. The technical PV system design differs between indoor and outdoor radio base stations. The main difference is the size of the system which is considered large for indoor sites and moderate for outdoor sites. The size of the system affects the selection of its place. Otherwise the economic and environmental analysis, results, and effects were common between all RBS types.

The use of PV system is not economically feasible for the grid connected radio communication sites. The cost of energy unit obtained by the utility grid is 0.165 USD/ kWh which is less than the average PV energy cost amounting to 0.49 USD/kWh.

The use of PV system to power radio communication stations in remote sites instead of diesel is contributing in the reduction of CO_2 emissions, since diesel generation is one of the main sources of CO_2 emissions globally, each 1 kg of diesel emits 2.34 kg of CO_2. Therefore the use of PV system save the environment from all the CO_2 emissions that would result from using diesel generation.

Using solar energy represented by PV systems strengthens the energy independency of the energy sector as well as the Palestinian economy in general, which is forced to be fully dependent on the Israeli energy sources. Moreover, the use of PV solar systems empowers Sustainability and development strategies in the country.

7.2Recommendations and perspectives

It's highly recommended to apply the discussed PV systems as illustrated since they represent the optimum design for such cases. Every single component was carefully selected to fit with the whole system, providing that the proposed PV system designs cover the radio sites energy needs for 2 autonomy days.

From my perspective, I recommend using outdoor RBS types for remote sites if it meets the required radio mobile communication conditions. The use of outdoor located RBS is preferred if the load demands of the RBS allow that.

Shutting down the diesel generators powering radio remote sites is recommended, since as proved it’s neither the smartest choice economically nor environmentally.

Periodic cleaning and checking for the PV modules is always necessary. Avoiding the partial or total shadowing of the PV modules especially during the daily peak sun hours should be seriously considered during the installation phase, in order to secure for continues proper operation of the PV power system.

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APPENDICES

Appendix A: Datasheets

Appendix B: Table of interest at i = 7%

Appendix A-1: Xtender Series Inverters, XTH 6000-48

Xtender series



Model	XTS 900-12	XTS 1200-24	XTS 1400-48	XTM 1500-12	XTM 2000-12	XTM 2400-24	XTM 2600-48	XTM 3500-24	XTM 4000-48	XTH 3000-12	XTH 5000-24	XTH 6000-48	XTH 8000-48
Inverter													
Nominal battery voltage	12V	24V	48V	12V		24V	48V	24V	48V	12V	24V	48V	
Input voltage range	9.5 - 17V	19 - 34V	38 - 68V	9.5 - 17V		19 - 34V	38 - 68V	19 - 34V	38 - 68V	9.5 - 17V	19 - 34V	38 - 68V	
Continuous power @ 25°C	650**/500VA	800**/650VA	900**/750VA	1500VA	2000VA	2000VA	2000VA	3000VA	3500VA	2500VA	4500VA	5000VA	7000VA
Power 30 min. @ 25°C	900**/700VA	1200**/1000VA	1400**/1200VA	1500VA	2000VA	2400VA	2600VA	3500VA	4000VA	3000VA	5000VA	6000VA	8000VA
Power 5 sec. @ 25°C	2.3kVA	2.5kVA	2.8kVA	3.4kVA	4.8kVA	6kVA	6.5kVA	9kVA	10.5kVA	7.5kVA	12kVA	15kVA	21kVA
Maximum load	Up to short-circuit												
Maximum asymmetric load	Up to Pcont.												
* Load detection (stand-by)	2 to 25 W												
Cos φ	0.1-1												
Maximum efficiency	93%	93%	93%	93%		94%	96%	94%	96%	93%	94%	96%	
Consumption OFF/Stand-by/ON	1.1W/1.4W/7W	1.2W/1.5W/8W	1.3W/1.6W/8W	1.2W/1.4W/8W	1.2W/1.4W/10W	1.4W/1.6W/9W	1.8W/2W/10W	1.4W/1.6W/12W	1.8W/2.1W/14W	1.2W/1.4W/14W	1.4W/1.8W/18W	1.8W/2.2W/22W	1.8W/2.4W/30W
* Output voltage	Pure sine wave 230Vac (+/- 2%) / 120Vac (1)												
* Output frequency	50Hz / 60Hz (1) +/- 0.05% (crystal controlled)												
Harmonic distortion	<2%												
Overload and short-circuit protection	Automatic disconnection with 3 time restart attempt												
Overheat protection	Warning before shut-off - with automatic restart												
Battery charger													
* Charge Characteristic	6 steps : Bulk-Absorption-Floating-Equalization-reduced floating-periodic absorption Number of steps, thresholds, end current and times completely adjustable with the RCC-02/-03												
* Maximum charging current	35A	25A	12A	70A	100A	55A	30A	90A	50A	160A	140A	100A	120A
* Temperature compensation	With BTS-01 or BSP 500/1200												
Power Factor Correction (PFC)	EN 61000-3-2												
General data	XTS 900-12	XTS 1200-24	XTS 1400-48	XTM 1500-12	XTM 2000-12	XTM 2400-24	XTM 2600-48	XTM 3500-24	XTM 4000-48	XTH 3000-12	XTH 5000-24	XTH 6000-48	XTH 8000-48
* Input voltage range	150 to 265Vac / 50 to 140Vac (1)												
Input frequency	45 to 65Hz												
Input current max. (transfer relay) / Output current max.	16A/20A			50A/56A									50A/80A
Transfer time	<15ms												
Multifunction contacts	Module ARM-02 with 2 contacts, in option			2 independent contacts (potential free 3 points, 16Aac/5Adc)									
Weight	8.2 kg	9 kg	9.3 kg	15 kg	18.5 kg	16.2 kg		21.2 kg	22.9 kg	34 kg	40 kg	42 kg	46 kg
Dimension hxwxl [mm]	110x210x310			133x322x466						230x300x500			
Protection index	IP54			IP20						IP20			
Conformity	Directive EMC 2004/108/EC : EN 61000-6-1, EN 61000-6-3, EN 55014, EN 55022, EN 61000-3-2, 62040-2 Low voltage directive 2006/95/EC : EN 62040-1-1, EN 50091-2, EN 60950-1												
Operating temperature range	-20 à 55°C												
Relative humidity in operation	100%			95% without condensation						95% without condensation			
Ventilation	Optional cooling module ECF-01			Forced from 55°C						Forced from 55°C			
Acoustic level	<40dB / <45dB (without/with ventilation)												
Warranty	5 years												
Accessoires													
Remote control RCC-02 or RCC-03	•	•	•	•	•	•	•	•	•	•	•	•	•
Module XCOM-232i	•	•	•	•	•	•	•	•	•	•	•	•	•
Bridge XCOM-MS	•	•	•	•	•	•	•	•	•	•	•	•	•
Remote Control Module RCM-10 (3 m)	•	•	•	•	•	•	•	•	•				
2 aux. contacts module ARM-02	•	•	•										
Cooling Module ECF-01	•	•	•										
Battery temp. sensor BTS-01 (3 m)	•	•	•	•	•	•	•	•	•	•	•	•	•
Communication cable for 3ph and // CAB-RJ45-8-2	•	•	•	•	•	•	•	•	•	•	•	•	•
Mounting frame X-Connect										•	•	•	•

* Adjustable with the RCC-02/-03

** These features are valid only when using the cooling module ECF-01.

(1) With -01 at the end of the reference, means 120V/60Hz. Available for all Xtenders except XTH 8000-48

Data may change without any notice.

Appendix A-2: Charge controller MPPT 150/70

BlueSolar charge controller MPPT 150/70

www.victronenergy.com

Solar charge controller
MPPT 150/70

Charge current up to 70 A and PV voltage up to 150 V
The BlueSolar 150/70-MPPT charge controller is able to charge a lower nominal-voltage battery from a higher nominal voltage PV array.
The controller will automatically adjust to a 12, 24, 36, or 48 V nominal battery voltage.

Ultra fast Maximum Power Point Tracking (MPPT)
Especially in case of a clouded sky, when light intensity is changing continuously, an ultra fast MPPT controller will improve energy harvest by up to 30% compared to PWM charge controllers and by up to 10% compared to slower MPPT controllers.

Advanced Maximum Power Point Detection in case of partial shading conditions
If partial shading occurs, two or more maximum power points may be present on the power-voltage curve.
Conventional MPPT's tend to lock to a local MPP, which may not be the optimum MPP.
The innovative BlueSolar algorithm will always maximize energy harvest by locking to the optimum MPP.

Outstanding conversion efficiency
No cooling fan. Maximum efficiency exceeds 98%. Full output current up to 40°C (104°F).

Flexible charge algorithm
Several preprogrammed algorithms. One programmable algorithm.
Manual or automatic equalisation.
Battery temperature sensor. Battery voltage sense option.

Programmable auxiliary relay
For alarm or generator start purposes

Extensive electronic protection
Over-temperature protection and power derating when temperature is high.
PV short circuit and PV reverse polarity protection.

BlueSolar charge controller	MPPT 150/70
Nominal battery voltage	12 / 24 / 36 / 48V Auto Select
Rated charge current	70A @ 40°C (104°F)
Maximum solar array input power	12V: 1000W / 24V: 2000W / 36V: 3000W / 48V: 4000W
Maximum PV open circuit voltage	150V
Minimum PV voltage	Battery voltage plus 7 Volt to start Battery voltage plus 2 Volt operating
Standby power consumption	12V: 0,55W / 24V: 0,75W / 36V: 0,90W / 48V: 1,00W
Efficiency at full load	12V: 95% / 24V: 96,5% / 36V: 97% / 48V: 97,5%
Absorption charge	14.4 / 28.8 / 43.2 / 57.6V
Float charge	13.7 / 27.4 / 41.1 / 54.8V
Equalization charge	15.0 / 30.0 / 45 / 60V
Remote battery temperature sensor	Yes
Default temperature compensation setting	-2,7mV/°C per 2V battery cell
Programmable relay	DPST AC rating: 240VAC/4A DC rating: 4A up to 35VDC, 1A up to 60VDC
CAN bus communication port	Two RJ45 connectors, NMEA2000 protocol
Operating temperature	-40°C to 60°C with output current derating above 40°C
Cooling	Natural Convection
Humidity (non condensing)	Max. 95%
Terminal size	35mm² / AWG2
Material & color	Aluminium, blue RAL 5012
Protection class	IP20
Weight	4,2 kg
Dimensions (h x w x d)	350 x 160 x 135 mm
Mounting	Vertical wall mount Indoor only
Safety	EN60335-1
EMC	EN61000-6-1, EN61000-6-3

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Appendix A-3: SCHOTT MONO 180

EN

Crystalline module with MONO cells

SCHOTT MONO® 180/185/190

SCHOTT MONO®
180/185/190

At a glance

- Monocrystalline high efficiency cells >17.6 %
- High annual energy yield
- Positive power tolerance
- Elegant design
- Thorough SCHOTT quality control with German engineering

The long-established German company SCHOTT Solar operates worldwide and started with the development and manufacturing of components for the solar industry in 1958.
SCHOTT Solar crystalline modules are specifically designed for both roof- and ground-mounted applications. Due to strict internal quality standards, all modules benefit from exceptionally long durability, which results in maximised profitability. The crystalline cells within each module are sorted to particularly narrow performance tolerances, thereby allowing series interconnections with minimal mismatch losses.

Monocrystalline high efficiency cells >17.6 %: The exceptional high cell efficiency indicates a high module power. Module efficiencies of up to 14.5 % will be generated.

High annual energy yield: The particular high module efficiencies deliver optimum yields for small areas. More power per module ensures high return on investment.

Positive power tolerance: The SCHOTT Solar modules hold a positive power tolerance of the nominal rating. This implies a high energy output and stable investment for the coming years.

Elegant design: The dark mono cells in relation with the black Aluminum frame look esthetically with excellent efficiency. The solid module frame secures superior torsional resistance. Therefore the elegant design reassures also a high degree of security for your investment.

Thorough SCHOTT quality control with German engineering: Stringent SCHOTT Solar quality standards mean internal tests twice as long as is required by the IEC. In connection with long-term performance guarantee German engineering offers long-term reliability for the owner of a SCHOTT Solar module.

SCHOTT
solar

Appendix A-3: SCHOTT MONO 180

Technical Data

Data at standard test conditions (STC)

Module type		SCHOTT MONO® 180	SCHOTT MONO® 185	SCHOTT MONO® 190
Nominal power [Wp]	P_{mpp}	≥ 180	≥ 185	≥ 190
Voltage at nominal power [V]	U_{mpp}	36.2	36.3	36.4
Current at nominal power [A]	I_{mpp}	4.97	5.10	5.22
Open-circuit voltage [V]	U_{oc}	44.8	45.0	45.2
Short-circuit current [A]	I_{sc}	5.40	5.43	5.46
Module efficiency (%)	η	13.7	14.1	14.5

STC (1000W/m²; AM 1.5; cell temperature 25°C)
Power tolerance (as measured by flasher): -0 W / +4.99 W

Data at normal operating cell temperature (NOCT)

Nominal power [Wp]	P_{mpp}	130	134	137
Voltage at nominal power [V]	U_{mpp}	32.9	32.8	32.9
Open-circuit voltage [V]	U_{oc}	39.3	40.2	41.0
Short-circuit current [A]	I_{sc}	4.30	4.32	4.35
Temperature [°C]	T_{NOCT}	46.0	46.0	46.0

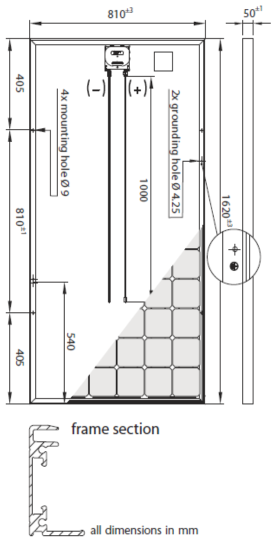
NOCT (800 W/m², AM 1.5, windspeed 1 m/s, ambient temperature 20°C)

Data at low irradiation

At a low irradiation intensity of 200 W/m² (AM 1.5 and cell temperature 25°C) 96 % of the STC module efficiency (1000 W/m²) will be achieved.

Temperature coefficients

Power [%/K]	P_{mpp}	-0.44
Open-circuit voltage [%/K]	U_{oc}	-0.33
Short-circuit current [%/K]	I_{sc}	+0.03



Characteristic data

Solar cells per module	72
Cell type	monocrystalline (pseudo-square, 125 mm x 125 mm)
Junction box	IP65 with three bypass diodes
Connector	Tyco-Connector IP67
Dimensions junction box [mm]	110 x 115 x 25
Front panel	low iron solar glass 3.2 mm
Backside panel	foil
Frame material	anodised aluminium, black

Dimensions and weight

Dimensions [mm]	1,620 x 810
Thickness [mm]	50
Weight [kg]	15.5

Limits

Maximum system voltage [V_{DC}]	1000
Maximum reverse current I_R [A]*	17
Operating module temperature [°C]	-40 … +85
Maximum load (to IEC 61215 ed. 2)	pressure: 5,400 N/m² or 550 kg/m² suction: 5,400 N/m² or 550 kg/m²
Application classification (to IEC 61730)	A
Fire classification (to IEC 61730)	C

** No external voltage in excess of U_{OC} shall be applied to the module.*

Permission and certificates

The modules are certified to IEC 61215 ed. 2 and IEC 61730, Electrical Protection Class II and the CE-guidelines. Moreover SCHOTT Solar is certified and registered to ISO 9001 and ISO 14001.

The **installation manual** contains additional information on installation and operation.
Power measurement accuracy: ± 4 %
All information complies with the requirements of the standard EN 50380.

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SCHOTT solar

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Appendix A-4: C60H-DC Circuit breaker

DC circuit supplementary protectors for feeders / distribution systems

C60H-DC

C curve

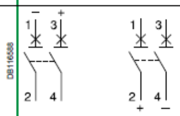
Country approval pictograms

CE

IEC/EN 60947-2, GB 14048.2, UL1077 (Supplementary Protector TC 3)

The C60H-DC supplementary protectors are used in direct current circuits (Industrial control and automations, transport, renewable energy...).
They combine the following functions of circuit protection against short-circuit and overload currents, control and isolation.

Catalogue numbers

C60H-DC				
Operating voltage (Ue)	12...250 V DC		12...500 V DC	
Rated voltage (Un)	250 V DC		500 V DC	
Number of poles	1P		2P	
Curve	C		C	
Number of modules of 9 mm	2		4	
Diagrams	 Supply from above or below, observing the polarity		 Supply from above *or* Supply from below	
Standards	UL1077	IEC 60947-2 EN 60947-2 GB 14048.2	UL1077	IEC 60947-2 EN 60947-2 GB 14048.2
Breaking capacity	5 kA / 250 V DC	20 kA / 110 V DC 10 kA / 220 V DC 6 kA / 250 V DC	5 kA / 500 V DC	20 kA / 220 V DC 10 kA / 440 V DC 6 kA / 500 V DC
Rating (A)*	**UL 1077, IEC 60947-2, EN 60947-2, GB 14048.2**			
0.5	MGN61500		MGN61520	
1	MGN61501		MGN61521	
2	MGN61502		MGN61522	
3	MGN61503		MGN61523	
4	MGN61504		MGN61524	
5	MGN61505		MGN61525	
6	MGN61506		MGN61526	
10	MGN61508		MGN61528	
13	MGN61509		MGN61529	
15	MGN61510		MGN61530	
16	MGN61511		MGN61531	
20	MGN61512		MGN61532	
25	MGN61513		MGN61533	
30	MGN61514		MGN61534	
32	MGN61515		MGN61535	
40	MGN61517		MGN61537	
Rating (A)*	**IEC 60947-2, EN 60947-2, GB 14048.2**			
50	MGN61518		MGN61538	
63	MGN61519		MGN61539	

** At 25°C / 77°F see temperature derating module 92515.*

Appendix A-5: OPzS Vented lead-acid battery

OPzS

Vented lead-acid battery

Motive Power Systems
Reserve Power Systems
Special Power Systems
Service

Your benefits with HOPPECKE OPzS

- **Very high expected service life** - due to optimized low-antimony selenium alloy
- **Excellent cycle stability** - due to tubular plate design
- **Maximum compatibility** - design according to DIN 40736-1
- **Higher short-circuit safety even during the installation** - based on HOPPECKE system connectors
- **Extremely extended water refill intervals up to maintenance-free** - optional use of AquaGen® recombination system minimizes emission of gas and aerosols[1]

Typical applications of HOPPECKE OPzS

- **Telecommunications**
  Mobile phone stations
  BTS-stations
  Off-grid/on-grid solutions
- **Power Supply**
- **Security lighting**

HOPPECKE
POWER FROM INNOVATION

Appendix A-5: OPzS Vented lead-acid battery

HOPPECKE
POWER FROM INNOVATION

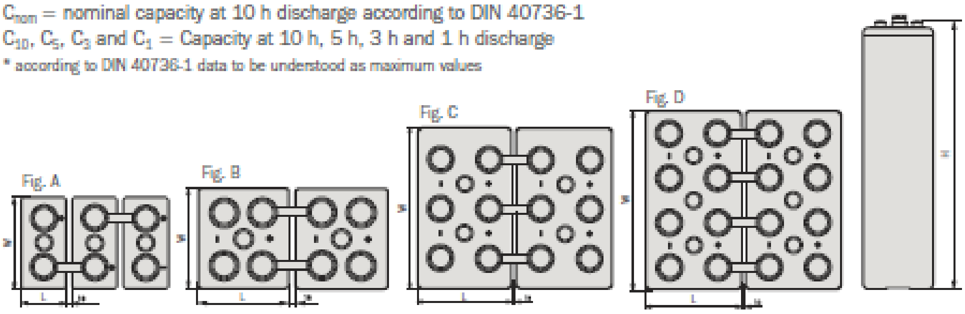
OPzS

Type Overview

Capacities, dimensions and weights

Type	C_{nom}/1.80 V Ah	C_{10}/1.80 V Ah	C_5/1.77 V Ah	C_3/1.75 V Ah	C_1/1.67 V Ah	max.* Weight kg	Weight electrolyte kg (1.24 kg/l)	max.* Length L mm	max.* Width W mm	max.* Height H mm	Fig.
4 OPzS 200	200	213	182	161	118	17.3	4.5	105	208	420	A
5 OPzS 250	250	266	227	201	147	21.0	5.6	126	208	420	A
6 OPzS 300	300	320	273	241	177	24.9	6.7	147	208	420	A
5 OPzS 350	350	390	345	303	217	29.3	8.5	126	208	535	A
6 OPzS 420	420	468	414	363	261	34.4	10.1	147	208	535	A
7 OPzS 490	490	546	483	426	304	39.5	11.7	168	208	535	A
6 OPzS 600	600	686	590	510	353	46.1	13.3	147	208	710	A
7 OPzS 700	700	801	691	596	411	59.1	16.7	215	193	710	B
8 OPzS 800	800	915	790	681	470	63.1	17.3	215	193	710	B
9 OPzS 900	900	1026	887	767	529	72.4	20.5	215	235	710	B
10 OPzS 1000	1000	1140	985	852	588	76.4	21.1	215	235	710	B
11 OPzS 1100	1100	1256	1086	938	647	86.6	25.2	215	277	710	B
12 OPzS 1200	1200	1370	1185	1023	706	90.6	25.8	215	277	710	B
12 OPzS 1500	1500	1610	1400	1197	784	110.4	32.7	215	277	855	B
14 OPzS 1750	1750	1881	1632	1397	914	142.3	46.2	215	400	815	C
15 OPzS 1875	1875	2016	1748	1496	980	146.6	46.7	215	400	815	C
16 OPzS 2000	2000	2150	1865	1596	1045	150.9	45.9	215	400	815	C
18 OPzS 2250	2250	2412	2097	1796	1176	179.1	56.4	215	490	815	D
19 OPzS 2375	2375	2546	2213	1895	1242	182.9	55.6	215	490	815	D
20 OPzS 2500	2500	2680	2330	1995	1307	187.3	55.7	215	490	815	D
22 OPzS 2750	2750	2952	2562	2195	1437	212.5	67.0	215	580	815	D
23 OPzS 2875	2875	3086	2678	2294	1503	216.8	65.9	215	580	815	D
24 OPzS 3000	3000	3220	2796	2394	1568	221.2	66.4	215	580	815	D
26 OPzS 3250	3250	3488	3028	2594	1699	229.6	65.4	215	580	815	D

C_{nom} = nominal capacity at 10 h discharge according to DIN 40736-1
C_{10}, C_5, C_3 and C_1 = Capacity at 10 h, 5 h, 3 h and 1 h discharge
* according to DIN 40736-1 data to be understood as maximum values



4 OPzS 200 - 6 OPzS 600
7 OPzS 700 - 12 OPzS 1500
14 OPzS 1750 - 16 OPzS 2000
18 OPzS 2250 - 26 OPzS 3250

Design life: up to 20 years

Optimal environmental compatibility - closed loop for recovery of materials in an accredited recycling system

¹ Similar to sealed lead-acid batteries

HOPPECKE
POWER FROM INNOVATION
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www.hoppecke.com

Form OPzS EN/08.12/0,5 K   Printed in Germany   All details in this brochure are based on state-of-the-art technology. Our products are subject to constant development. We therefore reserve the right to make changes.

Appendix A-6: SI Series inverters

SI serie

Model	SI 612, 624, 648	SI 812, 824	SI 1212,1224, 1248	SI 1624	SI 2324, 2348	SI 3324	SI 3548
Inverter							
Voltage input (Unom) [V]	12/24/48	12/24	12/24/48	24	24V/48	24	48
Input voltage range	Min. - Max. : < Unom x 0.95 to Unom x 1.33						
Dynamic correction of Umin.	- 10% @ Pnom						
Continuous power [VA]	600	800	1200	1600	2300	3300	3500
Power 15 min. @ 25°C	1.3 – 1.6 x Pnom / 25°C						
Power 3 min. @ 25°C	1.6 – 2 x Pnom / 25°C						
Power 5 sec. @ 25°C	3.5 x Pnom						
Asymmetric load	Up to 2 x Pnom						
Load detection (stand-by)	Adjustable : 0.3 → 20W						
Cos φ	0.1 – 1						
Maximum Efficiency [%]	91	92	93 - 95	93 - 95	95	95	95
«Stand-by» current [mA]	25/21/10	25/21	25/21/12	21	25/17	25	30
Power «ON» no load [W]	2.6	2.8	4.8	5.8	9	13	17
Power «ON» no load [W] TWINPOWER system			< 0.5	< 0.5	< 0.6	< 0.7	< 0.8
Output voltage	Sine wave 230 Vac ± 3%						
Frequency	50 Hz ± 0.01% (crystal controlled)						
Distortion	< 2% (at Pnom)						
Dynamic behaviour	From 0% fo 100% load change. Normalization : 0.5 ms						
Protections	Overload/Overheat/Short-circuit/Reverse polarity by internal fuse						
Overheating protection	75°C ± 3°C						
General data							
Weight	6.9	10.4	13.2	15.2	27	30	38
Length L x 124 (H) x 215 (W) [mm]	276		391		591	636	791
IP protection index	IP 20 complies with DIN 40050 / IP 22 with top cover C-IP22						
EC conformity	EN 61000-6-1, EN 61000-6-3, EN 55014, EN 55022, Dir. 89/336/EEC, LVD 73/23/EEC						
Forced ventilation	From 45°C +- 3°C						
Acoustic level	<40dB / <45dB (without/with ventilation)						
Options							
3-phase system (per unit) (-PE)			•	•	•	•	•
TwinPower system (-TP)			•	•	•	•	•
Top cover IP 22 (C-IP22)	•	•	•	•	•	•	•
Potential free alarm contact (60V/0.5A) (-A)	•	•	•	•	•	•	•
Solar charge controller 16A/12-24V (-S)	•	•					
Industrial casing in 19" rack - 3U x 400 mm (-IND)			•	•	•	•	•

Other output specifications on request (Ex: 120V/60Hz)

Appendix A-7: C60H-DC Circuit breaker

Product data sheet
Characteristics

MGN61515
miniature circuit breaker - C60H - 1 pole - 32 A - C curve

Main

Commercial Status	Commercialised
Circuit breaker application	Distribution
Range of product	C60
Device short name	C60H-DC
Poles description	1P
Number of protected poles	1
[In] rated current	32 A at 25 °C
Network type	DC
Trip unit technology	Thermal-magnetic
Curve code	C
Breaking capacity	20 kA Icu conforming to GB 14048.2 - 110 V DC 20 kA Icu conforming to IEC 60947-2 - 110 V DC 20 kA Icu conforming to EN 60947-2 - 110 V DC 6 kA Icu conforming to IEC 60947-2 - 250 V DC 6 kA Icu conforming to GB 14048.2 - 250 V DC 6 kA Icu conforming to EN 60947-2 - 250 V DC 10 kA Icu conforming to IEC 60947-2 - 220 V DC 10 kA Icu conforming to GB 14048.2 - 220 V DC 10 kA Icu conforming to EN 60947-2 - 220 V DC 5 kA AIR conforming to UL 1077 - 250 V DC
Utilisation category	Category A conforming to IEC 60947-2 Category A conforming to GB 14048.2 Category A conforming to EN 60947-2
Suitability for isolation	Yes conforming to GB 14048.2 Yes conforming to EN 60947-2 Yes conforming to IEC 60947-2

Complementary

Network frequency	-
[Ue] rated operational voltage	250 V DC
Magnetic tripping limit	7...10 x In
[Ics] rated service breaking capacity	15 kA 75 % x Icu conforming to GB 14048.2 - 110 V DC 7.5 kA 75 % x Icu conforming to GB 14048.2 - 220 V DC 4.5 kA 75 % x Icu conforming to GB 14048.2 - 250 V DC 7.5 kA 75 % x Icu conforming to IEC 60947-2 - 220 V DC 7.5 kA 75 % x Icu conforming to EN 60947-2 - 220 V DC 4.5 kA 75 % x Icu conforming to IEC 60947-2 - 250 V DC 4.5 kA 75 % x Icu conforming to EN 60947-2 - 250 V DC 15 kA 75 % x Icu conforming to IEC 60947-2 - 110 V DC 15 kA 75 % x Icu conforming to EN 60947-2 - 110 V DC
[Ui] rated insulation voltage	500 V DC conforming to UL 1077 500 V DC conforming to GB 14048.2 500 V DC conforming to EN 60947-2 500 V DC conforming to IEC 60947-2
[Uimp] rated impulse withstand voltage	6 kV conforming to UL 1077 6 kV conforming to GB 14048.2 6 kV conforming to EN 60947-2 6 kV conforming to IEC 60947-2
Contact position indicator	Yes
Control type	Toggle
Local signalling	ON/OFF indication
Mounting mode	Fixed

The information provided in this documentation contains general descriptions and/or technical characteristics of the performance of the products contained herein.
This documentation is not intended as a substitute for and is not to be used for determining suitability or reliability of these products for specific user applications.
It is the duty of any such user or integrator to perform the appropriate and complete risk analysis, evaluation and testing of the products with respect to the relevant specific application or use thereof.
Neither Schneider Electric Industries SAS nor any of its affiliates or subsidiaries shall be responsible or liable for misuse of the information contained herein.

Appendix A-7: C60H-DC Circuit breaker

Mounting support	35 mm symmetrical DIN rail
Comb busbar distribution block compatibility	Standard top or bottom
9 mm pitches	2
Height	81 mm
Width	18 mm
Depth	73 mm
Product weight	0.128 kg
Colour	Grey
Mechanical durability	20000 cycles
Electrical durability	6000 cycles - 250 V DC 3000 cycles - 250 V DC
Provision for padlocking	Padlockable
Locking options description	In position O
Connections - terminals	Tunnel type terminals, top or bottom for 1 rigid wire(s) 35 mm² max Tunnel type terminals, top or bottom for 1 flexible wire(s) 25 mm² max
Tightening torque	2.5 N.m top or bottom power circuit
Earth-leakage protection	Without
Product compatibility	C60 accessories C60 auxiliary

Environment

Standards	EN 60947-2 GB 14048.2 IEC 60947-2 UL 1077
Pollution degree	3 conforming to UL 1077 3 conforming to IEC 60947-2 3 conforming to GB 14048.2 3 conforming to EN 60947-2
Tropicalisation	2 conforming to GB 14048.2 2 conforming to IEC 60068-2
Relative humidity	95 % 55 °C
Operating altitude	2000 m
Ambient air temperature for operation	-25...70 °C
Ambient air temperature for storage	-40...85 °C

Offer Sustainability

Sustainable offer status	Green Premium product
RoHS	Compliant - since 0832 - Schneider Electric declaration of conformity
REACh	Reference not containing SVHC above the threshold
Product environmental profile	Available
Product end of life instructions	Need no specific recycling operations

RoHS compliance

RoHS EUR status	Compliant
RoHS EUR conformity date(YYWW)	0832

Contractual warranty

Period	18 months

Appendix B: Table of interest at i = 7%

7% Compound Interest Factors 7%

	Single Payment		Uniform Payment Series				Arithmetic Gradient		
n	Compound Amount Factor Find F Given P F/P	Present Worth Factor Find P Given F P/F	Sinking Fund Factor Find A Given F A/F	Capital Recovery Factor Find A Given P A/P	Compound Amount Factor Find F Given A F/A	Present Worth Factor Find P Given A P/A	Gradient Uniform Series Find A Given G A/G	Gradient Present Worth Find P Given G P/G	n
1	1.070	.9346	1.0000	1.0700	1.000	0.935	0	0	1
2	1.145	.8734	.4831	.5531	2.070	1.808	0.483	0.873	2
3	1.225	.8163	.3111	.3811	3.215	2.624	0.955	2.506	3
4	1.311	.7629	.2252	.2952	4.440	3.387	1.416	4.795	4
5	1.403	.7130	.1739	.2439	5.751	4.100	1.865	7.647	5
6	1.501	.6663	.1398	.2098	7.153	4.767	2.303	10.978	6
7	1.606	.6227	.1156	.1856	8.654	5.389	2.730	14.715	7
8	1.718	.5820	.0975	.1675	10.260	5.971	3.147	18.789	8
9	1.838	.5439	.0835	.1535	11.978	6.515	3.552	23.140	9
10	1.967	.5083	.0724	.1424	13.816	7.024	3.946	27.716	10
11	2.105	.4751	.0634	.1334	15.784	7.499	4.330	32.467	11
12	2.252	.4440	.0559	.1259	17.888	7.943	4.703	37.351	12
13	2.410	.4150	.0497	.1197	20.141	8.358	5.065	42.330	13
14	2.579	.3878	.0443	.1143	22.551	8.745	5.417	47.372	14
15	2.759	.3624	.0398	.1098	25.129	9.108	5.758	52.446	15
16	2.952	.3387	.0359	.1059	27.888	9.447	6.090	57.527	16
17	3.159	.3166	.0324	.1024	30.840	9.763	6.411	62.592	17
18	3.380	.2959	.0294	.0994	33.999	10.059	6.722	67.622	18
19	3.617	.2765	.0268	.0968	37.379	10.336	7.024	72.599	19
20	3.870	.2584	.0244	.0944	40.996	10.594	7.316	77.509	20
21	4.141	.2415	.0223	.0923	44.865	10.836	7.599	82.339	21
22	4.430	.2257	.0204	.0904	49.006	11.061	7.872	87.079	22
23	4.741	.2109	.0187	.0887	53.436	11.272	8.137	91.720	23
24	5.072	.1971	.0172	.0872	58.177	11.469	8.392	96.255	24
25	5.427	.1842	.0158	.0858	63.249	11.654	8.639	100.677	25
26	5.807	.1722	.0146	.0846	68.677	11.826	8.877	104.981	26
27	6.214	.1609	.0134	.0834	74.484	11.987	9.107	109.166	27
28	6.649	.1504	.0124	.0824	80.698	12.137	9.329	113.227	28
29	7.114	.1406	.0114	.0814	87.347	12.278	9.543	117.162	29
30	7.612	.1314	.0106	.0806	94.461	12.409	9.749	120.972	30
31	8.145	.1228	.00980	.0798	102.073	12.532	9.947	124.655	31
32	8.715	.1147	.00907	.0791	110.218	12.647	10.138	128.212	32
33	9.325	.1072	.00841	.0784	118.934	12.754	10.322	131.644	33
34	9.978	.1002	.00780	.0778	128.259	12.854	10.499	134.951	34
35	10.677	.0937	.00723	.0772	138.237	12.948	10.669	138.135	35
40	14.974	.0668	.00501	.0750	199.636	13.332	11.423	152.293	40
45	21.002	.0476	.00350	.0735	285.750	13.606	12.036	163.756	45
50	29.457	.0339	.00246	.0725	406.530	13.801	12.529	172.905	50
55	41.315	.0242	.00174	.0717	575.930	13.940	12.921	180.124	55
60	57.947	.0173	.00123	.0712	813.523	14.039	13.232	185.768	60
65	81.273	.0123	.00087	.0709	1 146.8	14.110	13.476	190.145	65
70	113.990	.00877	.00062	.0706	1 614.1	14.160	13.666	193.519	70
75	159.877	.00625	.00044	.0704	2 269.7	14.196	13.814	196.104	75
80	224.235	.00446	.00031	.0703	3 189.1	14.222	13.927	198.075	80
85	314.502	.00318	.00022	.0702	4 478.6	14.240	14.015	199.572	85
90	441.105	.00227	.00016	.0702	6 287.2	14.253	14.081	200.704	90
95	618.673	.00162	.00011	.0701	8 823.9	14.263	14.132	201.558	95
100	867.720	.00115	.00008	.0701	12 381.7	14.269	14.170	202.200	100

جامعة النجاح الوطنية
كلية الدراسات العليا

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الملخص

تقدم هذه الاطروحة المنهجية الامثل لتصميم انظمة طاقة شمسية لتزويد محطات الاتصالات الخلوية في المناطق الفلسطينية النائية، والتي يتم تزويدها حاليا بالطاقة عن طريق مولدات الديزل. تمت عملية تقييم فعالية النظام ومدى جدواه الاقتصاديه من خلال استخدام عدد من طرق المسح والمقارنة الاقتصادية المعتمدة على فترة حياة النظام و سعر وحدة الطاقة المنتجة. تخلص هذه الدراسة الى ان استخدام انظمة الخلايا الشمسية لتزويد محطات البث الخلوية في المناطق النائية هو اكثر فعالية وجدوى اقتصادية من استخدام مولدات الديزل كما انه يتيح توفير الطاقة بمعدل 65% سنويا. حيث ان معدل سعر وحدة الطاقة المنتجة من الخلايا الشمسية يساوي 0.49 دولارا لكل كيلو واط ساعة، مقارنة مع 1.5 دولارا من الديزل. ان استخدام انظمة الخلايا الشمسية لتوليد الطاقة يعزز من المحافظة على بيئة فلسطينية صحية ونظيفة حيث يتمثل التاثير الايجابي على البيئة في تقليل 2.63 كيلو غرام من ثاني اوكسيد الكربون لكل ليتر ديزل واحد مستخدم في توليد الطاقة. اضافة لذلك يعد استخدام انظمة الطاقة الشمسية من احد اهم اسباب تعزيز الاقتصاد الفلسطيني و تقليل الاعتمادية في مصادر الطاقة.