An-Najah National University
Faculty of Graduate Studies

TECHNO-ECONOMIC EVALUATION OF ELECTRIFICATION OF SMALL VILLAGES IN PALESTINE BY CENTRALIZED AND DECENTRALIZED PV SYSTEM

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TO

MY PARENTS,

MY WIFE,

MY DAUGHTERS AND SONS,

MY BIG FAMILY

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I would like to wholeheartedly thank my advisor and direct supervisor Dr.Imad Ibrik for his continued support, complete cooperation and distinguish supervision throughout the whole course of this study. I wish to express my gratitude to my Professor Dr.Marwan Mahmoud who participated as the second supervisor of this study and who shared with his valuable notes and long experience in the field of PV system and batteries. Special thanks and appreciation to DR.Imad Ibrik , the director of Energy Research Center of our university and his assistant, my friend Eng .Moien Omar for their support and providing me with the required meteorological data related to this study. Special thanks goes to my family [my excellent wife Ra'fat, my sons and daughters, specially my fantastic daughter Sakha'] who supported me and made this thesis possible.

الإقــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

TECHNO-ECONOMIC EVALUATION OF ELECTRIFICATION OF SMALL VILLAGES IN PALESTINE BY CENTRALIZED AND DECENTRALIZED PV SYSTEM

"التقييم الفني و الاقتصادي لإنارة تجمعات صغيرة باستخدام أنظمة الخلايا الشمسية (PV) المركزية واللامركزية في فلسطين"

اقر بأن ما اشتملت عليه هذه الرسالة إنما هي نتاج جهدي الخاص، باستثناء مـا تمـت الإشارة إليه حيثما ورد، وان هذه الرسالة ككل، أو أي جزء منها لم يقدم من قبل لنيل أية درجة علمية أو بحث علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

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

Student's name: **اسم الطالب:**

Signature: **التوقيع:**

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TECHNO-ECONOMIC EVALUATION OF ELECTRIFICATION OF SMALL VILLAGES IN PALESTINE BY CENTRALIZED AND DECENTRALIZED PV SYSTEM

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Abstract

This thesis presents the application of photovoltaic system for electrification of small villages by centralized or decentralized configuration. The purpose of this work is to select the optimum design and optimum PV system configuration based on the life cycle cost (LCC) of alternatives. This method is expected to stabilize the system operation, extends the system component lifetime and reduces the energy costs. The study on selection of the optimum design and configuration has been evaluated for the three small villages in Tubas district area (Salhab,Ibziq and Yarza) as case study. A variety of distances between houses and sizes of villages have been selected and tested in the model, to determine the life cycle cost and the cost annuity in each case.

The design of centralized PV system depends on the number of consumers, loads of the villages and the distance between consumers which affects the cost of distribution network of the system. The design of decentralized PV system, depends only on the individual electrical load for each house.

For the three selected villages mentioned before, the LCC and cost annuity of decentralized PV system found less than centralized PV system in the average of 12.87% and 5.38% respectively. Maximum overall efficiency found for decentralized 11.59%, which is more than 10.90% for centralized PV system.

DC load of decentralized PV system was also tested and cost annuity for the same villages found to equal 0.748 $/kWh which is less in 17.3% than of AC decentralized PV system.

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

1. Introduction

Having been applied for use with the terrestrial applications since early 1970[1], photovoltaic (PV) technology has been popularly used around the world. The survey for the retail prices of PV modules during the period between 2000 to 2007 in the world found that the price has continually reduced with the growth of PV demand, in addition, the market survey on the global cell and module production in the last years showed that the total number of the solar cell units are an increase of each year. These statistics confirm that PV has of late become an appealing option for the generation of electricity.

Various kinds of PV system technologies and configuration have been developed for use in many different applications. In rural areas, PV electrification can solve the economic problem of expanding the utility grids into rural villages. Moreover, utilization of this technology positively effects environmental conservation , especially by reducing the global warming crisis by saving on the use of fossil fuel used for the generators. Consequently, from many reasons above, PV electrification has turned out to be preferable to the conventional approaches in generating electricity in the rural areas. PV electrification plays an important role not only in many rural areas but also in several small urban communities which have high potential of solar radiation [2]. No matter how attractive this system is, its high capital cost has prohibited the PV utilization promotion. Hence, to compete with other types of the conventional electrification systems, PV projects need to be subsidized by governments or international organizations.

Anyhow, the PV technology is getting to have popular use only in some countries because the creation of awareness by the government of each country in the utilization of sustainable energy is different.

The information above shows that the number of residential areas or villages which use the PV electrification system is increasing. In addition, there are several kinds of PV electrification systems, the most suitable of which for application in a small community is the stand alone PV system or PV diesel hybrid system [3].

However, one important technical problem in the PV system is the energy storage. Normally, lead-acid batteries are installed in such system. The replacement for the degraded batteries and the need for additional batteries, resulting from an increase in the energy consumption, causes the overall system cost to rise above the predicted level.

The selection of optimum size of all PV system parameters according to selection the optimum configuration of centralized or decentralized PV system is very important.

This research aims at reducing the cost of PV system by utilizing of optimum PV design and by selection of optimum configuration of centralized or decentralized PV system based on the life cycle cost of the systems. The first step is the selection of PV parameters for both configurations (decentralized or centralized). Further more, the life cycle cost and unity cost are investigated.

1.1 Review of Small Village Electrification Systems

In the last decade, the suitable villages for application of PV electrification system were located only in the rural areas because the operation and generation costs of this system were more costly compared to other conventional systems. However, with government support in many countries, and continued reduction of the PV component cost, the PV systems become now more suitable for many urban communities. The general domestic loads of any village consist of : lamps, televisions, radios, refrigerators. Table (1.1) shows the typical energy consumed for each unit of electrical appliance in the small villages in west-bank of Palestine.

Table (1.1): Typical electrical power consumption in small villages, of West Bank

Appliance	Power (w)
Refrigerator	100 w
TV	50 w
CFL	13 w
Radio	15 w

The conventional technology of electricity generation of small villages is the fossil fuel generator. With this technology, there are several problems which can obviously be observed. Firstly, there is noise occurring from the operation process. Next, the environmental crisis, particularly the global warming problem, is contributed to by this technology . The last is the financial difficulty of the price of oil in the rural area where it is rather costly.

As an alternative to electricity generation, is to use PV systems alone or compound with diesel generators as hybrid systems.

The cost of the systems(centralized or decentralized) which reflect the cost of the energy storage and the remaining system components, including the planning and the installation costs, are dominant. Every development which can reduce the cost of PV unit generated should be supported to accelerate the dissemination of PV system [4].

1.2 Formation of Problems

The need for low cost electric power in remote areas of the world is the primarily force driving to wide use photovoltaic system the advantages of PV system are, it is modular and silent, they have no moving parts, so they require low maintenance and they do not produce emissions.

The selection of optimum size of all PV parameters and the optimum configuration of PV system(centralized or decentralized) are very important for reducing the total cost of 1 kWh generated from the PV system.

In the research process, the first step is selection the optimum size of all parameters in two options(centralized and decentralized) and after that by using mathematical model based on LCC the program will be selected the optimum configuration, given us minimum cost of 1 kWh generated.

1.3 Research Objectives

As elaborated in the previous section, electrical appliances on the user side need to be investigated.

Consequently, the distances between consumers, the system reliability and energy costs can be improved. The objective of this study is stated as follows:

- The use of high efficient standard appliances in these remote small villages has to be recommended to get the benefits of energy efficiency and energy management.
- Developing the simulation flow-chart to efficiently selected the size of PV system component. The method should be able to adjust the parameters which effect on PV module and the storage capability.
- Developing mathematical model based on Life cycle cost (LCC) for selection optimum configuration of the PV system. This objective can be divided into several small parts such as to stimulate the decrease of the energy demand when the energy management concept was applied to the village load, to estimate the cost of distribution network between consumers, as well as to study how the system cost changes at different configurations.

1.4 Research Procedures

The research has been divided into the following parts:

1. Investigating the house appliances is necessary in order to determine and estimate the electrical loads and energy needs from the alternative PV system.

2. The system simulation, the energy efficiency concept through selection high efficient equipment in the first step above was applied to the user side in the chosen village in order to study the possibilities of the reduction of the peak demand during daily load curve and to determine the optimum size of all PV parameters.

3. Accordingly, the main emphasis of the second part is to define the optimum configuration of centralized or decentralized PV systems based on the life cycle cost (LCC) of the configuration and accordingly to determine the annuity cost of 1 kWh produced from optimum configuration.

4. Small Palestinian villages in Tubas district are typical small villages that were used as a model to test the hypothesis in this research.

CHAPTER TWO

ELECTRIFICATION OF SMALL VILLAGES IN PALESTINE

CHAPTER TWO

2. Electrification of Small Villages in Palestine

Introduction

In Palestine there is approximately no electrical power generation. The electrical power generation in Palestine doesn't exceed 15% of total energy need, because of many causes, especially of very high cost of power generation.

Figure (2.1) Palestine map (West-Bank and Gaza Strip) [5]

So, approximately all electrical networks in Palestine are considered to as distribution networks .

The ranges of voltages of the networks are considered to be medium voltages; 33 kV, 22 kV, 11 kV, and to be low voltage; 6.6 kV, and 0.4 kV.

The domestic communities purchases electricity from the supplier, (the Israeli Electrical Corporation) (IEC) with 33-kV or 22-kV over head lines then distributed to the target areas with 11-kV or 6.6-kV , then to the consumers with 0.4-kV .

2. 1 The Problems of Electrical Networks in Palestine

1 – High electrical power losses

Come from technical and non technical losses, technical losses come from the generation, transmission, and distribution of electricity to consumers, and non technical losses come from the failure in administration & management.

The total losses in Palestine are in the range of [12% - 25%], where the normal loss doesn't exceed 6% of the total generated power.

2 – Low power factor (PF) in electrical network

It comes from the increased in the inductive loads connected the electrical supply, like motors and fluorescent lamps.

In Palestine, the acceptable power factor to the electricity suppliers (IEC) is 0.92. When the PF is less than 0.92 , the consumers will pay in addition to the electricity bill the following penalties ,

Table (2.1): Power factor penalties in Palestine [6]

P.F.	Penalty
≥ 0.92	None
0.8 ≤ P.F. < 0.92	1% of the total bill for every 0.01 of P.F. < 0.92
0.7 ≤ P.F. < 0.8	1.25 % of total bill for every 0.01 of P.F. < 0.92
<0.7	1.5 % of total bill for every 0.01 of P.F. < 0.92

This problem can be solved by adding proper capacitor banks .

3 – High drop voltage

The electrical drop voltage in the Palestinian networks is in the range of [10 % - 15 %], where normal drop voltage doesn't exceed 5% of the nominal voltage .

4 – Lack of supply

In Palestine due to Israeli occupation and high cost of generation, nowadays , the cost of generation after the rising of fuel price is more than 0.2 $/kWh and we can purchase electricity from IEC supplier at 0.10 $/kWh, therefore it's too much difference! So it's better to purchase electricity rather than to generate from fossil fuel.

This problem could be solved by looking for another sources of supply like renewable energy sources , specially for remote and isolates areas, as in our case study of electrification for remote villages of Tubas district area.

2.2 Potential of Renewable Energy in Palestine

The potential of renewable energy in Palestine is very high and the sources of renewable energy are mainly:

But before going to take a brief idea about these sources we have to illustrate the climate conditions of Palestine:-

Palestine is located between 34º:20΄ - 35:30΄ E and 31º: 10΄ **-** 32º:30΄ N **,** It consists of two separated areas from one another , the Gaza Strip is located on the western side of Palestine adjacent to the Mediterranean Sea and the West-Bank which extends from the Jordan River to the center of Palestine .

Palestine's elevation ranges from 350m below sea level in Jordan Valley, to sea level along Gaza Strip sea shore and exceeding 1000m above sea level in some mountains sites in the west-Bank.

Climate conditions in Palestine vary widely , the coasted climate in Gaza Strip is humid and hot during summer and mild during winter. These areas have low heating loads, while cooling is required during summer. The daily average temperature and relative humidity vary in the ranges: (13.3 – 35.4) C° and (67 – 75) % respectively [7] .

In the hilly areas of the West-Bank , cold winter conditions and mild summer weather are prevalent. Daily average temperature and relative humidity vary in ranges : (8 – 23) C^o and (51 – 83) % respectively[7]. In some areas the temperature decline below 0 C^o .

Hence, high heating loads are required , while little cooling is needed during summer.

In Jericho and Jordan Valley, almost no heating is needed during winter while high cooling during summer is needed [8]

2.2– 1 The potential of solar energy in Palestine

Palestine has high solar energy potential. It has about 3000 sunshine hours/year , and high annual average of solar radiation amounting to 5.4 kWh/m^2 - day on horizontal surface, It reaches 8.4 kWh/m^2 - day in June[8].

These figures are encouraging to exploit the solar energy for different applications such as water heating, drying of crops, vegetables, and fruits, water desalination, water pumping, and electrification of remote locations far from the electrical networks , and also for distributed generation of electricity for shaving peak demand as a DSM tool .

2.2 – 2 The potential of wind energy in Palestine

Utilization of wind energy had been till now not occurred in Palestine even in those areas which are considered to have potential; as known, wind velocity average in the range of 3.5 – 6 m/s in appropriate mostly for water pumping by using multiblade windmills[8] .

For generation of electricity, the annual average wind speeds must be mostly in the range of (6 – 13) m/s [8] .

2.2– 3 The potential of biogas & biomas in Palestine

Biogas: As known, the most important energy material is the animal dung for biogas production. Till now, the potential of biogas production in Palestine is not known, but we think it has a good reasonable potential, since one cow can produce about to 24 kg of liquid gas/month .

Biomas: Since Palestine is considered to be an agricultural country, it has different types of plant products that can be used as energy sources .

The main type of these products is the reject of olive oil pressers called gifet. Usually, gifet is used in household for heating in winter. Annual production of gifet hadn't been assessed yet .This task is essential and hopefully it will be carried out in cooperation between the ministry of agriculture and the Palestinian Central Bureau of Statistics (PCBS).

2.3 Electrification of Villages in Palestine by Using Centralized and Decentralized PV-Systems

Since Palestine possesses a potential for (PV) applications , due to the high average annual daily solar radiation, which exceeds 5.45 kWh/m².day, Palestine lacks for conventional energy resources such as oil and natural gas, therefore Palestine import most of its energy sources from Israel at a relatively high cost, and the Israeli occupation, which has stifled development in all fields related to infrastructure, all of these three factors make PV applications viable in Palestine, especially for the electrification of remote villages which would save hard currency and preserve the environment in addition to improving the standard of living rural areas and remote villages, nowadays there are some villages [8] are still without electricity and would benefit from such technologies according to the Palestinian energy and environment research center (PEC) studies, where these villages are distance from the nearest electric grid point exceed 10 km, there are less than 30 consumers houses in the village, houses of the village are spread apart ,assuming that domestic electricity use in these villages is limited to lighting, refrigeration and operation of radios and televisions, then the total PV watt peak necessary to cover the total electric load in village of an average of 30 houses is about 15 kWp.

Taking into account todays prices for PV panels, storage batteries ,charge regulators and inverters, the total cost of electrification of such village is estimated to be about USA $ 150000 (without taxes).Considering a possible financial arrangements for such projects is applicable for these remote villages where the villagers are really very poor [8]**.**

In this study, we will check the centralized or decentralized PV systems is more suitable in our case study of Tubas villages, and what are the criteria for selecting one of these two systems

CHAPTER THREE

POTENTIAL OF SOLAR ENERGY IN PALESTINE

CHAPTER THREE

3. Potential of Solar Energy in Palestine

There are two main elements affect the generation of electric energy from Solar energy , and we have to study these elements in Palestine.

3.1 Solar Radiation in Palestine

Since the area of Palestine is relatively small and the solar radiation(W/m²) doesn't change significantly within such short distance (31° 10′ - 32° 30′ N), the measuring data for all regions (West-Bank & Gaza Strip) may considered to be the same .

The following table (3.1) shows the measurement of the global irradiation (solar radiation) on a horizontal surface in the target area (Tubas area as case study) near to Nablus city [7].

Table (3.1) Hourly average solar radiation of typical summer day (11/6/2005) [7]

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	747	21:00	0
10:00	905	22:00	0
11:00	1019	23:00	0
12:00	1062	24:00	0

These measurements are achieved from the ERC. This measurement we've done by horizontally oriented measuring devices, and done on a 5-minute interval basis.

The following Figure (3.1) shows the daily irradiation-curve plotted from data of table (3.1) .

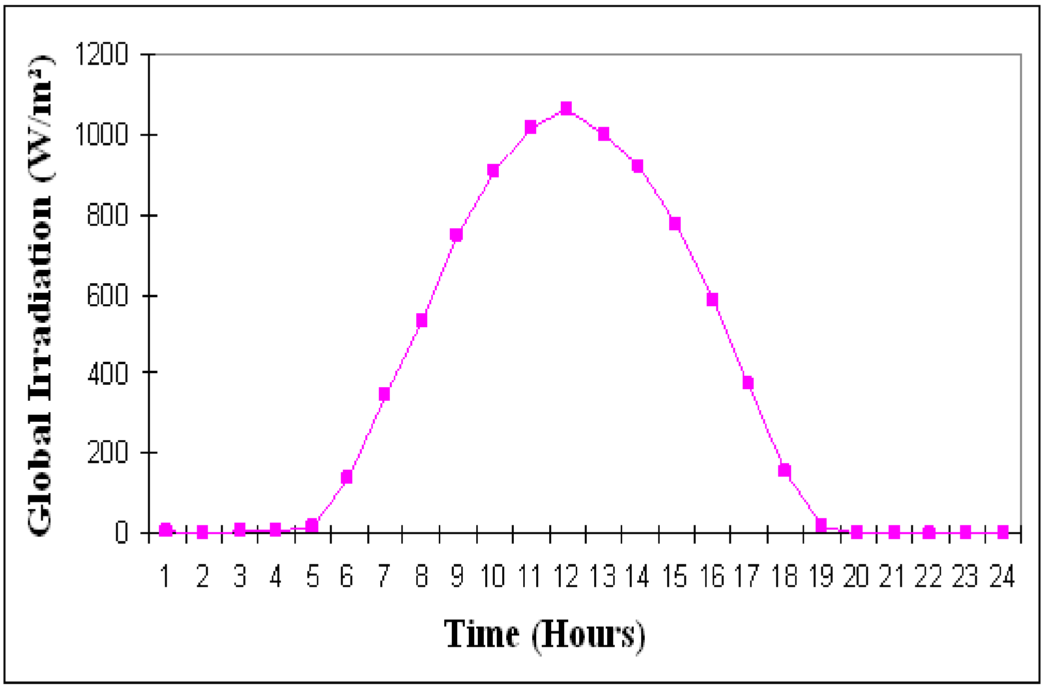

Figure (3.1): The global irradiation(W/m²) versus time (hours)

From the previous table & curve, it is obvious that the solar radiation is more than 900 W/m² during the hours : 10, 11, 12, 13, and 14 pm and it's also more than 135 W/m² in the morning hours 6, 7, 8, and 9 am, and in the evening hours 15, 16, 17, and 18 pm. This means that we have an enough potential for solar radiation in the interval period from 10 to 14 o'clock, also we can obtain electric energy even in morning or evening periods, as we will going to illustrate in the following chapters.

3.2 Ambient Temperature

As we mentioned before temperature affects the PV generators efficiency. The relation between temperature and efficiency is inversed. The ambient temperature is the main factor that affects the PV generator's temperature.

Table (3.2) shows for an example the ambient temperature of the target area achieved by ERC mentioned before. The shown data is the average of two days measurement in June 2006. The original measurements are done on a 5-minute interval basis [7].

Table (3.2): Ambient temperature [7]

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	23	19:00	26
8:00	24	20:00	24
9:00	25	21:00	24
10:00	27	22:00	23
11:00	28	23:00	22
12:00	31	24:00	22

Figure (3.2) shows the daily curve of the ambient temperature drawn from the data table (3.2). It's shown that the maximum temperature occurs around noon time (32°C), and the minimum temperature occurs in the early morning (21°C) .

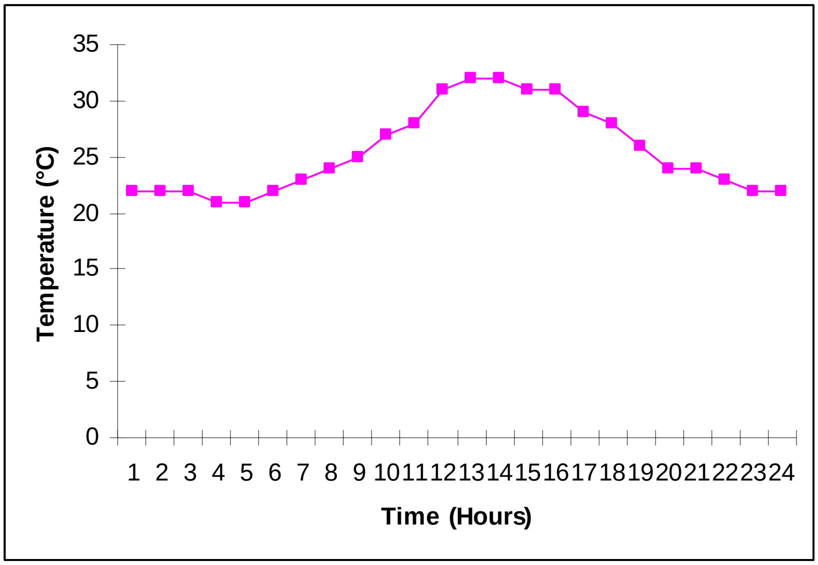

Figure (3.2): The daily ambient temperature curve

3.3 Solar Energy

As mentioned before in chapter (2.2-1), Palestine has high potential of solar energy. It has around 3000 sunshine hours/year and high annual average of solar energy radiation amounting to 5.45 kWh/m²-day on horizontal surface [8].

For the target area, the lowest solar energy average is in December, it amounts to 2.84 kWh/m²-day, and the highest one is in June, it amounts to 8.245 kWh/m²-day. As shown in table (3.3) and Figure (3.3) for the region of Nablus district. These figures are very suitable for PV system to generate electricity . Also these data were measured by the ERC of An-Najah University.

Table (3.3): Monthly solar energy on horizontal surface for Nablus district – 2005

month	kWh/m²-day
1	2.885
2	3.247
3	5.226
4	6.247
5	7.565
6	8.245
7	8.167
8	8.099
9	6.304
10	4.700
11	3.562
12	2.840

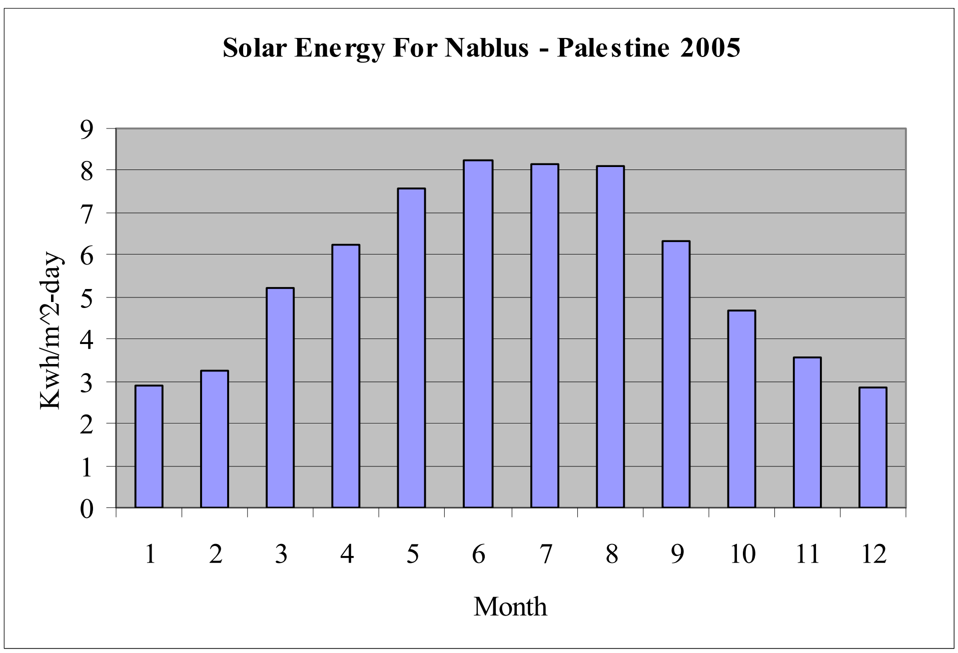

Figure (3.3): Monthly solar energy for Nablus district-2005 on horizontal surface

CHAPTER FOUR

THE ANALYSIS OF CENTRALIZED AND DECENTRALIZED PV-SYSTEMS

CHAPTER FOUR

4. The Analysis of Centralized and Decentralized PV-Systems

Introduction

Since we have a sufficient solar energy radiation per day in Palestine (in the average of 5.45 kWh/m²-day) , and it's very suitable for electricity generation from solar energy through PV systems. This encourage us to start to build a proper centralized or decentralized PV-Systems to solve the main problem of Palestine in general (the lack of supply, and the peak demand of electricity). It' is useful also to take a look at the advantages of PV system [9]. It has high reliability, because source is free and abundant – the sunlight source. It needs little maintenance, because there’s no moving parts. It has virtually no environmental impact, no air pollution, no noise, no hazardous waste. It’s produced domestically, no need for liquid or gaseous fuels to be transported or composted. Strengthening the national economy & reducing the trade deficit, by creating new jobs for relatively young, high tic industry. Its Modular & thus flexible, in terms of sizing and applications. It meets the demand and capacity challenges facing energy service providers, capability to produce the exact needed power and near the point of use. It Helps Energy Service Providers Manage Uncertainty and Mitigate risk, comes from variable cost and politically volatile regions. It Serves Both Form and Function in a Building Shape, nowadays they can replace PV modules on the walls of buildings instead of aluminum or glass.

The PV system has one disadvantage; The high capital cost for the PV-storage capacity system.

In our case study for electrification of small villages in Tubas area by using mini grid centralized or decentralized PV-Systems. So we have to study the PV systems principles and focus on a very important items and their performance which are suitable to apply for solving our problem.

4.1 PV Systems

A photovoltaic (PV) or solar cell is the basic building block of a PV (or solar electric) system. An individual PV cell is usually quite small, typically producing about 1 or 2 watts of power. To boost the power output of PV cells, we connect them together to form larger units called modules. Modules, in turn, can be connected to form even larger units called arrays, as shown in Figure (4.1) which can be interconnected to produce more power, and so on. In this way, we can build PV systems able to meet almost any electric power need, whether small or large [9].

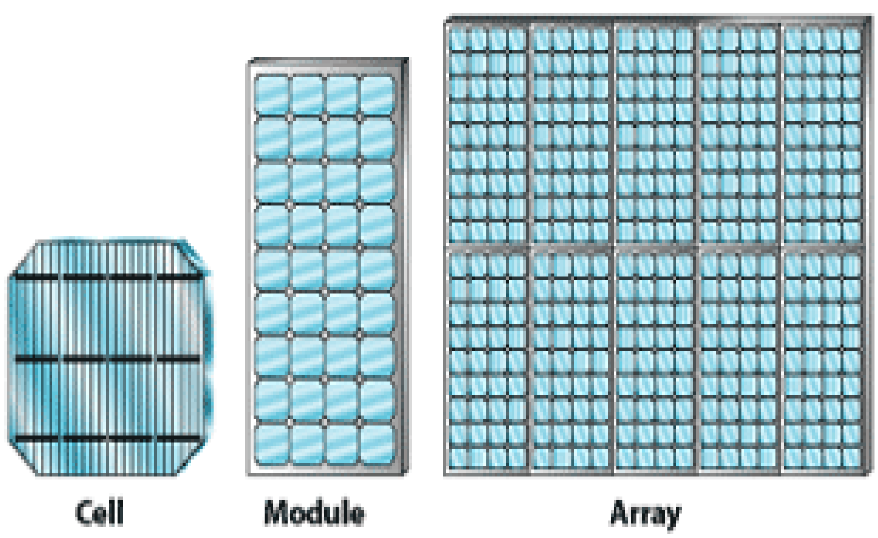

Figure (4.1): PV cell, module, and array of a PV system [9]

2.2 The Structure of PV Storage System

As shown in figure(4.2), the PV system consist from the main components: PV array, controller(Charge Regulator), batteries, inverter and DC load or AC load or both.

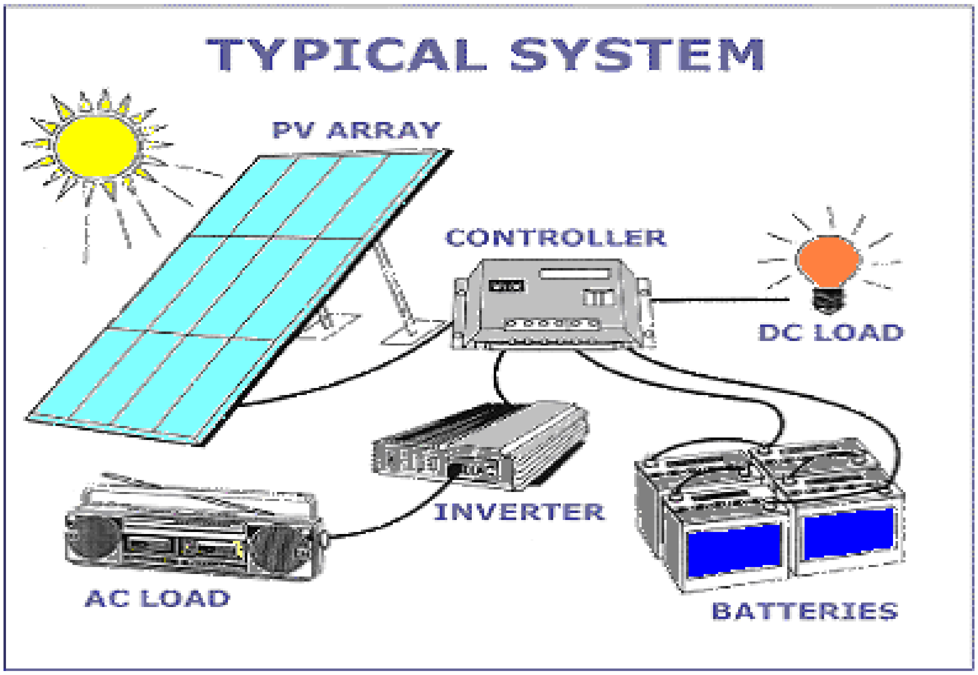

Figure (4.2): Components of PV storage system [10]

4.2-1 Mounting structures

Photovoltaic arrays must be mounted on a stable, durable structure that can support the array and withstand wind, rain, hail, and other adverse conditions. Sometimes, this mounting structure is designed to track the sun. However, stationary structures are usually used with flat-plate systems. These structures tilt the PV array at a fixed angle (tilt angle, the angle between the sun irradiation rays and the vertical lines, or between the plane of the PV array and the horizon) determined by the latitude of the site, the requirements of the load, and the availability of sunlight, as shown in Figure (4.3). The tilt angle in the target area varies between 23° in summer and 45° in winter [7], since this study deals with electrification at all the year we have to take the maximum tilt angle to be 45° as fixed mounting structures.

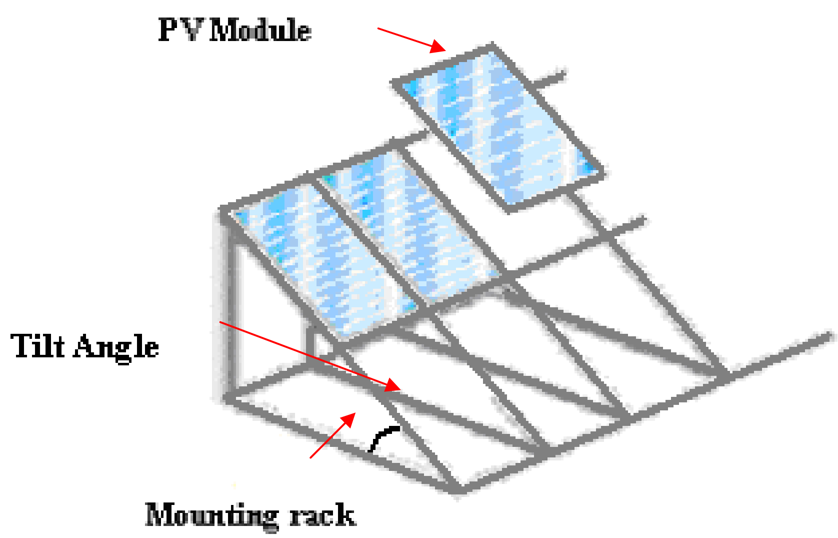

Figure (4.3): Typical PV array mounting rack [9]

4.2-2 Power conditioners of the load

Power conditioners process the electricity produced by a PV system so it will meet the specific demands of the load. Although most equipment is standard, it is very important to select equipment that matches the characteristics of the load. Power conditioners may have these functions:

- Limit current and voltage to maximize power output
- Convert DC power to AC

- Match the converted AC electricity to a utility's electrical network
- Have safeguards that protect utility personnel and the network from harm during repairs

Specific requirements of power conditioners depend on the type of PV system they are used with and the applications of that system. For DC applications, power conditioning is often done with **charge regulators**, which control output at some constant level of voltage and current to maximize output. For AC loads, power conditioning must include an **inverter** that converts the direct current generated by the PV array into alternating current. In our case study, we are concerning with AC loads so we have to use a proper power conditioner including an inverter.

4.2-3 Electricity storage

We need electricity at night and on cloudy days as well as on the sunny days that are so perfect for PV power generation. If tapping into the utility grid is not an option, a battery backup system is necessary for energy storage. However, batteries do lower the efficiency of a PV system, because only about 80% of the energy that goes into them can be reclaimed. They usually need to be replaced every 5 to 10 years. Also, they take up considerable floor space, pose a few possible safety problems, and require periodic maintenance. Still, they provide one way to store PV electricity for later use.

Since storage battery is a very important component of our system as shown in Fig (4.4) because, we need to electrify remote villages at night, where no solar radiation. So we have to focus more in details about batteries

The maximum power output of the generator varies according the solar radiation and temperature conditions.

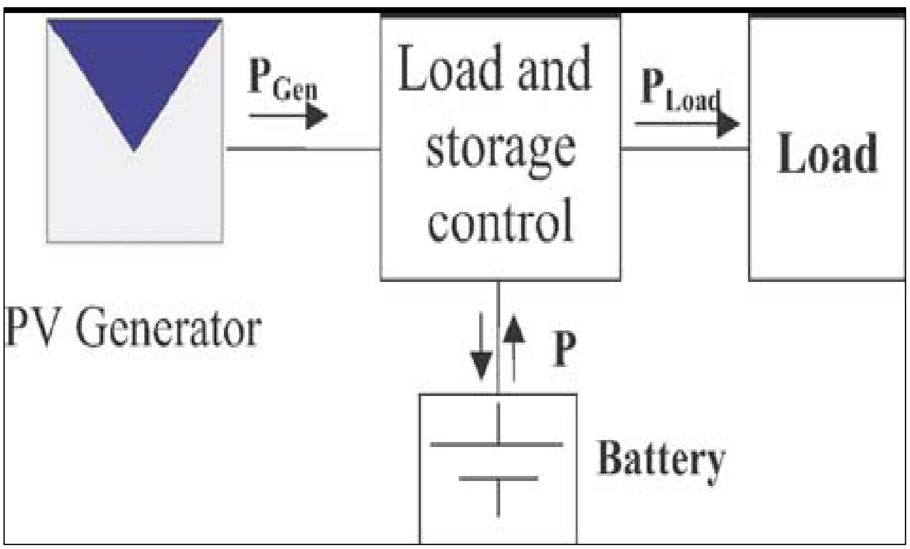

Fig. (4.4): Schematic diagram of a PV power system with battery storage [11].

In the early morning or late afternoon, the PV generator may not be able to meet the load demands especially with short high current peaks such as during motor-startup. A battery which is a constant voltage source acting as a power buffer between the PV generator and the load, will compensate for the limitation of the generator. When solar radiation is higher than needed to meet the load requirement, excess energy is stored in the battery to supply power to the load during night and cloudy days of low solar radiation [12].

4.2-3-1 Battery types

The two battery types that have been used for PV systems are lead–acid and nickel–cadmium. Due to higher cost, lower cell voltage (1.2 V), lower energy efficiency and limited upper operating temperature (40 □C). The lead–acid battery will remain the most important storage device in the near future, especially in PV systems of medium and large size [13].

4.2-3-2 Lead–acid battery characteristics

A - Voltage, specific gravity and state-of-charge

The nominal voltage of a lead–acid cell is 2V, while the upper and lower limits of discharging and charging open circuit voltage at 25 □C cell temperature are 1.75 and 2.4V, which corresponds to 10.5 and 14.4V for a 12V battery (respectively)[11]. The maximum acceptable battery cell voltage decreases linearly with increasing cell temperature as illustrated in Fig. (4.5). The specific gravity of the acid solution of the battery decreases slightly with increasing temperature. Cell voltage and specific gravity of the acid solution are mainly a measure for the state-of-charge of the battery cell.

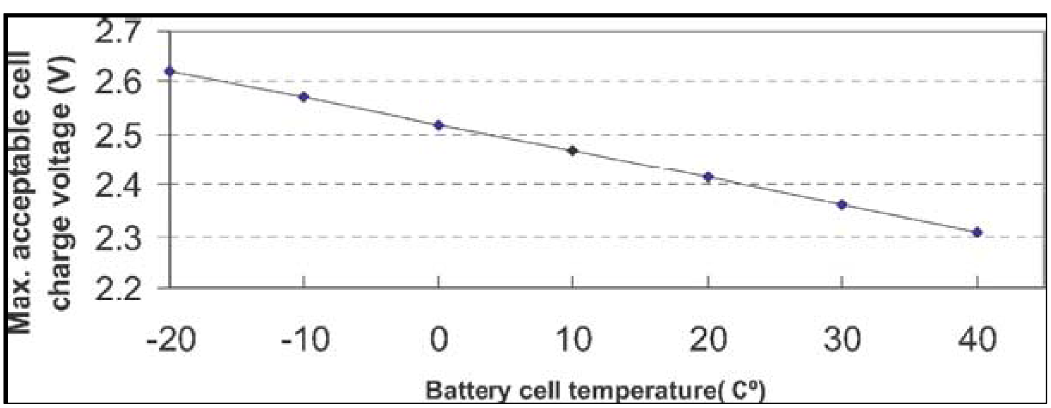

Fig. (4.5): Maximum acceptable battery cell charge voltage in function of internal cell temperature [11].

The depth of discharge (DOD) is the obverse of state-of-charge. Cell voltage decreases almost linearly with depth of discharge until a point called cut-off-voltage is reached as shown in figure (4.6).

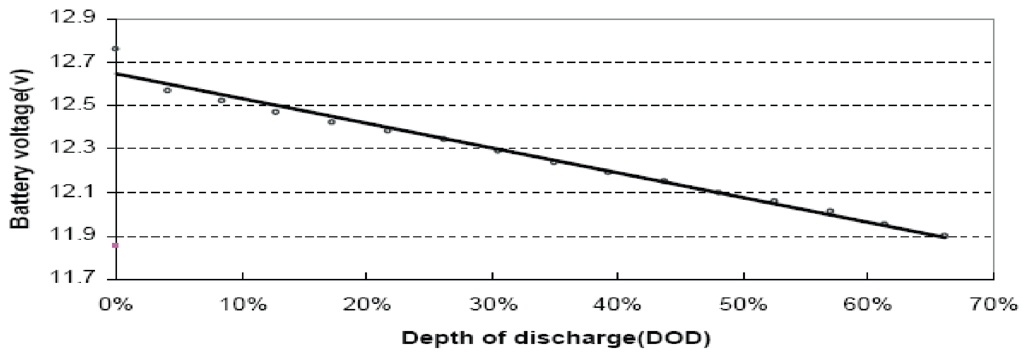

Fig. (4.6): The battery voltage in function of depth of discharge [11].

Battery cells should not be operated beyond the cut off voltage, because further discharge will result in increasing the internal resistance of the battery and can result in permanent damage. On other hand, overcharging the batteries until gassing leads also to cell damage [14].

Therefore, batteries have to be connected to the output of the PV generators and the load via a charge regulator as shown in Fig. (4.4). This regulator, protects the battery against deep discharge and excessive overcharge.

Lead–acid battery cells are available with either pure lead or lead–calcium grids to minimize the self-discharge rate. All lead–acid cells have some loss in capacity on standing due to internal chemical reactions. Fig.(4.7) presents typical self discharge rates for a cell containing antimony or calcium grids. Self-discharge rate, increases with increasing cell temperature and remain relatively low for cell with lead calcium grids [15].

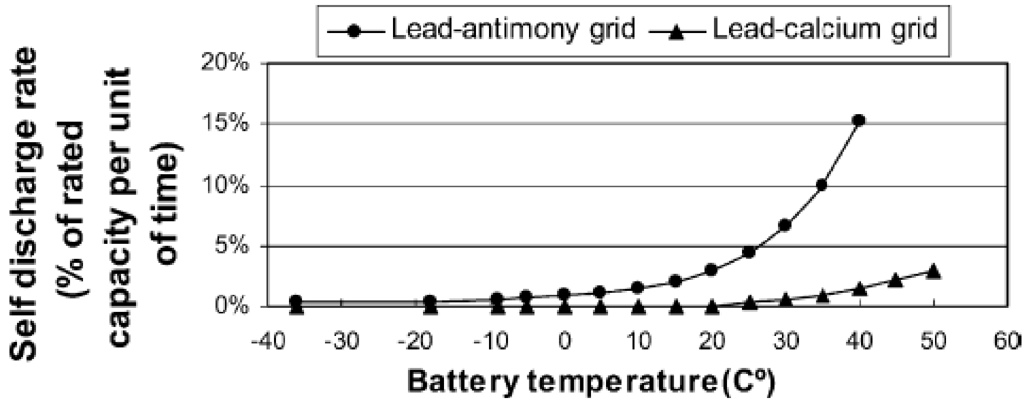

Fig. (4.7): Lead–acid battery self discharge rate in function of cell Temp. [11]

4.3 The Electrical Equivalent Circuit for PV cell

The equivalent circuit of a photovoltaic cell is shown in figure (4.8). The current source represents the photocurrent (I_L), generated at the junction region by the photons with energy enough to produce pairs of electrons-holes; the diode represents the PN junction with reverse saturation current (I_o); Joule losses and leakage currents are represented by the currents through the series resistance (R_S) and the shunt resistance (R_P) respectively [16].

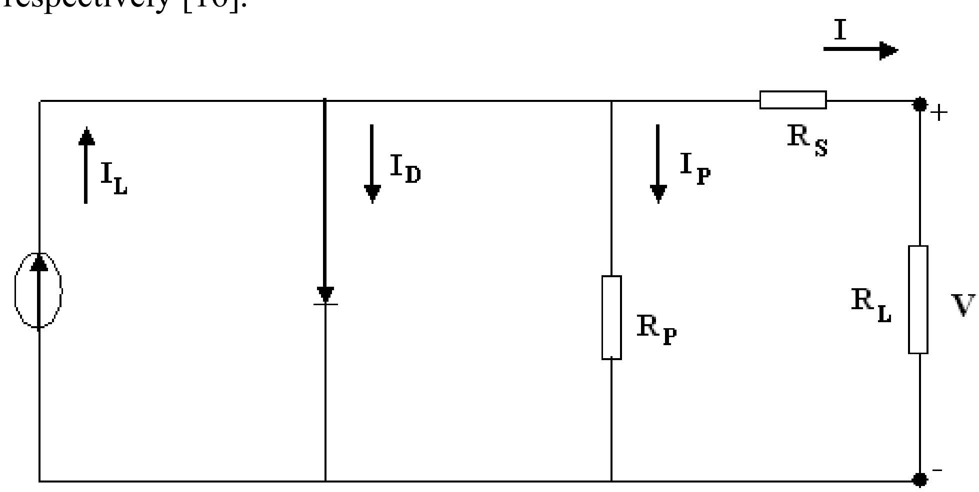

Figure (4. 8): Equivalent circuit of a photovoltaic cell

When the first Kirchoff law is applied to one of the nodes of the equivalent circuit, the current supplied by a cell, at a specified temperature, is given by [17]:

$$I = I_L - I_D - I_P = I_L - I_0\left\{\exp\left(\frac{q(V+IR_S)}{NAK_BT_{cell}}\right)-1\right\} - \frac{V+IR_S}{R_P} \qquad (4.1)$$

where; I is the output current .I_L is the photocurrent .I_D is the diode current .I_P is the leakage current flowing in the shunt resistance, which it's very small and can be negligible. I_0 is the reverse saturation current .N is the number of cells associated in series . A is the diode ideality factor, which lies between 1 and 2 for monocrystalline silicon .

K_B is the Boltzman constant = 1.38 x 10 J/K . T_{cell} is the absolute cell temperature in Kelvin (K°). q is the electronic charge = 1.602 x 10 C. V is the terminal voltage.

If an association of cells (photovoltaic modules) the case, N is the number of cells associated in series. Most of the photovoltaic modules available in the market are constituted by 36, and 40 cells [15].

Three points of the curve in the Fig (4.9) should be highlighted:

a) Open-circuit: this point is obtained when the terminals of the module are disconnected. The module presents a voltage called (VOC). Expressed analytically using the following expression[16]:

$$V_{OC} = \frac{AK_BT_{cell}}{q}\ln\left[\frac{I_L}{I_O}\right] \; ; \; I_L >> I_0 \qquad (4.2)$$

b) Short-circuit: the terminals of the module are connected with an ideal conductor, through which flows a current called (I_{SC}). In this situation, the voltage between module terminals is zero.

$$I_{SC} = I_L = KG \qquad (4.3)$$

where K is constant and G is the irradiance (W/m²)

c) MPP where the voltage versus current product is maximum.

V_{MPP} is related to V_{OC} through the relation [17]:

$$V_{MPP} \approx 0.8 * V_{oc} \qquad (4.4)$$

And I_{MPP} is related to I_{SC} through the relation [17] :

$$I_{MPP} \approx 0.9 * I_{SC} \qquad (4.5)$$

The relations shown in the above two equation can be used to approximate the maximum power point coordinates in terms of voltage and current for different working meteorological conditions. The best conditions, are the "standard operating conditions" happen at Irradiance equal to 1000 W/m², cells temperature equals to 25°C, and spectral distribution (Air Mass) AM is equal to 1.5.

Nevertheless, while in operation the modules are normally not under standard condition. So another condition was defined, named "normal operation condition", which presents the following values:

Irradiance = 800 W/m2 . Ambient temperature = 20 °C . Wind speed = 1 m/s , and Spectral distribution = AM 1.5

Figure (4.9) shows a generic characteristic curve. It can be observed that, from the short circuit, the current presents a slightly descending behavior until it reaches to an "elbow" from where it decreases quickly down to zero.

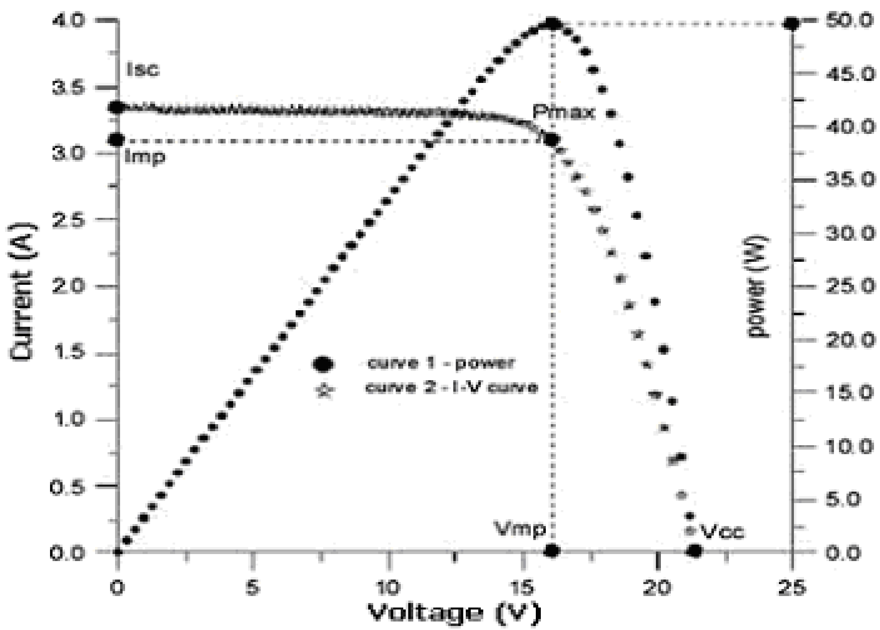

Figure (4.9) : Characteristic curve of a photovoltaic module [18]

4.4 PV Performance of Photovoltaic System

As researchers develop new types of photovoltaic (PV) cells and modify existing designs, they want to know how the cells perform electrically. Specifically, have the changes made to the cells led to improved characteristics relating to current, voltage, overall power, and the efficiency in converting the sun's energy into electrical energy? In this section, we will review the basics of the very important class of measurements conducted on solar cells to determine their performance (the current-voltage measurements).

4.4-1 Current voltage measurements

Researchers measure the performance of a PV device to predict the power the cell will produce. **Current-voltage (I-V)** relationships that measure the electrical characteristics of PV devices are depicted by what called "I-V curves." These I-V curves are obtained by exposing the cell to a constant level of light, while maintaining a constant cell temperature, varying the resistance of the load, and measuring the current that is produced.

The actual I-V curve typically passes through three significant points , as shown in Figure (4.10)

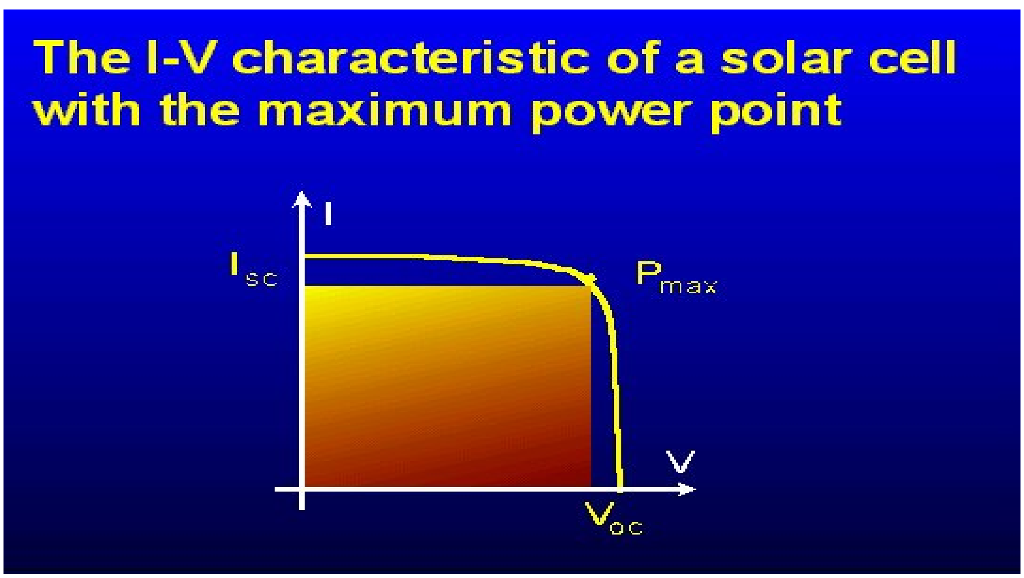

Figure (4.10) : The I-V characteristic of a PV cell [19]

The Short-Circuit Current (I_{sc}), the Open-Circuit Voltage (V_{oc}) , the Maximum-Power Point (P_m), which will be discussed later.

The cell may be operated over a wide range of voltage and currents. By varying the load resistance from zero (at short circuit) to infinity (at an open circuit), we can determine the highest efficiency as the point where the cell delivers maximum power.

4.4-2 The fill factor parameter

Measures the "square ness" of the I-V curve and describes the degree to which the voltage at the maximum power point (V_{mp}) matches V_{oc} and that the current at the maximum power point (I_{mp}) matches I_{sc}. The higher the fill factor's percentage or match, the "squarer" the curve as shown in Figure (4.11) .

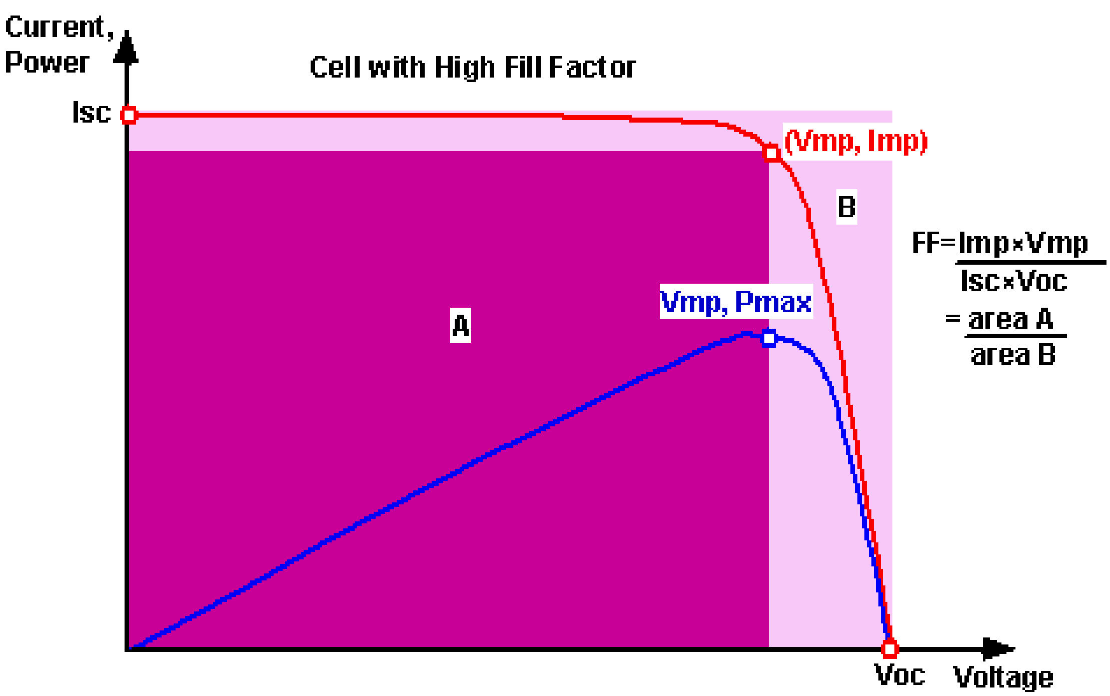

Figure (4.11): The fill factor parameter (FF) [16]

4.4-3 The conversion efficiency of a solar cell

Is the percentage of the solar energy shining on a PV device that is converted into electrical energy, or electricity. The efficiency of solar cells depends mainly on the following factors:

- The effect of the intensity of sunlight :

A cell's or module's (consisting of 36 monocrystaline silicon cells) current output is proportional to the intensity of solar radiation to which it is exposed. More intense sunlight will result in greater module output, as illustrated in Figure (4.12) .As the sunlight level drops, the shape of the I-V curve remains the same, but it shifts downward indicating lower current output. Voltage (of module is equal to 36 cells voltage of monocrystaline silicon = 36 * 0.6 =21.6 V) is approximately not changed.

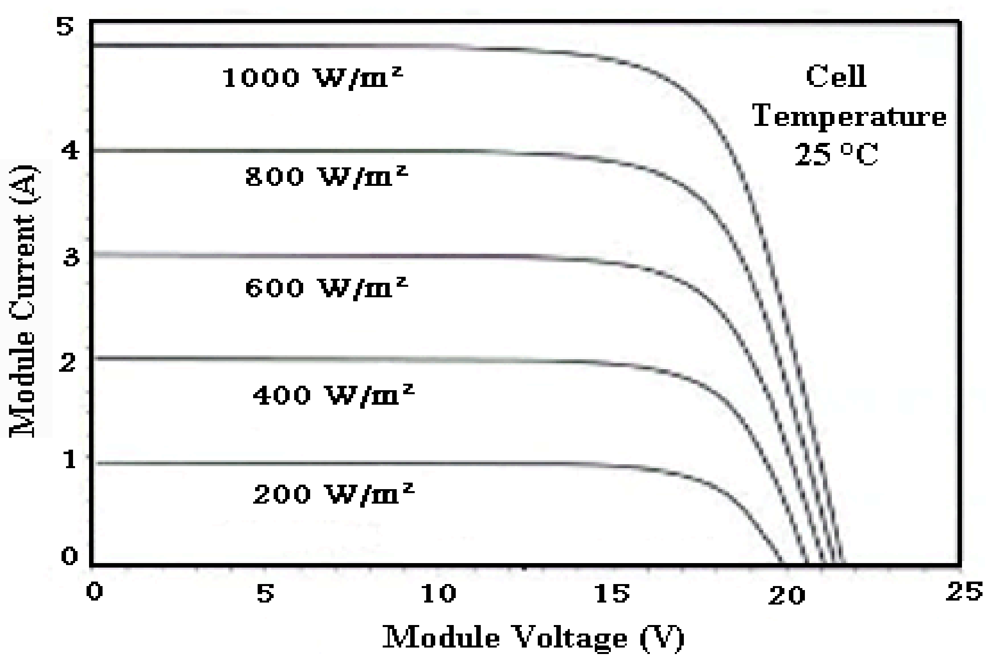

Figure (4.12) : Effect of insulation on module performance [21]

The effect of changing the irradiance level on the behavior of the solar cell can be found by finding the effect on the open-circuit voltage and the short circuit current. For a constant cell temperature of 25 °C. It is clear that the short circuit current is linearly proportional to the irradiance level. If irradiation changes from G_1 to G_2 , then the new short circuit current is found according to the following equation :

$$\frac{I_{SC\ 2}}{I_{SC\ 1}} = \frac{G_2}{G_1} \tag{4.6}$$

- The effect of cell temperature

As the cell temperature rises above the standard operating temperature of 25°C .The module of 36 cells operates with less efficiency and the voltage decreases as shown in figure (4.13).

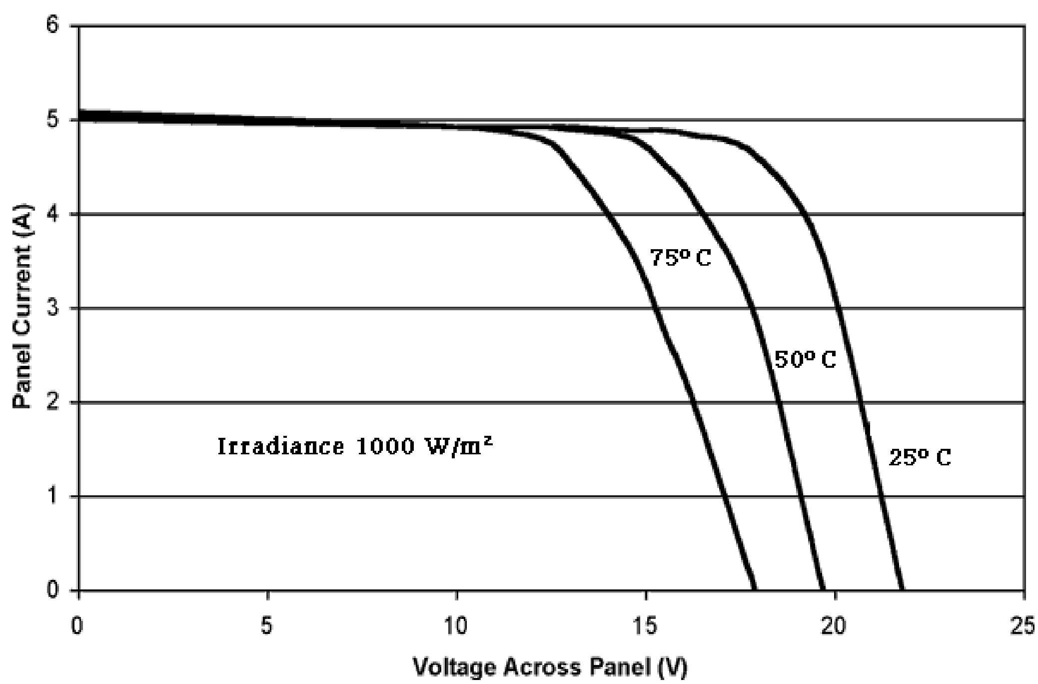

Figure (4.13) : The effect of cell Temp. on panel performance [22]

Solar cells work best at low temperatures, as determined by their material properties. All cell materials lose efficiency as the operating temperature rises. Much of the light energy shining on cells becomes heat.

It's also clear, that increasing the cell temperature increases the photocurrent slightly. This increase is in the range of 0.1 % / 1°C [17] and it's arises from a decrease in the band-gap energy of the material as the temperature increases. If the temperature changes from T_1 to T_2, then the short circuit current changes according to the equation[17] :

$$I_{SC\,2} = I_{SC\,2}\left[1 + \alpha\left(T_2 - T_1\right)\right] \tag{4.7}$$

Where α can be described as the current coefficient with respect to temperature change and is equal to (0.1 / (100 * I_{sc1})) .

On the other hand, the open-circuit voltage would decrease linearly with increasing cell temperature owing to the exponential increase in saturation current (I_o) . I_o is a current of minority careers created by thermal excitation. It's variation with temperature can be expressed as [17]:

$$I_0 = A_0 T^3 \exp\left(-\frac{E_g}{K_B T}\right) \tag{4.8}$$

Where E_g is the band-gap energy, K_B is the Boltzman's gas constant, and A_0 is the diode ideality factor. The change in the open-circuit voltage from a change in temperature from T_1 to T_2 can be expressed in the following form:

$$V_{OC2} = V_{OC1}\left[1 + \beta\left(T_2 - T_1\right)\right] \tag{4.9}$$

Where β can be described as the voltage coefficient with respect to temperature change and is equal to about (- 0.004) [17].

4.5 PV Module Performance Ratings

- **The peak watt (W_p) rating** is determined by measuring the maximum power of a PV module under laboratory conditions of relatively high light level, favorable air mass, and low cell temperature. But these conditions are not typical in the real world. Therefore, we may use a different procedure, known as the NOCT—or normal operating cell temperature—rating, which can be known from the following equation [17] :

$$T_{cell} = T_{amb} + 0.9 * \left(\frac{G}{8.5 + (3.2 * v)} \right) \qquad (4.10)$$

Where; v is the wind velocity

In this procedure, the module first equilibrates with a specified ambient temperature so that maximum power is measured at a normal operating cell temperature. This NOCT rating results in a lower watt value than the peak-watt rating, but it is probably more realistic.

- **The amount of electricity required**

may be defined by any one, or a combination, of the following performance criteria:

- **Power output**. Power (watts) available at the power regulator, specified either as peak power or average power produced during one day.
- **Energy output**. The energy (watt-hour or Wh) output. This indicates the amount of energy produced during a certain period of time. The parameters are output per unit of array area (Wh/m^2), output per unit of array mass (Wh/kg), and output per unit of array cost (Wh/$).

CHAPTER FIVE

SYSTEM CONFIGURATION OF CENTRALIZED OR DECENTRALIZED PV SYSTEMS FOR ELECTRIFICATION OF SMALL VILLAGES IN PALESTINE – TUBAS DISTRICT AREA

CHAPTER FIVE

5. System configuration of Centralized or Decentralized PV Systems for Electrifications of Small Villages in Palestine – Tubas District Area

Introduction

The world wide demand for solar photovoltaic energy systems has grown steadily over the past fifteen years. The need for reliable and low cost electric power in remote areas of the world is the primary force driving the world wide photovoltaic (PV industry). Solar photovoltaic energy systems have many advantages, in fact they are modular and silent, they have no moving parts, so they require low maintenance and they produce no emissions.

In Palestine, the PV systems can have a major contribution in generation electricity for people living in isolated areas, those who have or haven't mini diesel grid and are not connected to electricity network. The main factors favoring photovoltaic technology in this sector result from:

- The high cost of conventional energy sources in remote small villages locations.
- Price and cost of fuel transportation.

The major factors inhibiting the photovoltaic technology in this sector include high initial cost, lack of skilled manpower, lack of good social acceptance. Thus, developing mathematical model based on life cycle cost for selection of optimum configuration of PV system (centralized or decentralized system), is useful for optimizing the size of the components in each system, and to help us perform economical analysis of the entire system over the systems life time period .

The following three villages; Salhab, Ibziq, Yarza, were found to be the most appropriate villages for trying the PV electrification. As founded in a comprehensive assessment on Non-electrified villages in the West Bank [8], as shown in Figures (2.1) and (5.1):

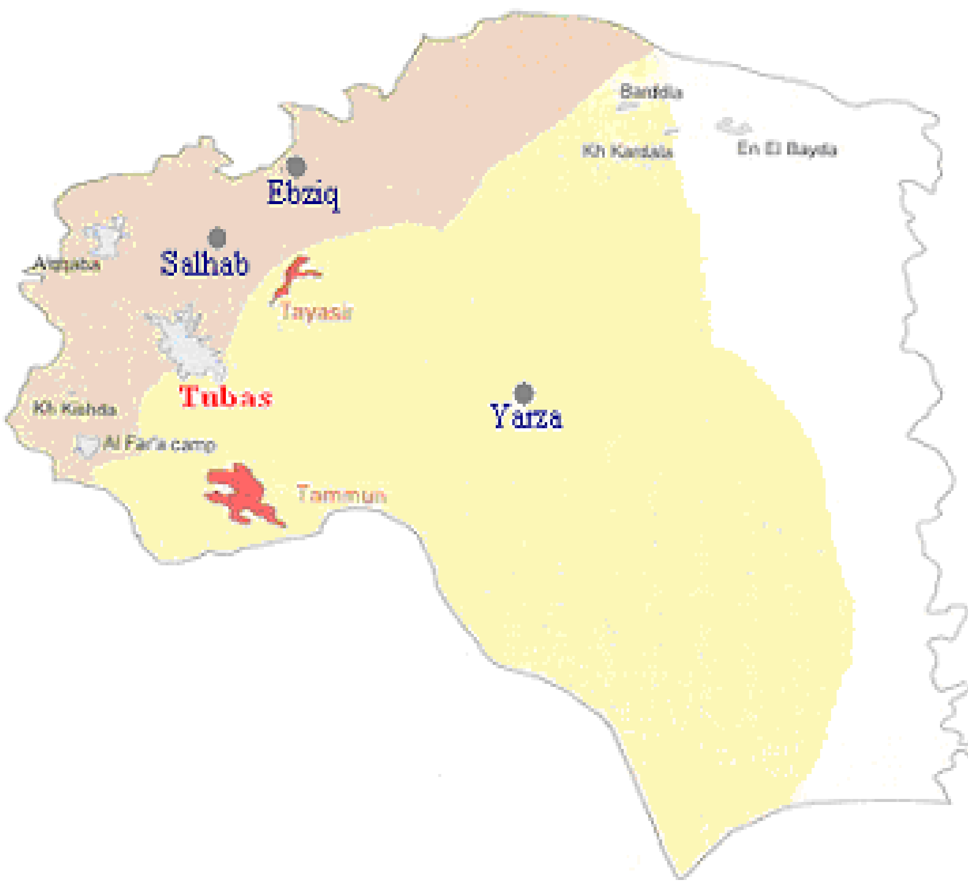

Figure (5.1): The target area (Tubas villages) non-electrified [24]

5.1 Selection of Some Non-Electrified Villages in Tubas District Area

The above three villages were selected to make this study, to electrify them by centralized or decentralized PV systems. They are located in Tubas District area (in the Eastern area of Tubas city and in the west of Jordan valley river), at the coordinates 32°15' N ; 35°30' E. The inhabitants work mainly in farming and cattle breeding. The inhabitants number of Salhab village amount to about 65 living in separated simple 10 houses. The inhabitants number of Ibziq village amount to be 165 living in separated simple 27 houses, the inhabitants number of Yarza village amount to about 85 living in separated simple 12 houses .

The average daily energy needs in such villages are very low. The households use mainly wood and biomass for cooking and baking bread. Kerosene and gas lamps are still used for lighting [8].

These villages have no gas station and are at least 4 km far from the nearest high voltage grid (33 kV) .

These villages are located in Tubas area which has high solar energy since the daily average of solar radiation on horizontal surface was measured to be more 5.45 $kWh/m^2.day$ as shown in chapter two.

During two months of summer season , high average of solar radiation exceeding 8 $kWh/m^2.day$ which has been registered as mentioned in chapter 2.

During winter season, the lowest average of solar radiation has been registered during December with a value of 2.84 kWh/m².day. The villages area has about 3000 sunshine hours per year. The annual average of ambient temperature amounts to 23° C while it exceeds 37° C during summer season.

5.2 Analysis of Electrical Loads in each Village

Actually, the electrical load in each of the mentioned villages is mainly concentrated on the night period, since the people work during the day in the field and cattle pasture.

As a result of my visit to these villages, I've noticed that most of their houses are very simple, separated, and almost similar to each other.

The main electrical loads necessary for improving the living conditions in each village are : the household appliances (lighting, radio, TV, refrigerator, washing machine, mobile charger and fan); there's no electrical load for street lighting, school, clinic, even small mosque.

5.2-1 The electrical loads of household for Salhab village

The electrical load for a simple house of two rooms in average, small kitchen, and a simple bathroom is summarized in Table (5.1) :

Table (5.1): The electrical load for typical household

Appliance	Power(W)	No.	Time(h)	Energy consumption (Wh/day)
CFL Lamps	13	3	4	156
TV	60	1	3	180
Small efficient refrigerator	80	1	8	640
Small washing Machine	160	1	0.25	40
Mobile Charger	10	2	1	20
Others	20	---	1	50
Total	373 W/house			1086 Wh/day/house

For all Salhab village (10 houses), the total required power is $373*10*\frac{1}{1.25}=2.984$ kW,where 1.25 is the diversity factor.

And the total electrical energy consumption is 1086*10 =10.860 KWh/day.

5.2-2 The electrical loads of households for Ibziq village

The number of houses in Ibziq village is 27 houses. The electrical loads in these houses are similar to those listed in Table (5.1).

Therefore,

The total required power is $373*27*\frac{1}{1.25}=8.057$ kW, and

The total electricity consumption is 1086*27 = 29.322 kWh/day

5.2-3 The electrical loads of households for Yarza village

The number of houses in Yarza village is 12 houses. With electrical loads as mentioned in Table (5.1), hence,

The total required power is $373*12*\frac{1}{1.25}=3.580$ kW, and

The total electricity consumption is 1086*12 = 13.032 kWh/day

5.3 Analysis of System Configuration Centralized or Decentralized PV System

The main differences between the above two configuration systems are:

1- The centralized PV system is more stable easy to control and to maintain.

2- The overall efficiency of centralized PV system is less than the decentralized (individual) unit, because of the inverters losses and greater wiring losses.

3- The centralized PV system is more expensive than the individual PV systems, because of eliminating the need for big mounting, big installation and big distribution infrastructure.

4- The reliability for all the village interest in decentralized PV system is more greater than the centralized PV system, so if the system stops in any house, the others will continue doing.

5- The use of land in decentralized PV system is nothing comparing to centralized PV system.

6- The decentralized PV system is modular in nature allowing for expansion or reduction based on need and economic means.

7- The decentralized PV system keeps the energy system close to the end user, allowing the end user direct control of acquisition, design, placement and consumption decisions.

8- The decentralized PV systems are holding tremendous potential for an improved quality of life for women, specially , such systems ease the time commitment and human energy required to meet daily needs**.**

CHAPTER SIX

THE DESIGN OF PV SYSTEM FOR ELECTRIFICATION OF SMALL VILLAGES IN PALESTINE

CHAPTER SIX

6. The Design of PV System for Electrification of Small Villages in Palestine

Introduction

The main characteristics of using PV system for electrification of small rural villages are: the fuel is free, technology is mature and almost world wide available and it has modularity, low maintenance requirements, high durability and also they can easily be connected to the utility network.

A rooftop mounted decentralized photovoltaic system is one of the applications of solar PV systems that has attracted lots of interest among the people in our region. The generation of electricity by this system is attractive because :

* Generation is one-site. This results in reduction of transmission and distribution costs and losses;

* The cost of roofing tiles can be eliminated by using mounted PV systems instead;

* There is no need for additional land for power generation:

The only factor hindering the growth of utilization of PV decentralized systems is relatively high capital cost.

Another configuration that photovoltaic can have a major contribution is in centralized generating electricity for people living in isolated areas. Developing a method based on life cycle cost to select the optimum configuration (centralized or decentralized) will help in increasing the utilization of PV systems.

6.1 Sizing of Centralized PV System Components for Non-Electrified Small Villages in Tubas Area

6.1-1 Design of centralized PV system components for Salhab village :

PV generator sizing

The peak power (Wp) of the PV generator (P_{PV}) is obtained from the following equation [24] :

$$P_{PV} = \frac{E_L}{\eta_V \eta_R PSH} S_f \tag{6.1}$$

where E_L (energy consumption per day) = 10.860 kWh ; PSH (the peak sun hours) = 5.587 ; η_R efficiency of charge regulator = 0.92 ; η_V efficiency of inverter = 0.9 ; S_f (the safety factor, for compensation of resistive and PV-cell temperature losses = 1.15, substituting these values in equation (6.1) to get the peak power (Wp) of the PV generator one obtains:

$$P_{PV} = \frac{10.86}{0.9 * 0.92 * 5.587} * 1.15 = 2.61 \text{ kWp}$$

To obtain this peak value, we select to install multicrystalline-36 rectangular cells module type KC 130 GHT-2 of a 0.929 m² area, rated at 12 VDC , and P_{mpp}= 130 W as shown in appendix-A. The number of necessary PV modules ($No._{PV}$) is obtained as:

$$No._{PV} = \frac{P_{PV}}{P_{mpp}} \tag{6.2}$$

$$No._{PV} = \frac{2610}{130} = 20.767 \text{ PV modules}$$

We select the voltage of the PV generator to be $V_{nominal} = 48$ V, so number of modules in series is obtained as :

$$No._{PVS} = \frac{V_{PV}}{V_{mpp}} = \frac{48}{17.6} = 2.73 \approx 3 \text{ modules} \tag{6.3}$$

And number of strings $= \frac{No._{PV}}{No._{PVs}} = \frac{20.767}{3} = 6.922 \approx 7$

The actual number of PV generator modules is 3 * 7 = 21 modules.

The configuration will be as shown in Figure (6.1). The area of the array is (3*1.425) (7*0.652) = 4.275*4.564 = 19.511 m²

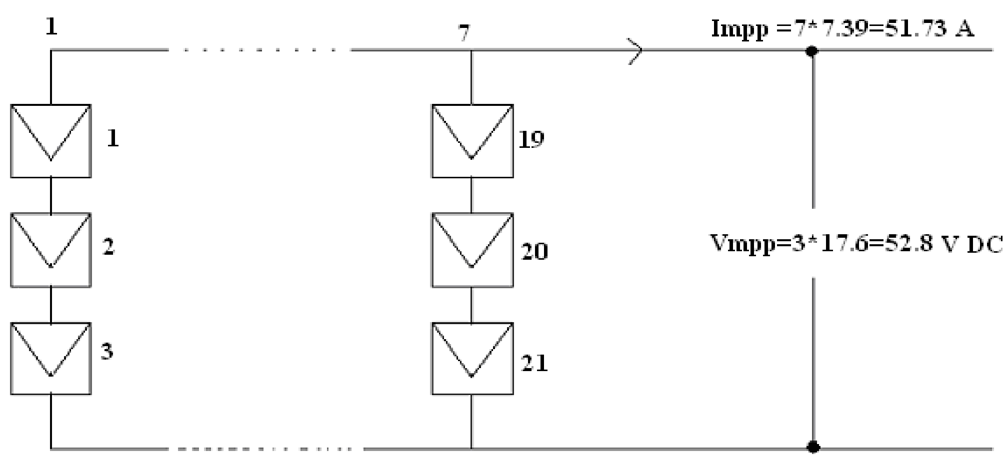

Figure (6.1): The configuration of the centralized PV generator for Salhab village

The actual maximum open circuit voltage is $V_{o.c.}$ = 3*21.9 = 65.7 V DC

The actual maximum current short circuit current is $I_{s.c}$ = 7*8.02 = 56.14 A

Accordingly, the maximum power point of this arrays will be in the I-V curve at the coordinates of 52.8 V DC and I_{mpp} of 51.73 A .

The actual maximum power obtained from PV = 52.8*51.73 = 2.731 kWp, which is more than the required power needed.

Battery block sizing

Since, the storage capacity for this system is considerably large, so we have to select a special lead-acid battery cell (block type) which are of long life (more than 10 years), high cycling stability (more than 1100 times) and standing very deep discharge [23].

The Ampere hour capacity (C_{Ah}) of the block battery, necessary to cover the load demands for a period of 2 days autonomy is obtained as [23]

$$C_{Ah} = \frac{2 * E_L}{V_B * DOD * \eta_B * \eta_V} \tag{6.4}$$

; where DOD is the depth of Discharge = 0.75

$$= \frac{2*10860}{48*0.75*0.85*0.9} = 788.671 \text{ Ah}$$

And the Watt hour capacity (C_{Wh}) is obtained as :-

$$C_{Wh} = C_{Ah} V_B \tag{6.5}$$

$$= 788.671 * 48 = 37.856 \text{ KWh}$$

To install this capacity, we need 24 block batteries in series (each battery rated at 2 V / 1000 Ah or two strings in parallel, each string of 24 batteries in series (each battery rated at 2 V / 500 Ah) as shown in Figure (6.2) (A), (B), to build a battery block of an out put rated at 48 V DC / 1000 Ah (2V/1000Ah block battery has been selected as shown in appendix B-1).

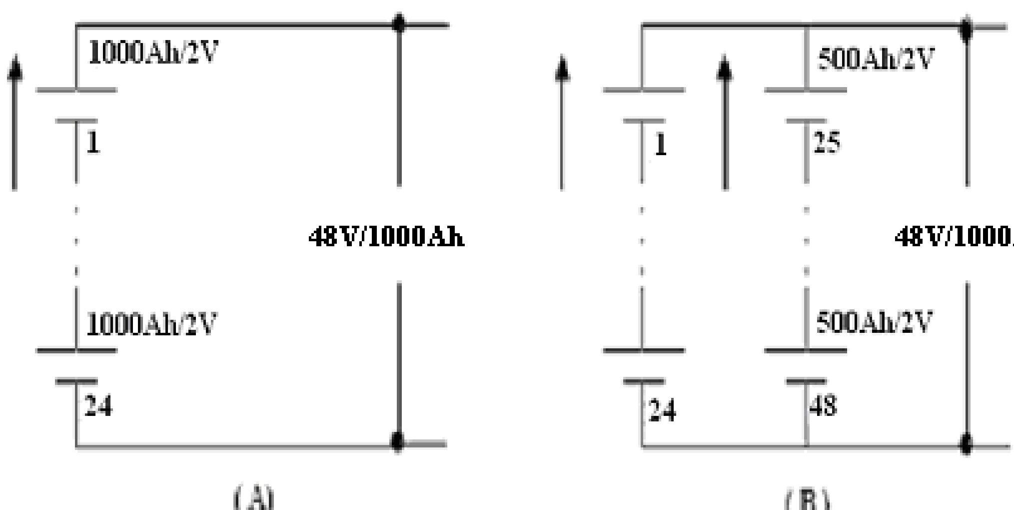

Figure (6.2): The configuration of battery blocks of the PV system for Salhab village

Charge regulator sizing

It's a DC/DC converter, used to regulate the out put 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 out put of the PV array and V_B [24] .

❖ V input , must equal to the $V_{o.c.(PV)}$ = (3*12) – (3*21.9)

= (36 – 65.7) V DC

❖ V output , must equal to $V_{nominal(PV)}$ = (48*0.875) – (48*1.2)

= (42 – 57.6) V DC

❖ The appropriate rated power of CR , must be equal to P_{PV} = 2.731 kW ≈ 3 kW. It's recommended that the CR should have a maximum power control unit.

❖ The efficiency must be not less of 92 % .

- 60A – 48V charge regulator have been selected for Salhab village, as shown in appendix C-1.

Inverter sizing

We have to determine also the following :

❖ V_{input} , has to be matched with battery block voltage = $V_{CRoutput}$ = (42 – 57.6) V DC

❖ V_{output} , should fulfill the specification of the electric grid of the village specified as: 230V AC ± 5%,single phase 50 HZ, (sinosoidal wave voltage) [24].

❖ Power of inverter :

$P_{nominal} \geq 2.984$, = 3 kW (6.6)

❖ The efficiency must be not less than 90 %

- 3 kW inverter have been selected for Salhab village, as shown in appendix D-1.

6.1-2 Design of centralized PV system components for Ibziq village:

PV generator sizing

According to equation (6.1), we get the peak power of the PV generator :

$P_{PV} = 7.289$ kWp.

To obtain this peak value, we select the same modules as before! The number of necessary PV modules ($No._{PV}$) is obtained from equation (6.2) to be :

$$No._{PV} = \frac{7289}{130} = 56.07 \text{ PV modules}$$

We select the voltage of the PV generator to be $V_{no\min al}$ = 48 V, so number of modules in series will be as before.

And number of strings $= \dfrac{56.07}{3} = 18.690 \approx 19$

The actual number of PV modules is 3 * 19 = 57 modules .

The configuration will be as shown in Figure (6.3). The area of the array is (3*1.425) (19*0.652) = 4.275*12.388 = 52.959 m²

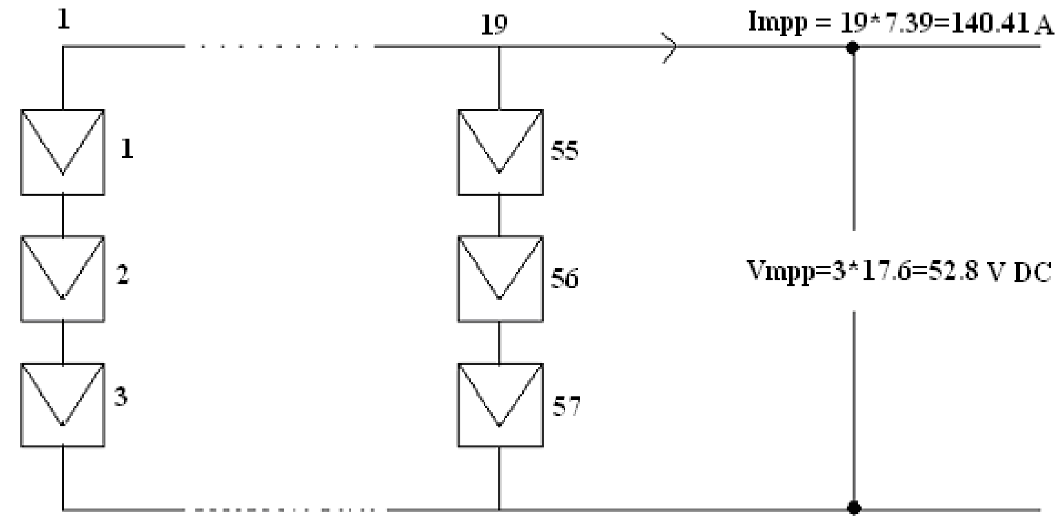

Figure (6.3): The configuration of the PV generator for Ibziq village

The actual maximum open circuit voltage $V_{o.c.}$ = 3*21.9 = 65.7 V DC

The actual maximum short circuit current $I_{s.c}$ = 19*8.02 = 152.38 A

Accordingly, the maximum power point of this array will be in the I-V curve at the coordinates of 52.8 V DC and Impp of 140.41 A .

The actual maximum power obtained from PV = 52.8*140.41 = 7.414 kWp, which is more than the required power needed.

Battery block sizing

According to equation (5.4), and 2 days autonomy.

The Ampere hour capacity :

$$C_{Ah} = 2129.41 \text{ Ah}$$

And the Watt hour capacity is obtained from equation (5.5) to be :

$$C_{Wh} = 102.212 \text{ kWh}$$

To install this capacity, we need 24 block batteries in series (each battery rated at 2 V / 2200 Ah or two strings in parallel, each string of 24 batteries in series (each battery rated at 2 V / 1100 Ah) as shown in Figure (6.4) (A), (B), to build a battery block of an out put rated at 48 V DC / 2200 Ah (2V/220000 Ah block battery has been selected) as shown in appendix B-2.

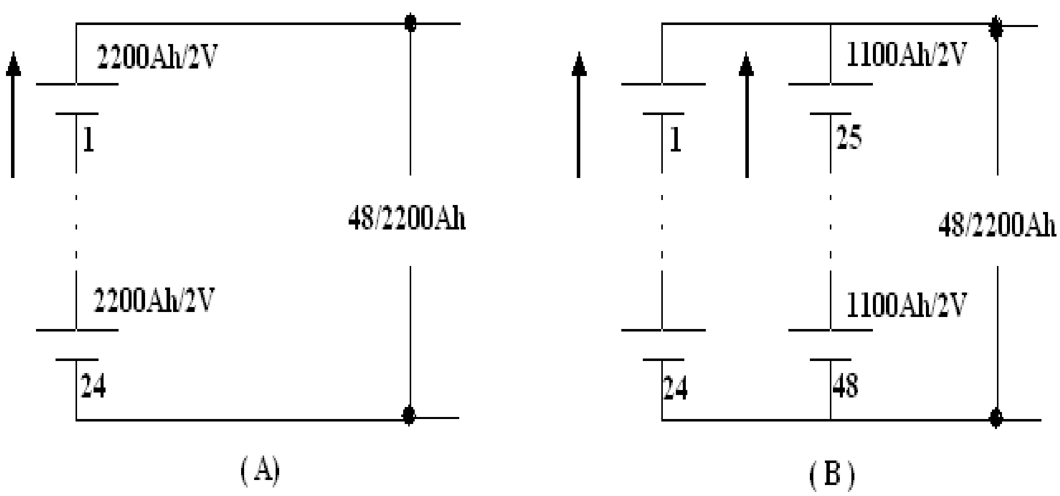

Figure (6.4): The configuration of battery blocks of the PV system for Ibziq village

Charge regulator sizing

All the characteristics of this charge regulator similar to that one of Salhab village, except that the appropriate rated power must be: P_{PV} = 7.414 kW ≈ 8 kW.

- Two in parallel of 80A – 48V Charge regulator have been selected for Ibziq village as shown in appendix C-2.

Inverter sizing

The characteristics of this inverter are similar to that of Salhab village except that the nominal power must be:

$P_{no\min al} \geq 8.057$ kW ≈ 8.5 kW

- 8.5 kW inverter have been selected for Ibziq village as shown in appendix D-2.

6.1-3 Design of centralized PV system components for Yarza village:

PV generator sizing

According to equation (6.1), we get the peak power of the PV generator :

$$P_{PV} = 3.240 \text{ kWp.}$$

To obtain this peak value, we select the same module as before. The number of necessary PV modules ($No._{PV}$) is obtained from equation (6.2) to be :

$$No._{PV} = \frac{3240}{130} = 24.920 \text{ PV modules}$$

We select the voltage of the PV generator to be $V_{no\min al}$ = 48 V, so number of modules in series will be as before ≈ 3 modules.

$$\text{And number of strings} = \frac{24.920}{3} = 8.307 \approx 9$$

The actual number of PV generator modules is 3 * 9 = 27 modules.

The configuration will be as shown in Figure (6.5). The area of the array is (3*1.425) (9*0.652) = 4.275*5.868 = 25.086 m²

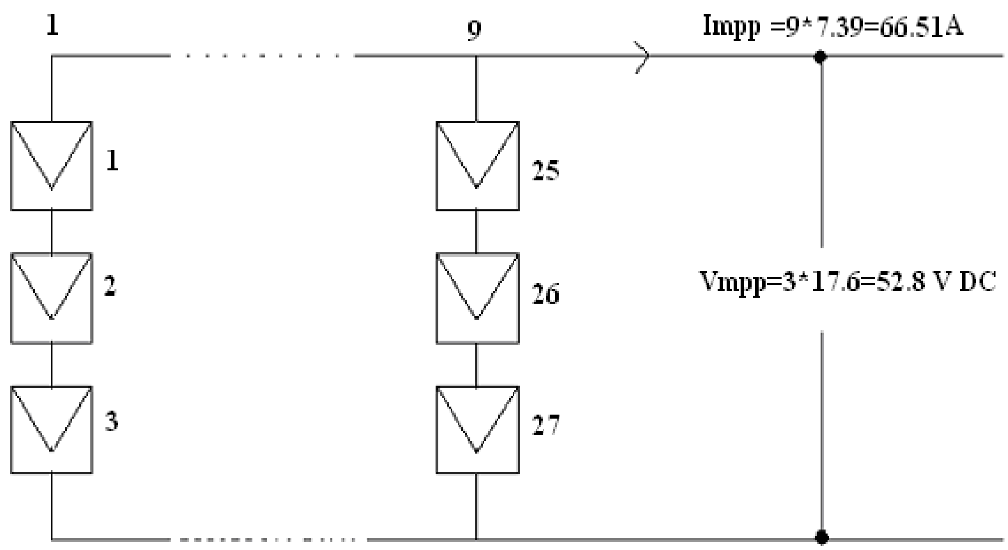

Figure (6.5): The configuration of the PV generator for Yarza village

The actual open circuit voltage $V_{o.c.}$ = 3*21.9 = 65.7 V DC

The actual short circuit current $I_{s.c}$ = 9*8.02 = 72.18 A

Accordingly, the maximum power point of this two array will be in the I-V curve at the coordinates of 52.8 V DC and Impp of 66.51 A .

The actual maximum power obtained from PV = 52.8*66.51 = 3.512 KWp, which is more than the required power needed.

Battery block sizing

According to equation (6.4), and 2 days autonomy.

The Ampere hour capacity:

$$C_{Ah} = 946.410 \text{ Ah}$$

and the Watt hour capacity is obtained from equation (6.5) to be :

$$C_{Wh} = 45.427 \text{ KWh}$$

To install this capacity, we need 24 block batteries in series (each battery rated at 2 V / 1000 Ah or two strings in parallel, each string of 24 batteries in series (each battery rated at 2 V / 500 Ah) as shown in Figure (6.6) (A), (B), to build a battery block of an out put rated at 48 V DC / 1000 Ah (2V/1000Ah block battery has been selected) as shown in appendix B-1

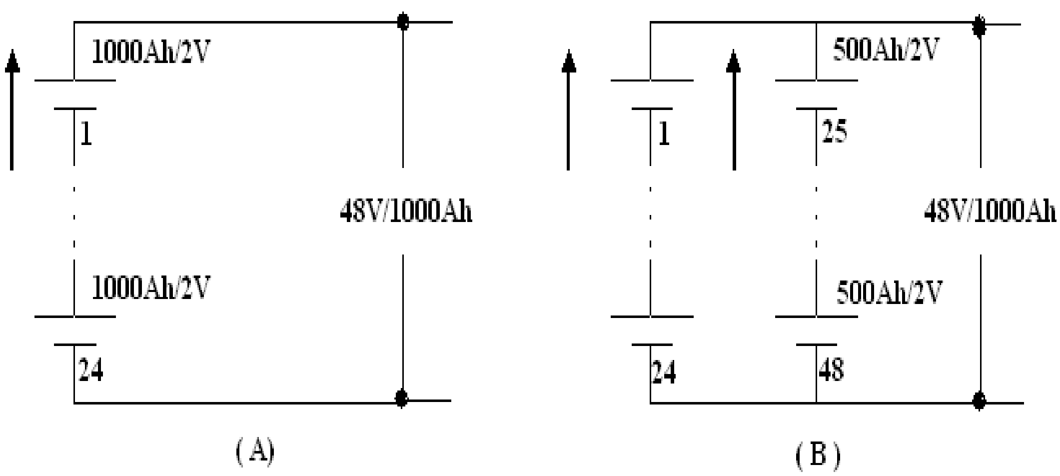

Figure (6.6): The configuration of battery blocks of the PV system for Yarza village

Charge regulator sizing

All the characteristics of charge regulator are similar to that one of Salhab village, except the appropriate rated power of CR , must be; P_{PV} = 3.512 KW ≈ 4 kW.

- 80A – 48V Charge regulator have been selected for Yarza village as shown in appendix C-2.

Inverter sizing

All the criteria of the inverter is the same to that of Salhab village except the nominal power:

$$P_{no\min al} \geq 3.580 \text{ kW}, \ = 4 \text{ kW}$$

- 4 kW inverter have been selected for Yarza village as shown in appendix D-3.

6.2 Design of Decentralized PV System Components for Non-Electrified Small Villages in Tubas Area

6.2-1 Salhab decentralized PV system sizing

Sine the houses of Salhab village are almost similar to each others, we take one of these houses and according to its electrical load, we can calculate of the peak power (W_P) of the PV generator (P_{PV}) for one house to be the same for other houses. From equation (6.1) we obtain :

$$P_{PV} = \frac{1086 * 1.15}{0.9 * 0.92 * 5.587} = 269.972 \text{ Wp}$$

To realize this peak power, we select the same module as before. The number of necessary PV modules ($No._{PV}$) is obtained from equation (6.2) to be:

$$No._{PV} = \frac{269.972}{130} = 2.076 \text{ PV modules}$$

We select the voltage of the PV generator to be $V_{nominal} = 24$ V, so number of modules in series is obtained from equation (6.3) to be :

$$No._{PVS} = \frac{24}{17.6} = 1.364 \approx 2 \text{ modules}$$

And number of strings $= \dfrac{2.076}{2} = 1.038 \approx 1$

The actual number of PV modules is 2 * 1 = 2 modules .

The configuration will be as shown in Figure (6.7). Area of the array is 2*1.425*0.652 = 1.858 m²

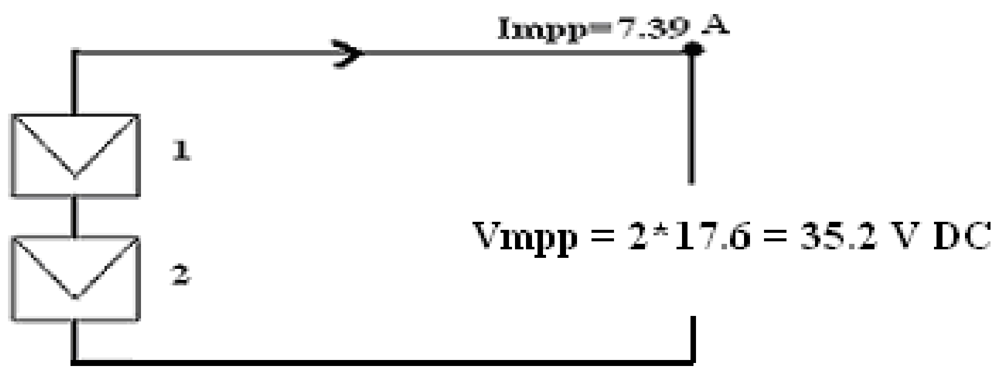

Figure (6.7): The configuration of the PV generator for a typical unit of decentralized PV system

The actual open circuit voltage $V_{o.c.}$ = 2*21.9 = 43.8 V DC

The actual short circuit current $I_{s.c}$ = 1*8.02 = 8.02 A

Accordingly, the maximum power point of this generator in the I-V curve has the coordinates 35.2 V DC and 7.39 A .

The actual maximum power obtained from PV = 35.2*7.39 = 260.128 Wp.

Battery block sizing

According to equation (6.4), and 2 days autonomy.

The ampere hour capacity :

$$C_{Ah} = \frac{2*1086}{24*0.75*0.85*0.9} = 157.734 \text{ Ah}$$

and the watt hour capacity is obtained from equation (6.5) to be :

$$C_{Wh} = 157.734*24=3.786 \text{ kWh}$$

To install this capacity, we need 1 regular (lead acid) battery rated at 24 V / 160 Ah or 2 batteries in series (each battery rated at 12 V / 160 Ah) as shown in Figure (6.8) (A), (B), to build a battery block of an out put rated at 24 V DC / 160 Ah (12 V / 160 Ah block battery has been selected) as shown in appendix B-3.

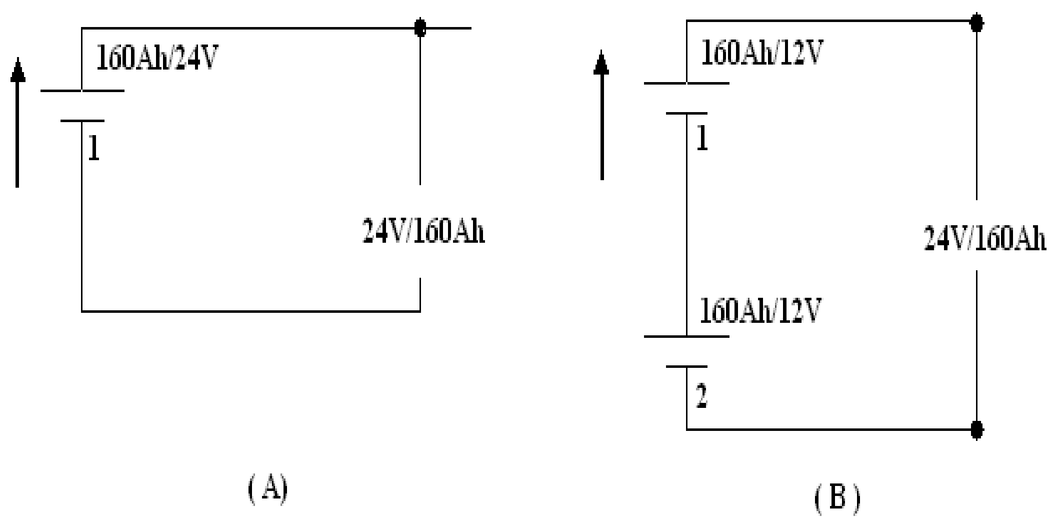

Figure (6.8): The configuration of battery blocks of the PV system for a typical unit of decentralized PV system

Charge regulator sizing

All the characteristics of charge regulator is the same to that of Salhab village in (5.1-1), except that the appropriate rated power of CR , must be equal to P_{PV} = 260.128 W ≈ 300 W.

- 10A – 24V Charge regulator have been selected for a typical unit of decentralized system as shown in appendix C-3.

Inverter sizing :

All the criteria of the inverter is the same to that of Salhab village except :

- The output voltage(210-230)V AC, single phase, 50 Hz, sinosoidal wave voltage .
- The nominal power : $P_{nominal} \geq 373$ W ≈ 400 W
- 400 W inverter have been selected for each separated house as shown in appendix D-4.

>> So, we need 10 units (similar to this calculated unit) for Salhab village

6.2-2 Ibziq decentralized PV system sizing

>> So, we need 27 units (similar to the calculated unit for Salhab village)

6.2-3 Yarza decentralized PV system sizing

>> So, we need 12 units (similar to the calculated unit for Salhab village)

6.3 Maximum overall efficiency for centralized and decentralized PV system

$$\zeta_{\max.} = \frac{P_{\max.output}}{P_{\max.input}} = \frac{V_{mpp} * I_{mpp}}{G * A_{PV}} * \zeta_{\max.CR} * \zeta_{\max.Inverter} * \zeta_{distribution\ \ lines}$$

(6.7)

Hence, $\zeta_{\max.centralized.(Salhab)} = \frac{525.8 * 51.73}{1000 * 19.511} * 0.92 * 0.90 * 0.95 = 11.01\%$

$$\zeta_{\max.centralized.(Ibziq)} = 11.01\%$$

$$\zeta_{\max.centralized.(Yarza)} = 10.68\%$$

Hence, $\zeta_{\max}$ for centralized in average equals 10.90% and,

$\zeta_{\max}$ for decentralized PV system equals 11.59%

It's clear that, $\zeta_{\max.decentralized\ PV\ system} > \zeta_{\max.centralized\ PV\ system}$

CHAPTER SEVEN

ECONOMIC MODEL FOR SELECTION OF OPTIMUM CONFIGURATION OF PV SYSTEMS (CENTRALIZED OR DECENTRALIZED)

CHAPTER SEVEN

7. Economic Model for Selection Optimum Configuration of PV Systems (Centralized or Decentralized)

Introduction

The basis of most engineering decisions is economics, beside other significant scientific & environmental factors. Designing and building a device or system that functions properly is only a part of the engineer's task.

The economic model is based on the use of conventional life cycle cost. This includes yearly cash flows, the present value of system costs, incomes and levelized annual costs. In addition, the analysis has been designed to allow economical comparison of centralized and decentralized PV system.

7.1 Mathematical Model of Centralized PV System

This model, which we are going to approach in this section is based primarily on the Life Cycle Cost (LCC) concept.

LCC is a multi-step process. This process requires sets of data from field systems and the development of a sophisticated database tool for analysis of the data. LCC determines which power supply systems can be cost-competitive with other energy options [25,26], as shown in equation (7.1):

$$LCC_{centr.} = C_{cap.tot} + C_{pw.Ann} + C_{pw.\mathrm{Re}\,p} + C_{pw.Loss} - C_{pw.Sal} \tag{7.1}$$

Where ; $C_{cap.tot}$; is the total capital cost for the centralized PV system

= the capital cost of PV array, charge regulator, batteries, networks, others and the installation cost for whole system .

$C_{pw.Ann}$; is the present worth value of annualized maintenance cost of the system

$= (C_{tot.Ann}$ x $(SPWF, i, T))$

Where ;

$C_{tot.Ann}$; is the total annual cost of the system it consists of regular maintenance costs.

$SPWF$; is the series-present-worth factor available in any interest factors tables from any engineering economy book [26].

$$= A \left[\frac{(1+i)T - 1}{i\,(1+i)T} \right]$$

i ; is the interest value (10 %)

T ; is the system life time (years)

$C_{pw.\mathrm{Rep}}$; is the present worth value of the replacement cost

$= (C_{\mathrm{Re}\,p}$ x $(SPWF, i, T))$

Where;

C_{Rep} ; is the replacement costs, which involve regular cost payments but are not truly annual , it consists of the replacement cost of batteries, inverters and others .

$C_{pw.Loss}$; is the present worth value of the total annual losses and it concentrated on the losses of the electrical system network and partly losses of DC wiring between PV system component. DC wiring losses can generally be neglected.

$C_{pw.Sal}$; is the present worth value of the salvage amount.

7.2 Mathematical Model for Decentralized PV System

The LCC model will be as shown in equation (6.2) :

$$LCC_{Decent.} = \left(C_{cap.tot} + C_{pw.Ann} + C_{pw.\mathrm{Re}p} - C_{pw.Sal} \right) n$$

(7.2)

Where ;

$LCC_{Decent.}$ is the total of LCC for all the houses in the village

n is the number of all separated simple and similar houses .

7.3 Software Programming (Flow Chart) for Selection of Optimum Configuration of Centralized or Decentralized PV System

The following flow chart Figure (7.1) is explaining how the software can select the optimum configuration design of the system.

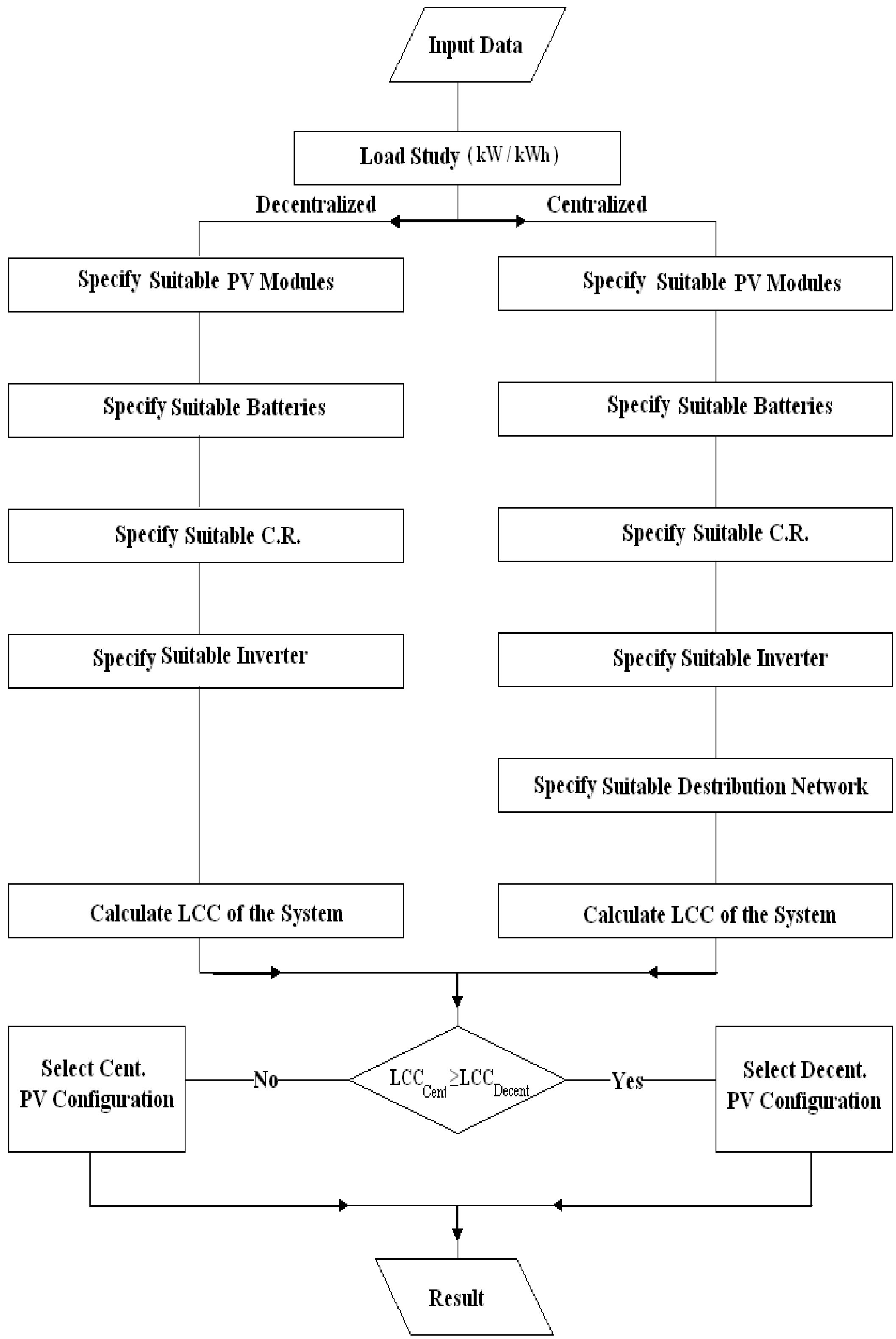

Figure (7.1): Flow chart for optimum configuration design of the system.

7.4 Economic Evaluation of Centralized and Decentralized PV System for Tubas Villages as Case Study :

7.4-1 The cost of centralized PV system for Tubas villages:

For Salhab village, the associated costs of the components, materials and erection of the centralized PV power system are shown in table (7.1):

Table (7.1): The costs of the centralized PV system for Salhab village

Component	Quantity	Unit price US $	Total price US $	Life time year
PV-module (KC 130)	2731Wp	4/Wp	10924	25
Support Structure	7	100	700	25
Batteries (2V/1000Ah)	24	500	12000	10
Charge Regulator 3 kW	1	600/kW	1800	12
Inverter 3 kW	1	1000/kW	3000	12
C.B. & switches	---	---	200	10
Installation Material	---	---	500	25
Civil Work	---	---	2500	25
Installation Cost	---	---	1400	---
Network* Cost;poles	10	150	1500	25
Joints	10	5	50	25
User connection	10	20	200	25
Conductors ($3x16mm^2$ ABC)	400m	5	2000	25
Installation	---	3/m	1200	---
Total Capital System Cost	**37974 US $**			
O&M** System Cost /year	---	---	350	---
Electrical Losses*** /year	---	---	250	---
Salvage Value			4000$	

- Suppose , the land of project is free of money

* See Fig.(7.2), Salhab electrical network map.

** O&M System Cost means operating and maintenance system cost, and it's suggested generally to be (1-2)% of total investment cost .

*** Electrical losses is suggested generally to be 5% of total electricity generated.

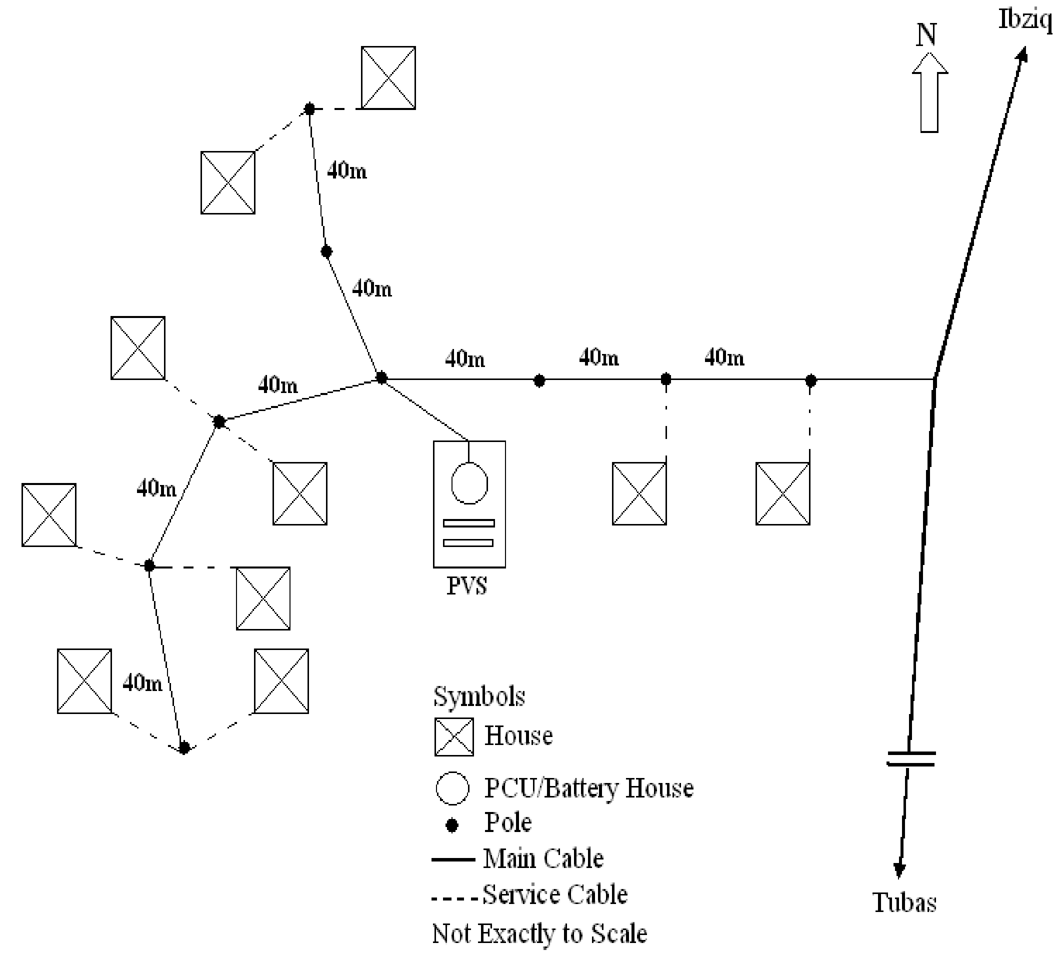

Figure (7.2): Salhab electrical network map

The Cash flow for centralized PV system for Salhab village is shown in Figure (7.3):

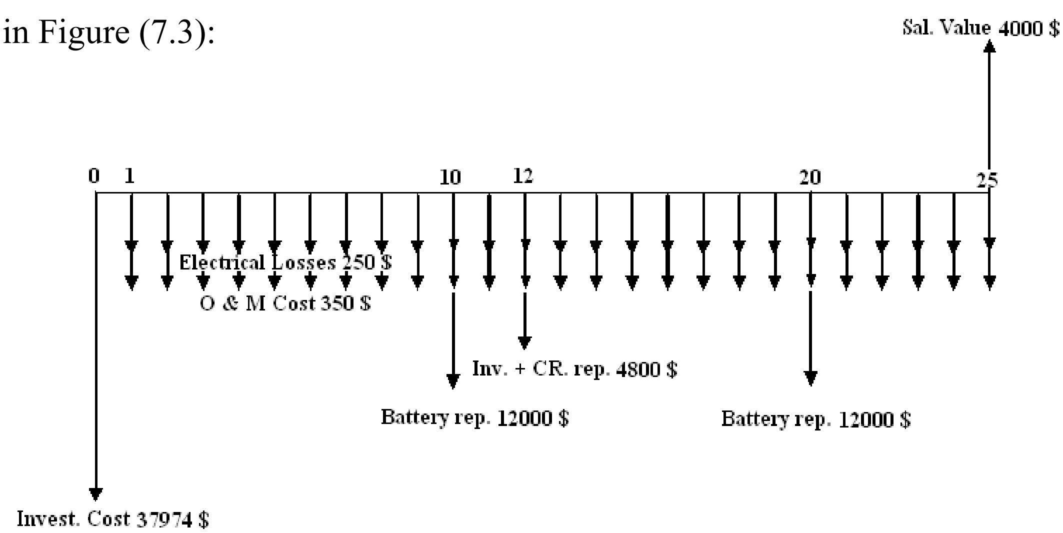

Figure (7.3): The cash flow for centralized PV system for Salhab village

For Ibziq village, the associated costs of the components, materials and erection of the centralized PV power system are shown in table (7.2):

Table (7.2): The costs of the centralized PV system for Ibziq Village

Component	Quantity	Unit price US $	Total price US $	Life time year
PV-module (KC 130)	7414Wp	4/Wp	29656	25
Support Structure	19	100	1900	25
Batteries (2V/2200Ah)	24	1000	2400	10
Charge Regulator 8 kW	1	600/kW	4800	12
Inverter 8.5 kW	1	1000/kVA	8500	12
C.B. & switches	---	---	300	10
Installation Material	---	---	600	25
Civil Work	---	---	2500	25
Installation Cost	---	---	3800	---
Network* Cost;poles	24	150	3600	25
Joints	24	5	120	25
User connection	27	20	540	25
Conductors (3x16mm² ABC)	900m	5	4500	25
Installation	---	3/m	2700	---
Total Capital System Cost	**87516 US $**			
O&M** System Cost 1%	---	---	800	---
Electrical Losses 5%	---	---	700	---
Salvage Value			9000$	

- Suppose , the land of project is free of money

* See Fig. (7.4), Ibziq electrical network map.

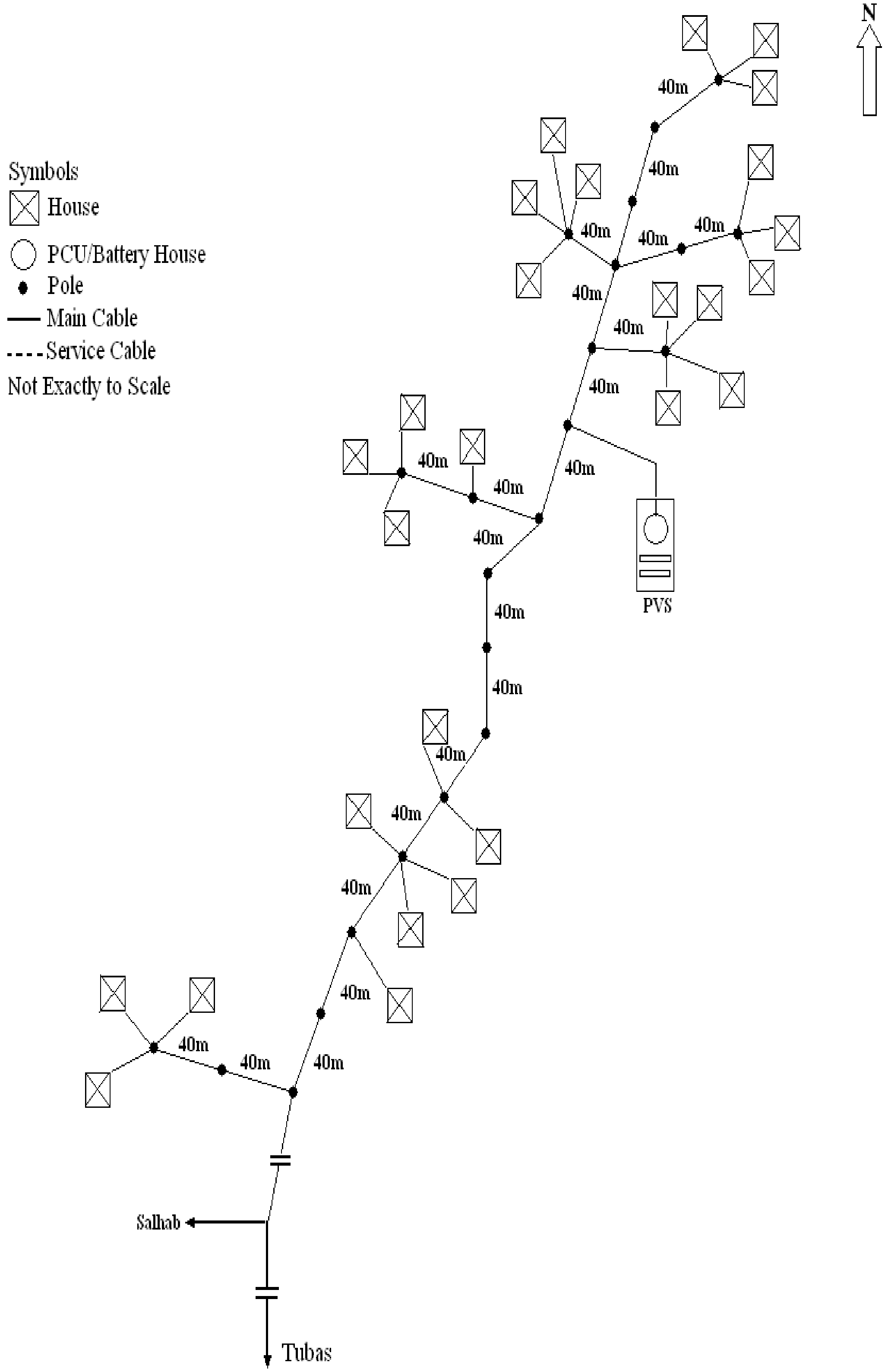

Figure (7.4): Ibziq electrical network map

The Cash flow for centralized PV system for Ibziq village is shown in Figure (7.5)

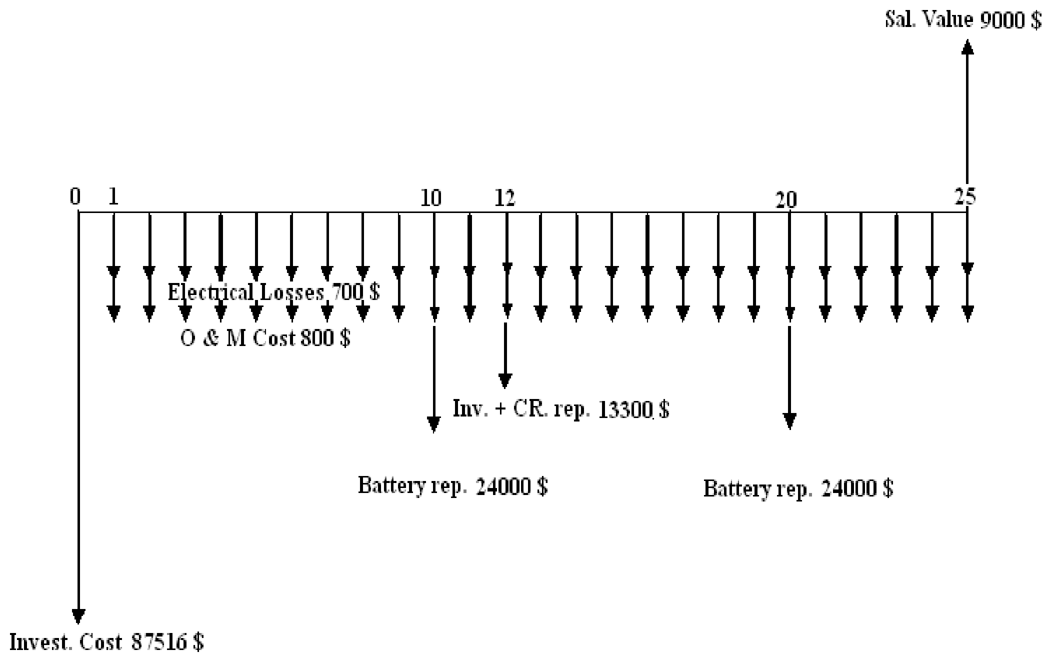

Figure (7.5): The cash flow for centralized PV system for Ibziq village

For Yarza village, the associated costs of the components, materials and erection of the centralized PV power system are shown in table (7.3):

Table (7.3): The costs of the centralized PV system for Yarza village

Component	Quantity	Unit price US $	Total price US $	Life time year
PV-module (KC 130)	3512Wp	4/Wp	14048	25
Support Structure	9	100	900	25
Batteries (2V/1000Ah)	24	500	12000	10
Charge Regulator 3 kW	1	600/kW	2400	12
Inverter 3 kW	1	1000/kVA	4000	12
C.B. & switches	---	---	200	10
Installation Material	---	---	500	25
Civil Work	---	---	2500	25
Installation Cost	---	---	1800	---
Network* Cost;poles	10	150	1500	25
Joints	10	5	50	25
User connection	12	20	240	25
Conductors (3x16mm² ABC)	400m	5	2000	25
Installation	---	3/m	2700	---
Total Capital System Cost	**44788 US $**			
O&M** System Cost /year	---	---	400	---
Electrical Losses	---	---	200	---
Salvage Value			5000$	

- Suppose , the land of project is free of money

* See Fig.(7.6), Yarza electrical network map

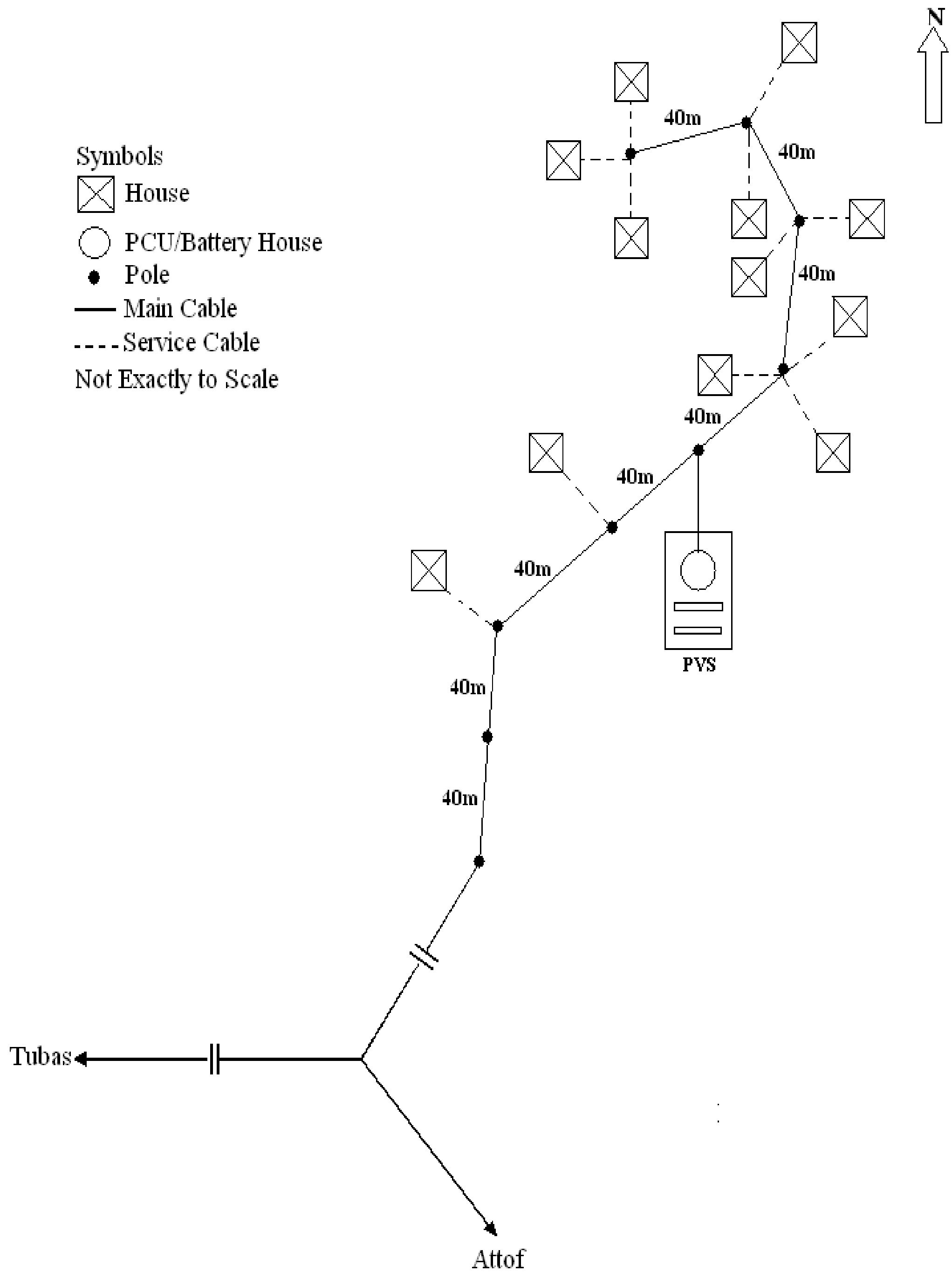

Figure (7.6): Yarza electrical network map

The cash flow for centralized PV system for Yarza village is shown in Figure (7.7)

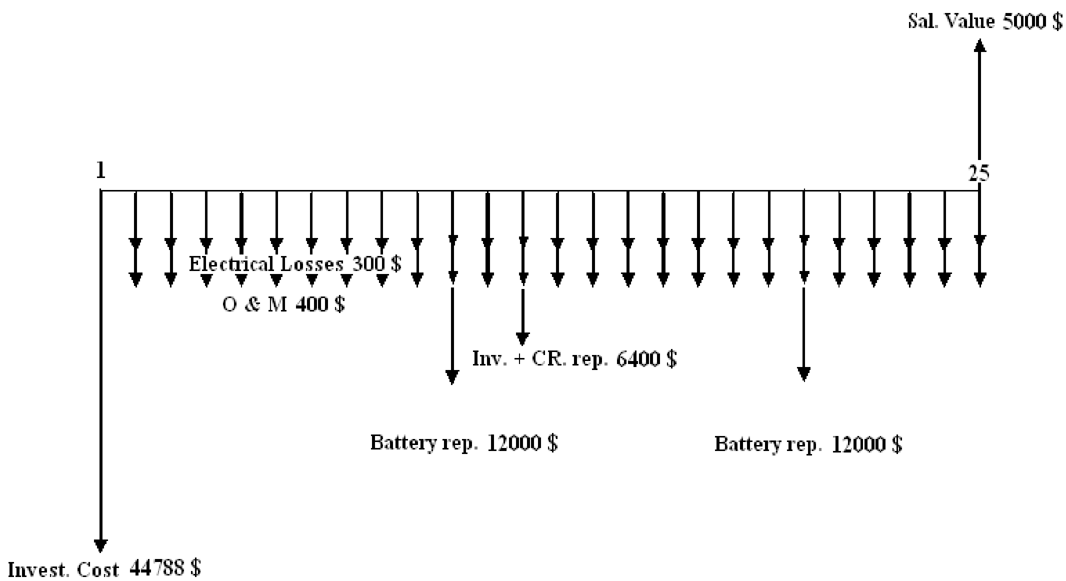

Figure (7.7): The cash flow for centralized PV system for Yarza village

7.4-2 The cost of decentralized PV power system for Tubas villages

For Salhab village, the associated costs of the components, materials and erection of one unit for decentralized PV power system are shown in table (7.4):

Table (7.4): The Costs of two component of the Decentralized PV System

Component	Quantity	Unit price US $	Total price US $	Life time year
PV-module (KC 130)	260.128Wp	5/Wp	1300.6	25
Support Structure	1	100	100	25
Batteries (12V/160Ah)	2	000	200	5
Charge Regulator 300 W	1	700/kW	210	12
Inverter 400W	1	1200/kVA	480	12
C.B. & switches	---	---	100	10
Installation Material	---	---	300	25
Box Work	---	---	200	25
Total Capital System Cost	**2890.6 US $**			
Installation Cost	---	---	300	---
O&M** System Cost	---	---	100	---
Salvage Value			500$	

• Suppose , the land of project is free of money

We have 10 similar simple houses, so we need 10 similar units .

>> The total capital cost will be 10 * 2890.6 = 28906 US $

The cash flow for one unit of decentralized PV system in Figure (7.8)

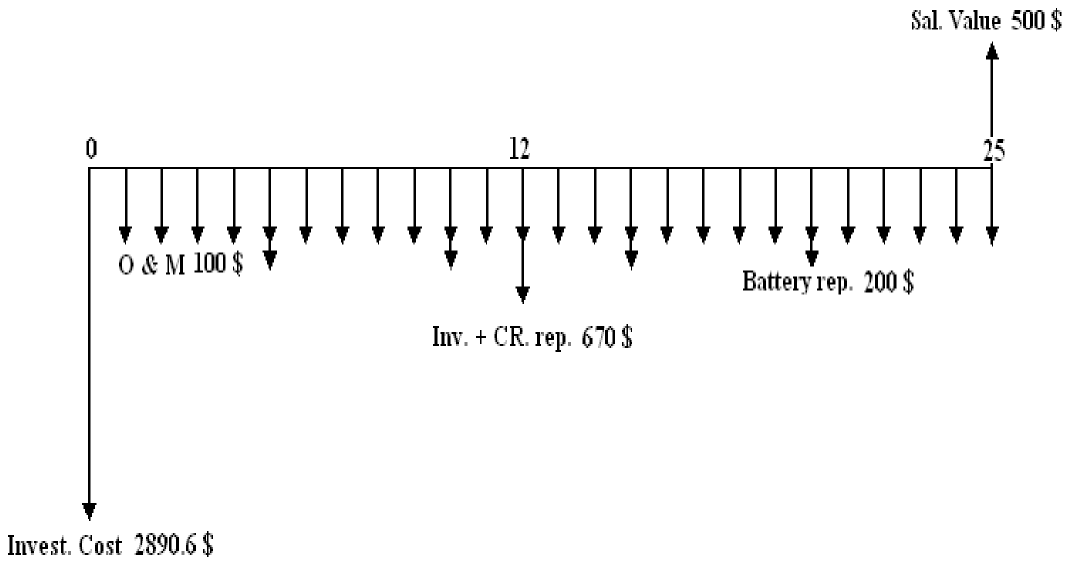

Figure (7.8): The cash flow for one unit of decentralized PV system

For Ibziq village,

We have 27 similar simple houses, so we need 27 similar units

>> The total capital cost will be 27 * 2890.6 = 78046.2 US $

For Yarza village,

We have 12 similar simple houses, so we need 12 similar units

>> The total capital cost will be 12 * 2890.6 = 34687.2 US $

7.4-3 Economic evaluation for both, centralized and decentralized PV power System

In order to establish the absolute or relative acceptability of an investment, we can use two different procedures, the static method or the dynamic method. The difference between them is that dynamic method takes into account the different times at which payments on an investment are receivable. This means in our case that payments are discounted if they come after a project is commissioned.

Therefore, by using dynamic procedures, receipt and payments are given higher value the earlier they fall and lower value later.

Because of this time component is evaluating investment linked payments, the dynamic method produce undoubtedly better results than the static method [22].

One of the most dynamic method indicators is the Life Cycle Cost (LCC) indicator .

Economic evaluation of small Tubas villages by (LCC) economic indicator

For centralized PV system, we easily use the equation (7.1), and for decentralized PV system, use equation (7.2)

And apply the available cost information from the previous cost tables to get the following :

Salhab village

Option I – Centralized system

LCC = 37974 + 350(P/A,10%,25) + 12000(P/F,10%,10) + 4800(P/F,10%,12) + 12000(P/F,10%,20) + 250(P/A,10%,25) - 4000(P/F,10%,25) = **$ 50989.48**

Where; (P/A, 10%,25) : find present value from annual value at the interest rate of 10% and at the life time of 25 years.

(P/F,10%,10) : find present value from future value at the interest rate of 10% and at the life time of 10 years.

Option II – Decentralized system

LCC = **$ 42444.9**

Ibziq village

Option I – Centralized system

LCC = **$ 117356.2**

Option II – Decentralized system

LCC = **$ 114601.28**

Yarza village

Option I – Centralized system

LCC = **$ 59128.64**

Option II – Decentralized system

LCC = **$ 50933**

The following table (7.5) summarize the Life Cycle Cost (LCC) for both centralized and decentralized PV system for Tubas villages:

Table (7.5) : LCC for both systems for Tubas villages

Village Name	LCC for Centralized ($)	LCC for Decentralized ($)
Salhab	50989.48	42444.9
Ibziq	117356.2	114601.28
Yarza	59128.64	50933.9

It's clear that for Salhab village, Ibziq and Yarza, the LCC of the decentralized PV system is less than LCC of centralized PV system, hence, the decentralized PV system will be adopted for the three selected villages.

It's obvious also, that the LCC for Ibziq village is approximately the same in both centralized and decentralized PV system, centralized PV system exceeds only 2.4% than decentralized PV system. On versus, the other villages (Salhab and Yarza) centralized PV system exceeds 20.13% and 16.09% respectively.

7.4-4 Cost annuity for selected Tubas villages :

Cost annuity bases on annual cost for annual production of electricity.

Annual cost = present worth cost (A/P, i , n) (7.3)

Annual production of electricity is the summation of electricity for each month of the year

Salhab village

For selected configuration (decentralized P system) the annual cost will be:

Annual cost = 42444.9 (A/P,10%,25)

= 4676.15 $/year

Table (7.6) shows the production of electricity for each month.

Table (7.6): Monthly electricity produced from decentralized PV system

Month	kWh
1	232.531
2	244.823
3	421.216
4	487.266
5	609.739
6	643.110
7	658.260
8	652.779
9	491.712
10	378.820
11	277.836
12	228.904
Total	5326.996

And figure (7.9) shows also how electricity produced from decentralized PV system during the year.

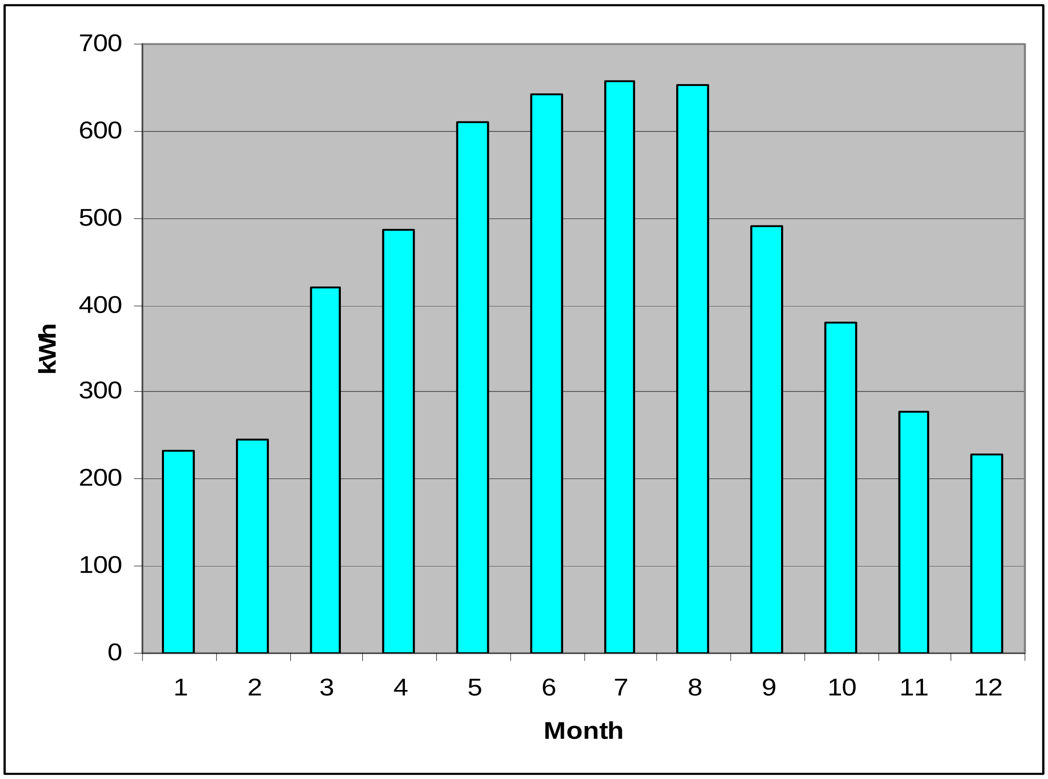

Figure (7.9) : Monthly electricity produced from decentralized PV system

Hence, annual production of electricity = 5326.996 kWh

Hence, the cost annuity for Salhab village = 0.877 \$/kWh

= 3.511 NIS/kWh

For Ibziq and Yarza village, the cost annuity will be the same to Salhab village (0.877 \$/kWh = 3.511 NIS/kWh), since we are considering the same decentralized PV system.

Table (7.7) summarize the cost annuity for both centralized and decentralized PV system.

Table (7.7) :Cost annuity for both centralized and decentralized PV system

Village nam	Cost annuity for centralize $/kWh	Cost annuity for decentraliz $/kWh
Salhab	1.008	**0.877**
Ibziq	**0.855**	0.877
Yarza	0.909	**0.877**

It's obvious that cost annuity for both Salhab and Yarza is less in decentralized PV system, in contrast to, for Ibziq village, the cost annuity is less in centralized PV system, that's because of the specific cost of any big size project has to be less of any small size project.

7.5 LCC and cost annuity for DC load of decentralized PV system

Since we have the total peak power (Wp) for each house in decentralized PV system is less than 300 watt, we have to use DC load system [27] as all the appliances needed in the simple houses are available in DC in the local market.

Consequently, inverter is not needed anymore in DC load system, so the LCC will be less than of the AC system calculated before.

Hence, LCC for each unit (simple house)

LCC = $ 3617.33

For Salhab village = 3617.33*10 = $ 36173.3

For Ibziq village = 3617.33*27 = $ 97667.937

For Yarza village = 3617.33*12 = $ 43407.792

Cost annuity :

Annual cost = $ 3985.2

Annual production = 5326.996 kWh

Hence, cost annuity = 0.748 $/kWh = 2.998 NIS/kWh

Table (7.8) summarizes the cost annuity for three options, centralized AC load, decentralized AC load and decentralized DC load PV system.

Table (7.8) : Cost annuity for centralized AC load, decentralized AC load and decentralized DC load

Village name	Cost annuity for cent.AC load $/kWh	Cost annuity for decent. AC load $/kWh	Cost annuity for decent. DC load $/kWh
Salhab	1.008	0.877	0.748
Ibziq	0.855	0.877	0.748
Yarza	0.909	0.877	0.748

And figure (7.10) shows also how cost annuity differs for each village and for each one of the three systems mentioned before.

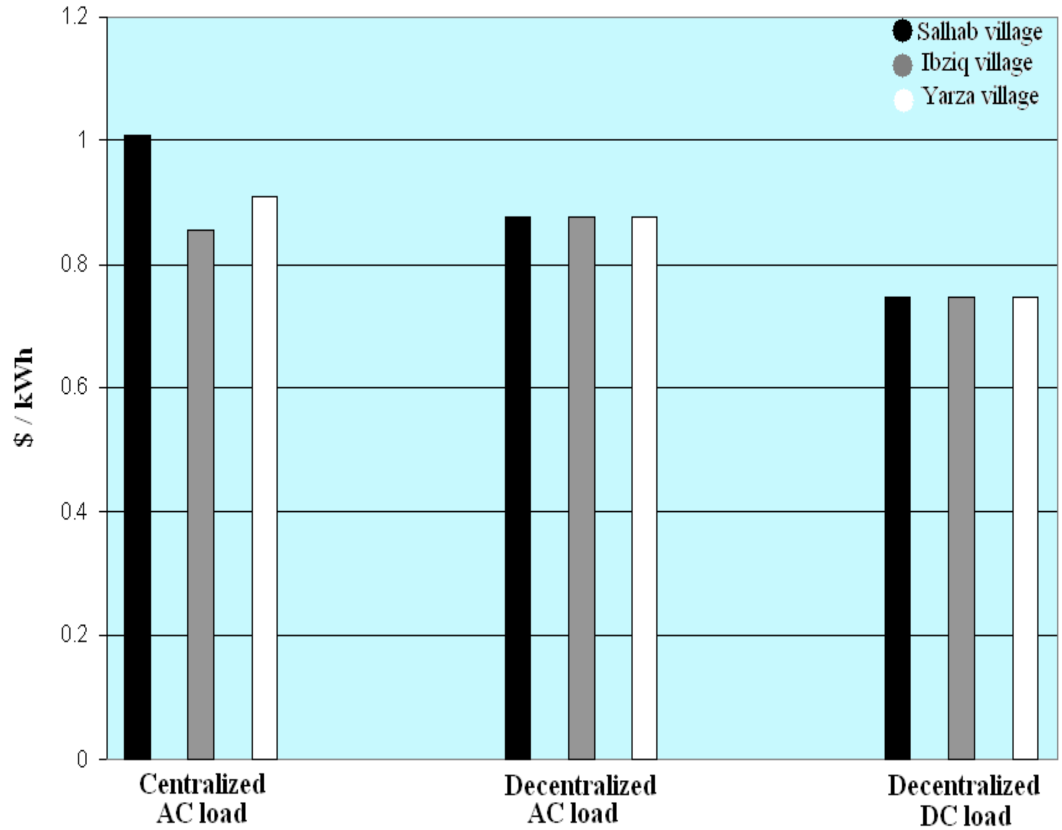

Figure (7.10): Cost annuity for centralized AC load, decentralized AC load and decentralized DC load

It's obvious that cost annuity for decentralized DC load is the lowest one, so it's the best alternative to choose and to adopt for electrification of these remote and isolated villages.

CHAPTER EIGHT

CONCLUSIONS

CHAPTER EIGHT

8. Conclusions

- This study was set out to examine two goals; firstly whether the Palestinian Territories are suitable for applying of PV systems as clean power supply or not and secondly which system of centralized or decentralized systems is most proper for electrify rural and isolated areas in Palestine.

- The first goal was strongly achieved in Palestine as shown in chapter 3. Palestine and the target area, Tubas selected remote villages (Salhab, Ibziq and Yarza) has more of 3000 sunshine hours/year. It has quit high global irradiation(more than 910 w/m^2 in the interval period from 10-14 o'clock pm specially during summer). It has very good solar energy radiation in the average of 5.587 kWh/m^2-day, which is very suitable for generating electricity from solar energy and the ambient temperature of the target area is in the average of 32°C which it's also very suitable for power generation from solar energy by PV generator.

- The analysis of PV systems, the understanding of general behavior of the I-V characteristics of PV generators, the basic functions and efficiency of the charge regulator, inverter, batteries and the maximum power point were discussed widely in chapter 4.

- Load study for each remote Tubas Villages as case study was done in chapter 5. It is concentrated at night and it's considered to be household load only, there is no electrical load for street lighting, school, clinic even small mosque.

The electrical load for a typical small and separated household is relatively small and is about 1086 Wh/day/house .

- Design of PV systems (centralized or decentralized) for each village in the target area was done in chapter 6. It is obvious for decentralized PV system, we need only 2 PV modules, 2 of 12V regulator batteries, very small charge regulator and inverter, so it's recommend to be movable and transferable PV system . Max. overall efficiency found to be for centralized and decentralized PV systems in 10.90%, 11.59%, respectively.

- The second goal where actually is the main goal of this study is to select the optimum configuration of PV systems(centralized or decentralized). As shown in chapter 7, economic mathematical model of centralized and decentralized PV system based primarily on the use of Life Cycle Cost LCC were made. Software Programming (Flow Chart) for selection of centralized or decentralized PV system was also done.

- Economic evaluation for both centralized and decentralized PV system for Tubas remote villages based on LCC as economic indicator was done also in chapter 7 . It is found that LCC for decentralized PV system for the three villages is less in the average of 12.87% than LCC of centralized PV system, since the electrical load is the same for all simple and similar houses and solar radiation is the same for this limited area(Tubas district). The distance between separated houses is only the unique variable criteria affects the LCC, rising the cost of distribution network, rising the LCC of centralized PV system.

- Cost annuity for selected remote Tubas villages was also done in chapter 7. it's found that cost annuity for decentralized PV system,(0.877 $/kWh = 3.11 NIS/kWh) is less in the average of 5.38% than cost annuity for centralized PV system, so decentralized PV system is better and it has to be adopted.

- Third option, has been tested the DC load for decentralized PV system in chapter 7 also, since the peak power for each house is very small, less than 300 Wp/day. The LCC of DC load system will be less than the previous systems (AC centralized and AC decentralized). The cost annuity (0.748 $/kWh = 2.99 NIS/kWh) will be also less 17.3% than AC decentralized PV system.

- So, we advice to select DC load of decentralized PV system to electrify these remote Tubas village, where the houses there are separated too much, very simple and similar to each other.

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Appendixes

Appendix A

MODEL
KC130GHT-2

KC130GHT-2

HIGH EFFICIENCY POLYCRYSTALLINE
PHOTOVOLTAIC MODULE

TÜV
IEC 61215

Kyocera is **"ISO9001"** certified and registered.
TUVdotCOM Internet platform for tested quality and service ID 0000007358.

HIGHLIGHTS OF KYOCERA PHOTOVOLTAIC MODULES

Kyocera s advanced cell processing technology and automated production facilities produce a highly efficient polycrystalline photovoltaic module.
The conversion efficiency of the Kyocera solar cell is over 16%.
These cells are encapsulated between a tempered glass cover and a pottant with back sheet to provide efficient protection from the severest environmental conditions.
The entire laminate is installed in an anodized aluminum frame to provide structural strength and ease of installation.
Equipped with plug in connectors.

APPLICATIONS

Grid-Connected Systems

- Residential Solar Power Systems
- Public and Industrial Solar Power Systems

Stand-Alone Solar Power Systems for

- Villages in remote areas
- Homes and summer cottages
- Microwave / Radio repeater stations
- Medical facilities in rural areas
- Emergency communication
- Water quality and environmental data monitoring
- Drinking water and livestock water pumping
- Irrigation pumping
- Cathodic protection
- Aviation obstruction lights
- Environmental data monitoring
- Railway signals
- Street lighting
- Desalination
- etc.

LIMITED PERFORMANCE WARRANTY

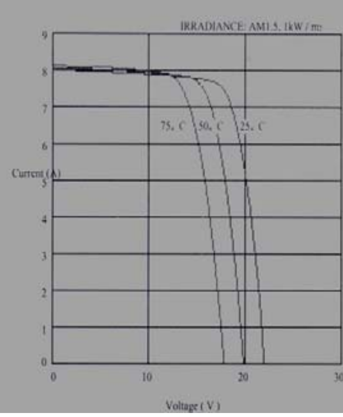
※2 years limited warranty on material and workmanship

※25 years limited warranty on power output.

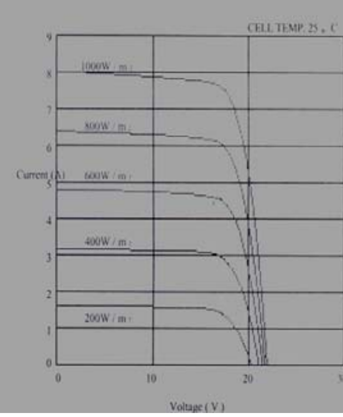
(Long term output warranty shall guarantee that loss of output is not more than 10% of the minimum warranty value of the product specifications within 12 years and is not more than 20% within 25 years after the purchase of the product by customer. The output values shall be those measured under Kyocera standard measurement conditions. Regarding the warranty conditions in detail, please refer to Warranty issued by Kyocera.)

ELECTRICAL CHARACTERISTICS

Current-Voltage characteristics of Photovoltaic Module KC130GHT-2 at various cell temperatures

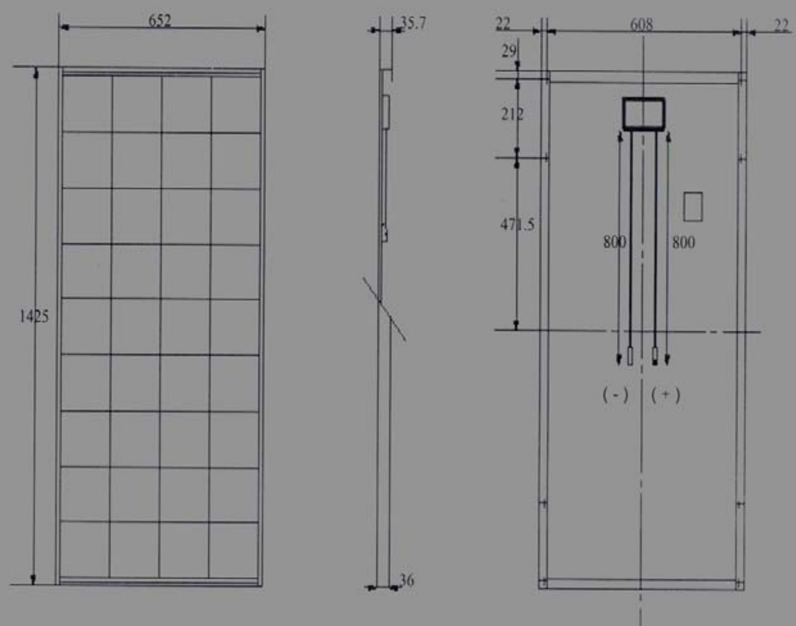


Current-Voltage characteristics of Photovoltaic Module KC130GHT-2 at various irradiance levels



■ **Physical Specifications**

(Unit : mm)



■ **Specifications**

Electrical Data		
Maximum Power(Pmax)	[W]	130
Tolerance	[%]	+ 10 / −5
Maximum Power Voltage	[V]	17.6
Maximum Power Current	[A]	7.39
Open Circuit Voltage (Voc)	[V]	21.9
Short Circuit Current (Isc)	[A]	8.02
Temp. coefficient of Voc	[V/℃]	-8.21×10^{-2}
Temp. coefficient of Isc	[A/℃]	3.18×10^{-3}
NOCT	[℃]	47
Max System Voltage	[V]	1000

Dimension		
Length	[mm]	1425
Width	[mm]	652
Depth without box	[mm[	36
Weight	[kg]	12.2
Cable	[mm]	(+) 800／(-) 800

Cells	
Number per module	36
Cell Technology	Polycrystalline
Cell Shape	Rectangular

Note : The electrical specifications are under test conditions of Irradiance of 1kw/m², Spectrum of 1.5 air mass and cell temperature of 25℃.
Kyocera reserves the right to modify these specifications without notice.

Please contact our office to obtain details without hesitation.

KYOCERA

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LIE/108K0601S5SAGK-00 (Recycled Paper)

Appendix B-1
Sonnenschein Solar Series Gel Battery 2V 1000 Ah

- Model: **A602/1000**
- Shipping Weight: **68kg**
- Manufacturer: **Sonnenschein**

In Stock
2-5 business days delivery

Sonnenschein®

Sonnenschein 2Volt 1000Ah Solar Series Battery

Sonnenschein A 600 Solar Series batteries are developed for medium to large solar powered applications. The recycle ability and long storage life without recharge makes this environmentally friendly solar battery system absolutely recommendable for various requirement profiles. Typical applications for these maintenance free VRLA " Valve regulated lead acid " batteries with successful dry fit technology range has been designed for ultra high cyclic applications therefore making it ideal for solar and wind power stations, power distribution companies, telecommunications, railways, military applications and safety equipment power supplies.

Technical Specifications

Electrical Characteristics		
Nominal Voltage		2 V
Nominal Capacity - 20°C	At 1 hour Rate - 1.67 Volt/Cell	432 Ah
	At 3 hour Rate - 1.75 Volt/Cell	605 Ah
	At 5 hour Rate - 1.77 Volt/Cell	701 Ah
	At 10 hour Rate - 1.80 Volt/Cell	800 Ah
	At 100 hour Rate - 1.85 Volt/Cell	1000 Ah
Discharge Current at 100 hour rate		7.20 A
Mechanical Characteristics		
Type		8 OPzV 1000
Part Number		NGS6020960HS0FA
Terminal		F-M8
Pole pairs		2
Dimensions		215 L x 193 W x 650 H mm
Total height with terminal		688 mm
Installed length -B/L		220 mm
Weight		68.0 kg

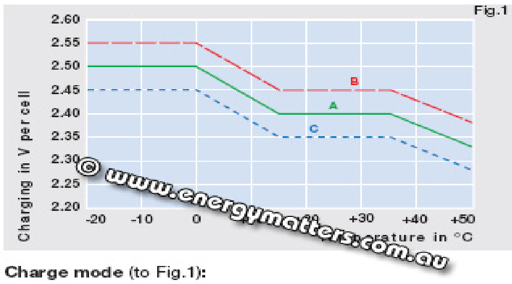
Quality and Safety

- No acid leakage, No acid pollution, even when the casing is damaged
- No corrosion damage, No aggressive acid vapours
- Not classed as a hazardous product during transport
- Each cell is closed with a safety valve

Quality and Safety

- No acid leakage, No acid pollution, even when the casing is damaged
- No corrosion damage, No aggressive acid vapours
- Not classed as a hazardous product during transport
- Each cell is closed with a safety valve
- Proof against deep discharge according to DIN 43 539 T5
- Cells in compliance with DIN 40742

Additional pictures and graphs

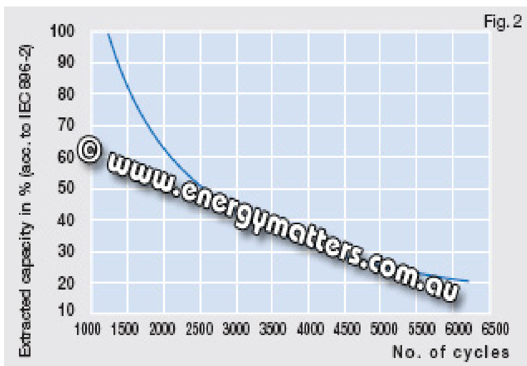


Charge mode (to Fig.1)**:**

1.) with switch regulator (two-step controller)
  - charge on curve **B** (max.charge voltage) for max.2 hrs/day then switch over to continous charge - curve **C**

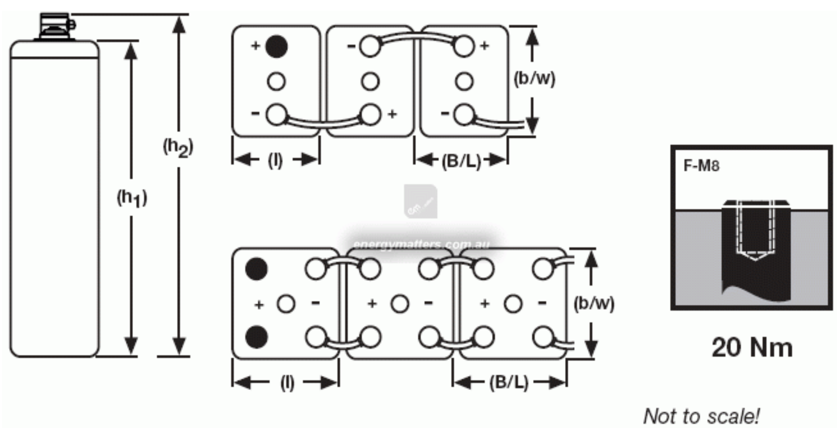
2.) Standard charge (without switching) - curve **A**

3.) Boost charge (Equalizing charge with external generator)
  - charge on curve **B** for max. 5 hrs/month, then switch over to curve **C**



(to Fig. 2)

Endurance in cycles according to IEC 896-2



Appendix B-2
Sonnenschein Solar Series Gel Battery 2V 2200Ah

- Model: **A602/2200**
- Shipping Weight: **160kg**
- Manufacturer: **Sonnenschein**
- **In Stock**
  2-5 business days delivery

Sonnenschein®

Sonnenschein 2Volt 2200Ah Solar Series Battery
Sonnenschein A 600 Solar Series batteries are developed for medium to large solar powered applications. The recycle ability and long storage life without recharge makes this environmentally friendly solar battery system absolutely recommendable for various requirement profiles. Typical applications for these maintenance free VRLA " Valve regulated lead acid " batteries with successful dry fit technology range has been designed for ultra high cyclic applications therefore making it ideal for solar and wind power stations, power distribution companies, telecommunications, railways, military applications and safety equipment power supplies.

Technical Specifications

Electrical Characteristics		
Nominal Voltage		2 V
Nominal Capacity - 20°C	At 1 hour Rate - 1.67 Volt/Cell	1035 Ah
	At 3 hour Rate - 1.75 Volt/Cell	1449 Ah
	At 5 hour Rate - 1.77 Volt/Cell	1679 Ah
	At 10 hour Rate - 1.80 Volt/Cell	2000 Ah
	At 100 hour Rate - 1.85 Volt/Cell	2200 Ah
Discharge Current at 100 hour rate		23.0 A
Mechanical Characteristics		
Type		16 OPzV 2200
Part Number		NGS60202300HS0FA
Terminal		F-M8
Pole pairs		3
Dimensions		215 L x 400 W x 775 H mm
Total height with terminal		815 mm
Installed length -B/L		220 mm
Weight		160 kg

Appendix B-3
Haze Gel VRLA Deep Cycle Battery 12Volt 160Ah

- Model: **MR12-160**
- Shipping Weight: **53.7kg**
- Manufacturer: **Haze**
- **In Stock**
  2-5 business days delivery

Haze 12 volt 145 Ah EV Pure Gel VRLA Deep Cycle Battery
When you're out in the heart of this sunburnt country, or on that unexplored river somewhere, what price would you put on the reliability of your power system? The ability to turn on the lights, start the motor, or simply to have a cold beer from the fridge?
With over 20 years battery building experience, Haze have spent the past six years perfecting an economically priced gel battery for everyday use with proven German gel technology. The Haze gel battery range can withstand the rigors of demanding power applications such as;

• Fridges	• Inverters	• Winches
• HF radios	• Lighting	• Electric Outboards

Innovative Features

- Maintenance-free. Never top up acid again. Allows installation in confined areas.
- Resistant to under-bonnet heat, vibration and heavy discharge cycles.
- More available Ampere-Hour (Ah) capacity than the equivalent size flooded cell battery.
- Non-spillable. No more leaks or topping up. No more rusted battery trays. No risk of chlorine gas production in boats.
- Low self-discharge. Can be stored and used in seasonal or infrequently used vehicles without going "flat".

Warranty

- 12 months warranty

Technical Specifications

Electrical Characteristics	
Voltages	12 V
Terminal Type	Dual Post
Capacity - C20	160 Ah
Mechanical Characteristics	
Dimensions	530L x 209W x 214H mm
Weight	53.7 kg

Quality and Safety

- The Quality and management system governing the manufacture of this product is ISO 9001:2000 and ISO 14001:2004 certified.

Appendix C-1
Plasmatronics 60A Multi-voltage Solar charge controller

- Model: **PL60**
- Shipping Weight: **1.1kg**
- Manufacturer: **Plasmatronics**
- **In Stock**
  2-5 business days delivery

PLASMATRONICS

Plasmatronics 60A Multi-voltage Regulator - PL60
The PL series of charge controllers give you freedom to operate your solar electric system the way you want to.
They offer complete control over the charge cycle, plus an unprecedented amount of useful information about current and past performance.
PL regulators help to protect the system with a build in low battery disconnect switch. In addition the versatile event controller can switch power on or off according to criteria set by the user. This allows PL to do extra tasks such as switching a light on at night or keeping a water tank full by operating a pump when needed.
Advantages
The user can select either Pulse Width Modulation or slow speed switching. Regulation can be done in both series and shunt modes. Other features can backup generator control and charging a second battery.

Features

• Adjustable	• Generator Control
• LCD display	• Event Control
• Energy Metering	• Alarm
• Protection	• Second Battery
• History Record	• Three Step Regulation

Warranty
- 1 year manufacturers warranty

Technical Specifications

Electrical Characteristics	
Nominal System Voltages	12, 24, 32, 36, 48 V
Solar Charge Current Maximum	60 A
Load Switch Current Maximum	30 A
Voltage Drop at Rated Current	0.42 V
Operating Ambient Temperature	-20 to +50 ºC
Supply Current	20 mA
Battery Temperature Sensor Range	-5 to +50
Regulation Set Points	4 adjust
Mechanical Characteristics	
Dimensions	225H x 175W x 62D mm
Weight	1.1 kg

Informative: Display shows battery voltage, charge current, ampere hours in and out of battery, load being drawn from the battery and which part of the charge cycle the battery is in.

Easy to maintain: Information is available for the past 30 days - so even if the user doesn't remember what happened, the regulator will.

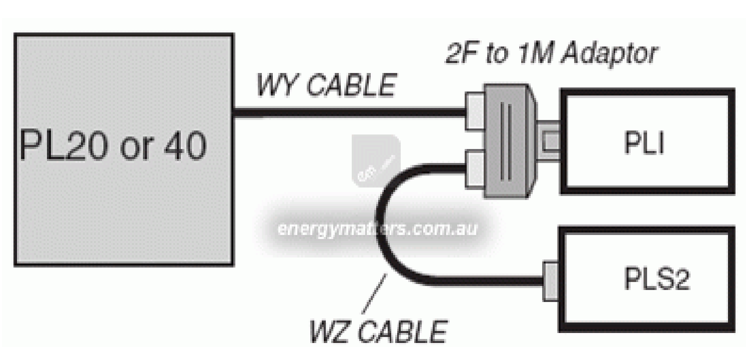
Well connected: With the optional PLI interface and PLcom software, the user can access the regulator from a computer. Data can be read or settings adjusted. This can be done remotely by using a modem.

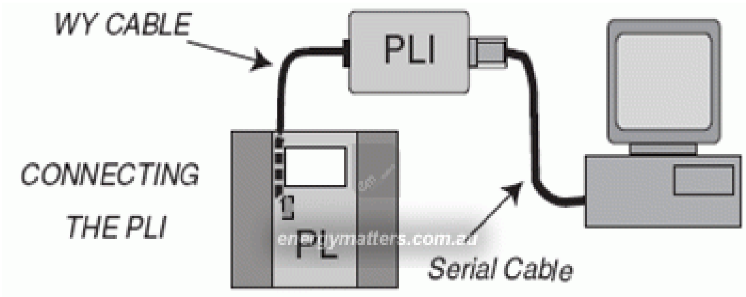
Versatile: It may be the only regulator you will ever need to stock. Its capacity to handle 12, 24 and 48V systems and allow complete control of the regulation cycle mean you can use it almost anywhere.

Quality and Safety

- Top of the line Australian made regulator.

Additional pictures and graphs





Connecting the PLI to a PL20 or 40.
For a PL60 use a WZ cable.

Appendix C-2

Apollo Turbo Charger 80Amp MPPT Battery Charger Management System

- Model: **T80**
- Shipping Weight: **7.3kg**
- Manufacturer: **Apollo Solar**
- **In Stock**
  2-5 business days delivery

Apollo Turbo Charger 80Amp MPPT Battery Charger Management System

Design Features

- Proprietary Maximum Power Point Tracking (MPPT)
- Process up to 5300 watts of PV power
- 80 amps continuous output at 400 C
- Wire PV modules in series up to 72 VDC nominal (140 VOC max)
- Charge 12, 24, 36 or 48 V batteries
- Built-in battery energy meter
- Serial computer link
- TUV type-tested to UL 1741-2005
- Made in the USA

Warranty

- 10 Years Warranty

Power and Control in a Single Device

The TurboCharger™ T80 integrates Maximum Power Point Tracking, battery charge management, state of charge information and communications into a single device. With 80 amps continuous output the T80 will process up to 5300 Watts of PV power - the largest capacity in the industry by over 30%.

Maximum Charging Efficiency

The T80 captures up to 35% more power from the photovoltaic (PV) array. It offers two user selectable MPPT modes. The controller uses the same technology we developed to help NASA harness additional power from their solar arrays.

Unique Charge Management System

Supports Flooded Lead Acid (FLA), gel and absorbed glass mat (AGM) batteries. Four stage charging with fully adjustable set points for all parameters (flooded lead acid batteries only). Includes pre-loaded custom settings for many popular batteries.

Energy Monitor

The T80 includes a built-in energy monitor which tracks energy production and consumption and calculates the power remaining in the battery. State of Charge (SOC) is displayed in percentage or bar graph format. Historical data on power production, usage, days since fully charged is stored in the T80 for ninety days.

Unequalled Communications

The T80 is designed to communicate. With it's on-board RS-232 port the T80 can easily accept software upgrades and custom programming modes. All that is required is an internet connection and a portable PC.

Continuous Rating to 400 C

The TurboCharger™T80 produces full rated power without temperature derating up to 400C. This means that full power output can be maintained even in extreme temperature conditions, when it is most needed.

Reduce System Costs

Our efficient MPPT technology dramatically reduces the cost of a PV system by reducing the number of PV panels required, eliminating the need for heavy gauge wiring, and increasing the life of the storage batteries.

Technical Specifications

Output Current	80 amps continuous @ 400 C
Battery Voltages	12, 24, 48 Vdc NOMINAL
Max PV input	70 amps
Max PV Array	5300 Watts
Max. PV Open Circuit Voltage (VOC)	140 Vdc
Charge Regulation	Bulk, Absorption, Float, and Stand-by with Auto or Manual Equalize
MPPT Mode	Apollo proprietary algorithm which recalculates the maximum power point each 1 mS. MPPT may be defeated for non PV input.
Battery Temperature Compensation	5.0 mV per 0C per 2 Vdc cell (Temp. Comp. Sensor included at no extra cost)
DC to DC Conversion Capability	72 Vdc nom in: 12, 24, 36, 48 Vdc out, 60 Vdc nom in: 12, 24, 36, 48 Vdc out, 48 Vdc nom in: 12, 24, 36, and 48, Vdc out, 36 Vdc nom in: 12, 24 and 36, Vdc out, 24 Vdc nom in: 12 and 24 Vdc out, 12 Vdc nom in: 12 Vdc out

Power Conversion Efficiency (max)	>97% 48 Vdc to 48 Vdc @ full rated current
Dimensions	387 x 216 x 111 mm
Weight	7.3 kg
Conduit Knockouts	Two 3/4" - 1" on back, one 1 1/4' - 1" of left side, two 1 1/4" - 1" and one 3/4" - 1" on bottom. Bottom knockouts fit industry standard 2 1/2" O/C spacing
Environmental Rating	Indoor Type 1 (Not intended for use in extremely damp or humid locations)
Operating Temperature Range	Minimum -400 C (-400 F) to maximum 550 C (1310 F) Output current is automatically reduced above 400 C (1040 F)
Display (standard)	Built-in back-lit 4-line LDC display with 4-key soft keys.
Auxiliary Relays	Two, built-in programmable relays
Status Reporting	Displays; volts and current in and out, battery voltage and SOC % (using external 50 mV/500 A shunt). Secondary screen displays; charge mode, MPPT status, MPPT mode
Data Logging	Logs "Energy Harvest" for 90 days. Data screens display kW hours, Watt hours and Amp hours and length of time each day that Float mode was active. Shows data in daily, weekly and monthly format.
Energy Monitor	Displays; SOC (state of charge) in an empty/full fuel gauge style bar graph. It also displays power remaining in batteries in Amp hours and kW hours, time remaining in batteries at average load, time since last fully charged. Logs SOC information for 90 days in daily, weekly and monthly format. Includes Shunt — 50 mV/500 Amp shunt required to access Energy Monitor features.
Agency	Type-tested to UL1741-2005 by TUV
Specifications Notice	These are pre-commercial release specifications which are subject to addition and change before the release of the T80.

Appendix C-3
Morningstar Sunlight 24Volt 10Amp Regulator with LVD and Light C

- Model: **SL-10L24V**
- Shipping Weight: **0.4kg**
- Manufacturer: **Morningstar**
- **In Stock**
  2-5 business days delivery

Morningstar Sunlight 24Volt 10Amp Regulator With Low Voltage Disconnect

Morningstar's advanced SunLight solar lighting controller combines the SunSaver design with a microcontroller for automatic lighting control functions.

Morningstar Technology Provides

- Proven Reliability
- Precise Lighting Control
- PWM Battery Charging

Operation

- Rotary digital switch to select among 10 lighting options (see back)
- Test button flashes red LED to confirm correct rotary switch selection
- Test button turns lights on for 5 minutes (in LVD limited to 3 times)
- LVD overrides lighting timer
- Sunrise overrides lighting timer
- Timer accuracy is within 2 seconds

Features

- Microcontroller digital accuracy
- Fully automatic operation
- Ten field adjustable lighting control options
- Special on/off/on functions
- Manual test capability
- LVD override protection

- Detects day and night using the PV array
- Suitable for all 12/24 Vdc lamps
- Sealed/Flooded battery select
- Temperature compensation
- Parallel with a SunSaver for 40 amps solar
- Includes SunSaver battery charging circuit

Warranty

- 5 Year Warranty Period
- 99.8% of Morningstar's products never fail

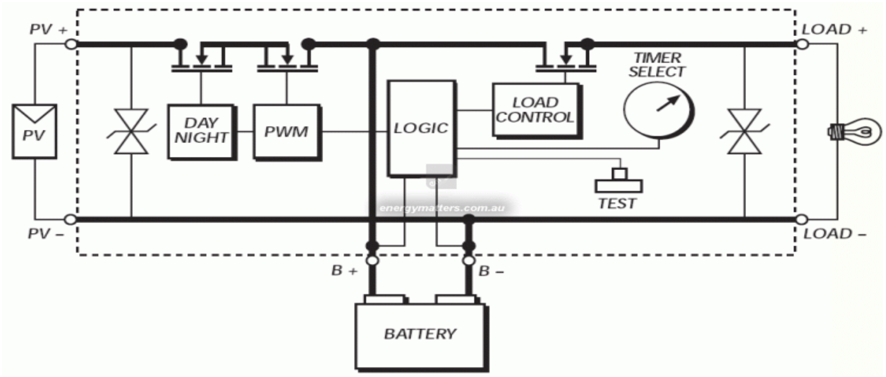
Technical Specifications

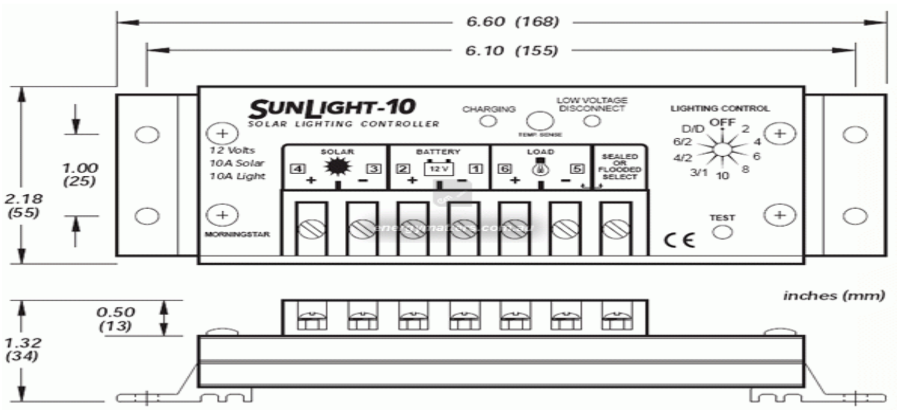
Electrical Characteristics		
Rated Solar Input		10 A
Rated load		10 A
25 % current overload		5 mins
Regulation voltage	Sealed battery	28.2 V
	Flooded battery	28.8 V
Load disconnect		23.4 V
LVD reconnect		25.6 V
Temp compensation		-54 mV/ºC
Self consumption		9 mA
Operating temp		-40 to +85 ºC
Mechanical Characteristics		
Wire size 5.2 mm² (#10 AWG)		Epoxy encapsulated
Anodized aluminum case		Weight 0.26 kg
Marine rated terminals		

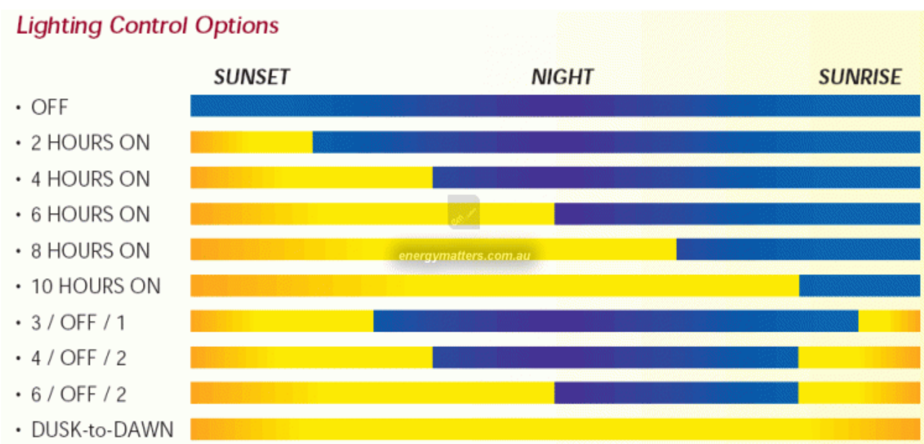
What is PWM ?

Pulse Width Modulation "PWM" is the most effective means to achieve constant voltage battery charging by switching the solar system controller’s power devices. When in PWM regulation, the current from the solar array tapers according to the battery’s condition and recharging needs.

Additional pictures and graphs







Appendix D-1
Outback Inverter Charger 3000Watt 48Volt 45Amp

- Model: **VFX3048**
- Shipping Weight: **27.7kg**
- Manufacturer: **Outback Power Systems**
- **In Stock**
  2-5 business days delivery

OutBack Power Systems

Outback 3000Watt 48Volt 45amp Inverter Charger - VFX3048
The Outback VFX3048 is a modular "building block" sine wave inverter/charger that can be used for both small and large power systems. The OutBack VFX3048 inverter/charger is a complete power conversion system - DC to AC inverter, battery charger and AC transfer switch. Additional FX inverter/chargers can be connected at any time in either parallel, or three-phase configurations. The OutBack VFX3048 is designed to survive harsh environments anywhere in the world. Our unique sealed, gasketed die-cast aluminium chassis protects and keeps the power conversion components cool - without requiring outside air to be blown through the sensitive electronics. This reduces the major causes of inverter failure - corrosion, dust, insect and animal damage.
OutBack Power Systems is an engineer-owned, customer focused, power systems equipment manufacturer. Our engineers all have decades of power conversion design and equipment installation experience. We share a passion for leading the industry into a new era of balance of systems equipment performance, ease of use, and standardization. Our mission is to be a leading manufacturer of power electronic products for renewable energy, back-up power and vehicle applications. The goals for OutBack Power Systems is to offer high value product with the best possible performance while operating reliably in severe environmental conditions. OutBack Power System's goal is also to support our

customers and their applications with an exceptional level of technical support and customer service.

Warranty

- Two years standard warranty, plus optional 5 Year Extended Warranty

Technical Specifications

Continuous Power Rating at 25 degrees C	3000VA
Nominal DC Input Voltage	48
Nominal AC Input Voltage/Frequency	230V / 50Hz
Continuous AC RMS Output current at 25 degrees C	13 amps
Idle Power(typical at no AV load) (Sleep - 3 watts)	21-23 Watts
Efficiency (typical at 25 degrees C and 75% resistive load)	90%
Total Harmonic distortion voltage (typical / max)	2% / 5%
Output Voltage Regulation	+/- 2% typ
Surge Power Capability Peak (1mSec)	35 amps AC
Surge Power Capability RMS (100mSec)	25 amps AC
Overload Capability (from 25 C start) 5 second	4800 VA
Overload Capability (from 25 C start) 30 minutes	3300 VA
Automatic AC transfer Relay (at nominal AC)	30 amps AC
AC Input Current (adjustable limits)	30 amps max
AC Input Voltage Range (adjustable limits)	200-260 VAC
Frequency Range – AC Input	40 to 60 Hz
DC Input Range (adjustable low battery cutout)	40 - 66 VDC
Recommended DC Breaker	OBDC-175
Continuous Battery Charger Output amps DC	45 amps
Shipping Weight	28 kg

Quality and Safety

- Non-volatile memory
- High Surge Power
- Safety Instructions

Appendix D-2
Latronics Sinewave Inverter 8500Watt 48Volt

- Model: **LS 7048**
- Shipping Weight: **34kg**
- Manufacturer: **Latronics**
- **In Stock**
  2-5 business days delivery

LATRONICS®
A NEW WORLD POWER

Latronics 8500Watt 48Volt Pure Sinewave Inverter
Convert your battery power to a more useable high quality AC mains electricity and create your own independent mains supply for your boat, caravan, motorhome or remote area power system. Simply connect a suitable battery bank to the LS Series Inverter and you're ready to power a wide range of every day appliances. Suitable for operating: TV, VCR, stereo,computer, office equipment, fridges, power tools and pumps.
The Latronics® LS Series Inverter utilizes the most advanced microprocessor algorithms, which guarantees your power conversion is pure and stable.
The Latronics® LS Series Inverter is the most powerful and reliable Inverter on the market.

Warranty

- 3 Years parts and labour

Features

Wall mount design	Allows flexibility and ease of installation.
Performance	True sinewave output with unmatched surge power enables the operation of demanding appliances, such as fridges, microwaves washing machines & pumps.
Pure Sinewave Output	Provides the ideal power source for all modern electronics.
Short Circuit Proof	Indestructible design protects itself against any AC shorts.

Reliability	Benchmark quality standards ensure optimum reliability, backed by a full 2 year parts and labour warranty.
Full Electronic Protection	Sophisticated circuitry provides protection against overload, short circuit, over temperature and high/low voltage shutdowns.
Frequency 50/60Hz Selectable	Fully selectable between 50/60Hz via a set of internal dip switches.
Autostart	Sophisticated sensing circuitry automatically switches the inverter ON and OFF with applied appliances. The Autostart is an important feature as it maximises valuable battery capacity. Sensitivity of the Autostart can be easily adjusted to either start small appliances or run continuously.
Durable Construction	Latronics® Inverters are a quality industrial product made to withstand vibration and constant movement in mobile or marine installations, as well as the diverse range of home or commercial applications.
Corrosion Conscious Design	Latronics® Inverters are built for extreme environments using a recyclable powder coated aluminium casing, a more noble metal than steel
High Efficiency Toroidal Transformer	Toroidal transformers provide the highest efficiency and durability.
High Surge Rating	High surge rating allows easy starting of motors and high inrush current devices.
DC Circuit Breaker	Protects the inverter and cables from becoming a potential fire hazard under fault conditions, as well as providing full isolation from your batteries while switched OFF, reducing the need for additional battery fuses.
AC/DC Isolation	Full 3500V AC/DC isolation.
Heavy Duty DC Battery Leads	High quality, high current DC leads for low loss power delivery.
LED Status Indicators	A full set of LED's keeps the user informed of its operation at all times.
Options	A complete Australian made product, proudly designed and manufactured in Australia by a 100% Australian owned company.

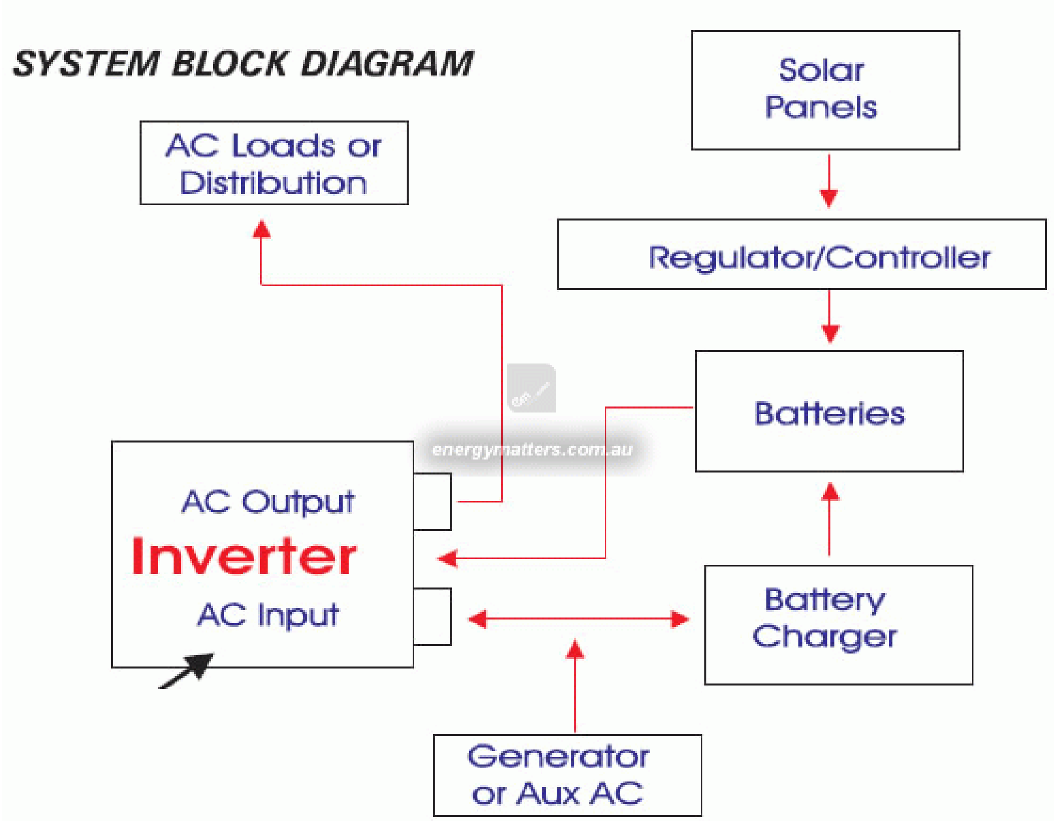
Technical Specifications

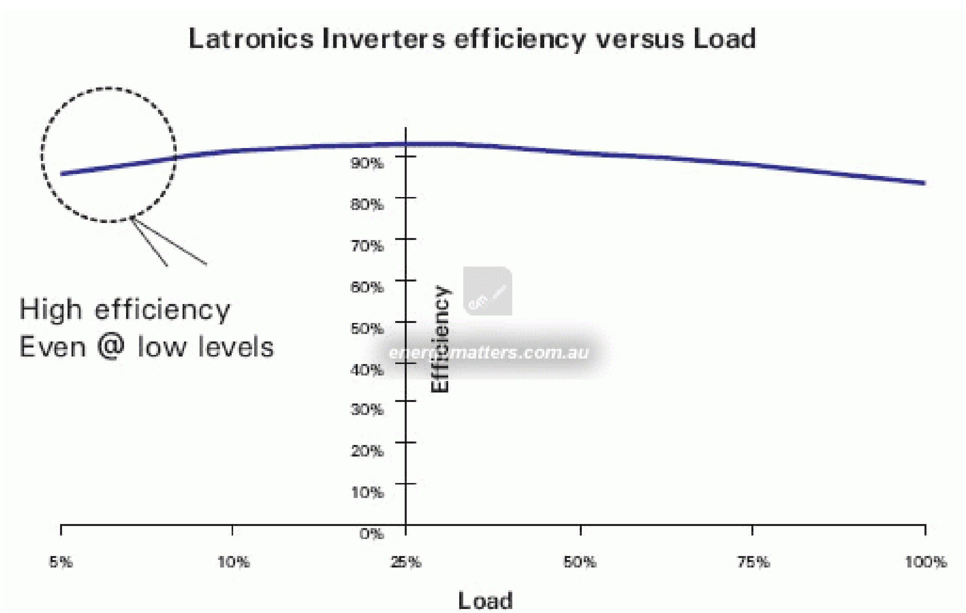
Electrical Characteristics	
Nominal DC Voltage	48 V
Continuous Power	8500 W
½ Hour Rating	8500 W
Surge Rating (5 seconds)	20000 W
Input Voltage Range	42 - 68 V
Standby Current	60 mA
Inverter ON – no load	0.5 A
Peak Efficiency	95 %
Output Voltage	230Vac +/- 4% (110Vac Available)
Output Waveform	True Sinewave
Total Harmonic Distortion	< 4 %
Output Frequency	50 Hz +/- 0.1%
Power Factor	All Conditions
Operating Temperature	-10° C to + 50° C
Auto start Sensitivity	0 – 20 W adjustable
DC to AC Isolation	3500 V
Protection Circuitry	Over temperature, Overload/Short Circuit, Battery Under voltage/Over voltage
Mechanical Characteristics	
Dimensions	475L x 458W x 187H mm
Weight	34 Kg
Chassis	Powder coated 3 mm Aluminium
AC Output Wiring	3 Terminal Hardwire Junction Box, labeled "AC Output"
AC Input Wiring	3 Terminal Hardwire Junction Box, labeled "AC Input" (AC Transfer Switch OPTION)
Battery Leads	1.5 m long with 10mm mounting lugs

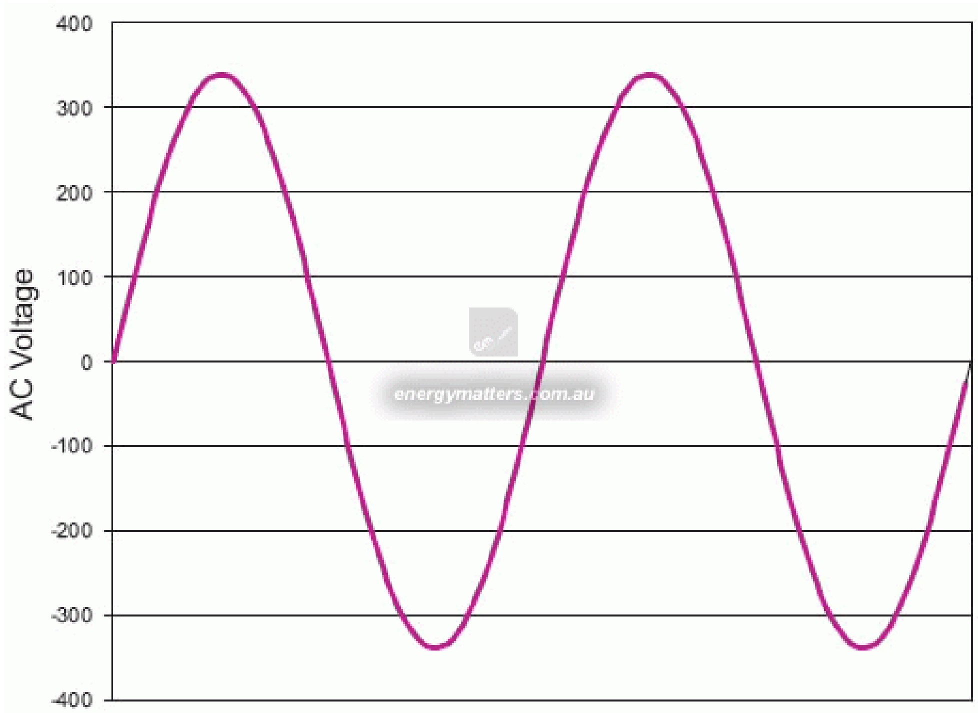
Quality and Safety

- A complete Australian made product, proudly designed and manufactured in Australia by a 100% Australian owned company.
- Manufactured by AS2279, AS3000, AS3100, EN55014, EN61000-4, & C-Tick standard .
- Rating: Specifications @ 25°C Ambient, Nominal Battery Voltage & Unity Power Factor

Additional pictures and graphs






400
300
200
100
0
-100
-200
-300
-400
AC Voltage
energymatters.com.au

Appendix D-3
QUATTRO 4000Watt 48Volt 70Amp Inverter Charger

- Model: **QUATTRO 12-5000-70**
- Shipping Weight: **30kg**
- Manufacturer: **Victron Energy**
- **In Stock**
  2-5 business days delivery

QUATTRO 4000Watt 48Volt 70Amp Inverter Charger

Energy. Anytime. Anywhere. That's what Victron Energy's new Quattro is all about. It's the only inverter/charger that will provide up to 5kVA of power! Your spin-off: more freedom. Not only that, but the Quattro also offers more on all counts. Allow us to introduce you to new vistas in the world of mobile power by Victron Energy.

More power

Laundry and dish washing, electric cooking, air-conditioning, diving compressors, computer systems – with 5kVA at its disposal, it's no problem at all for the Quattro. Are your power requirements even greater? You simply connect more units in parallel: 10kVA, 15kVA, three-phase power – the possibilities are unlimited.

More control

Charging batteries while power resources are already at their limits can cause serious overloading. Victron Energy has developed a smart solution. If power consumption is high, the Quattro charges at a low or zero rate. As power consumption decreases, the Quattro uses the additional power that becomes available to charge at higher levels. We call this innovative feature PowerControl.

More energy

Power connections to provide all the power you need are not always available. That's why Victron Energy developed Power Assist. This feature monitors power consumption and supplies additional power to prevent overloading. The Quattro can temporarily turn a 16A connection into 38A and a 5kVA generator into 10kVA. No other brand offers better functionality in this arena than the inventor: Victron Energy.

More independence

Is the grid unreliable? Or would you rather be completely independent? No problem at all. The Quattro can handle enough power to supply an entire home . You can connect a diesel generator or a sustainable energy system directly to the batteries. Or to the AC input or output. The batteries are then charged through the Quattro. You determine what is best in your specific situation.

More teamwork

Quattro units can connect to VE.Net and the ESP system panels. In this way, you can monitor and operate the whole system from a single point with everything at your fingertips – on-site or from the other side of the world if you like – the Quattro itself, the generator, battery monitors, tank meters and your Internet connection. Isn't freedom what it's all about?

More sustainable energy

Solar energy, wind energy, micro-scale heating and power plants for homes and buildings are becoming increasingly popular. Often such sustainable energy resources are both connected to and feed power back into the grid. In the event of a power failure, therefore, one would imagine there would be enough energy available to keep your essential equipment working. Unfortunately, that is not the case. If the grid fails, so do your sustainable energy resources, leaving your computer, refrigerator, freezer, central heating pump, anti-burglary alarm system etc. without power. The solution? Install a Quattro and a battery or two in your home. The Quattro will replace the grid when needed and ensure that your sustainable energy resources remain in operation. How many devices and how much lighting can you keep using? That depends on battery capacity and the amount of sustainable power that is generated.
But one thing is certain: you will have power – always!

More convenience

Just a few LEDs and a switch – that's all you need to operate a Quattro. And the same applies for installation. Shore-side power and a generator can both be connected directly to the Quattro. An AC transfer system is no longer required. The Quattro is unique in this regard too. Devices that you don't want powered by costly battery energy can simply be connected to the load shedding 'boiler' output. Configuration is just as easy with either our new, simple DIP switch system or with your notebook and free software. It's totally up to you!

More Security

A power failure? Or switching from generator to inverter operation? In that case, you must be able to rely on seamless transfer without noticeable effects on computers and other sensitive equipment. The Quattro will not let you down.

Warranty

- 2 Year Warranty

Technical Specifications

Quattro	Charge 48/5000/70
Power Control / Power Assist	Yes
Intergrated transfer switch	Yes
AC inputs 2x	Input voltage range: 187 - 265 VAC Input frequency: 45-55 Hz, Power factor: 1
Max feed through current	30 A
Inverter Characteristics	
Input voltage range	38V - 66V DC
Output [1]	Output voltage: 230 VAC ± 2 % Frequency: 50Hz ±0.1 %
Cont output power at 25°C	5000 VA
Cont output power at 25°C	4250 W
Cont output power at 25°C	3350 W
Peak power	7800 W
Maximum efficiency	95 %
Zero load power	30 W
Load shedding output	Maximum load: 10A switches off when no external AC source available
Charger Characteristics	
Charge voltage absorption	57.6 V DC
Charge voltage float	55.2 V DC
Storage mode	52.8 V DC
Charge current house battery *	70 A
Charge current starter battery	4 A
Battery temperature sensor	Yes
Mechanical Characteristics	
Dimensions	444H x 328W x 240H mm
Weight	30 kg
General	
Multi purpose relay driver or relay **	Yes
Protection [2]	a - f

Common characteristics	Operating temperature: -20 to +50°C (fan assisted cooling) Humidity (non condensing): max 95%
Enclosure	
Common characteristics	Material & Colour: aluminium (blue RAL 5012) Protection category: IP 21
Battery connection	Four M8 bolts (2 plus and 2 minus connections)
230V AC connection	Screw clamp 13 mm2 (AWG 6)

[1] Can adjusted to 60 Hz, 120V 60Hz on request
[2] Protection: a. Output short circuit, b. Overload, c. Battery voltage too high, d. Battery voltage too low, e.230VAC on inverter output and f. Temperature too high
[3] Non linear load, crest factor 3:1
* At 25°C ambient
**Multi purpose relay which can be set for general alarm, DC under voltage or genset start signal function

Quality and Safety

- Safety EN60335, EN 60335-2-29
- Emission / immunity: En 55014-1, EN 61000-3-2 / EN 55014-2, EN 61000-3-3
- Automotive directive 2004/100/EC

Appendix D-4
Latronics Sinewave Inverter 400Watt 24Volt

- Model: **LS 624**
- Shipping Weight: **5.5kg**
- Manufacturer: **Latronics**
- **In Stock**
  2-5 business days delivery

Latronics 400Watt 24Volt Pure Sinewave Inverter

Convert your battery power to a more useable high quality AC mains electricity and create your own independent mains supply for your boat, caravan, motorhome or remote area power system. Simply connect a suitable battery bank to the LS Series Inverter and you're ready to power a wide range of every day appliances. Suitable for operating: TV, VCR, stereo,computer, office equipment, fridges, power tools and pumps.

The Latronics® LS Series Inverter utilizes the most advanced microprocessor algorithms, which guarantees your power conversion is pure and stable.

The Latronics® LS Series Inverter is the most powerful and reliable Inverter on the market.

Warranty

- 2 Years parts and labour

Features

Wall mount design	Allows flexibility and ease of installation.
Performance	True sinewave output with unmatched surge power enables the operation of demanding appliances, such as fridges, microwaves washing machines & pumps.
Pure Sinewave Output	Provides the ideal power source for all modern electronics.
Short Circuit Proof	Indestructible design protects itself against any AC shorts.

Reliability	Benchmark quality standards ensure optimum reliability, backed by a full 2 year parts and labour warranty.
Full Electronic Protection	Sophisticated circuitry provides protection against overload, short circuit, over temperature and high/low voltage shutdowns.
Frequency 50/60Hz Selectable	Fully selectable between 50/60Hz via a set of internal dip switches.
Autostart	Sophisticated sensing circuitry automatically switches the inverter ON and OFF with applied appliances. The Autostart is an important feature as it maximises valuable battery capacity. Sensitivity of the Autostart can be easily adjusted to either start small appliances or run continuously.
Durable Construction	Latronics® Inverters are a quality industrial product made to withstand vibration and constant movement in mobile or marine installations, as well as the diverse range of home or commercial applications.
Corrosion Conscious Design	Latronics® Inverters are built for extreme environments using a recyclable powder coated aluminium casing, a more noble metal than steel
High Efficiency Toroidal Transformer	Toroidal transformers provide the highest efficiency and durability.
High Surge Rating	High surge rating allows easy starting of motors and high inrush current devices.
DC Circuit Breaker	Protects the inverter and cables from becoming a potential fire hazard under fault conditions, as well as providing full isolation from your batteries while switched OFF, reducing the need for additional battery fuses.
AC/DC Isolation	Full 3500V AC/DC isolation.
Heavy Duty DC Battery Leads	High quality, high current DC leads for low loss power delivery.
LED Status Indicators	A full set of LED's keeps the user informed of its operation at all times.
Options	A complete Australian made product, proudly designed and manufactured in Australia by a 100% Australian owned company.

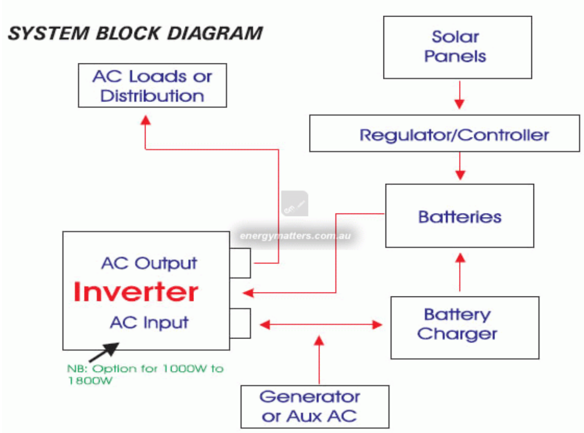
Technical Specifications

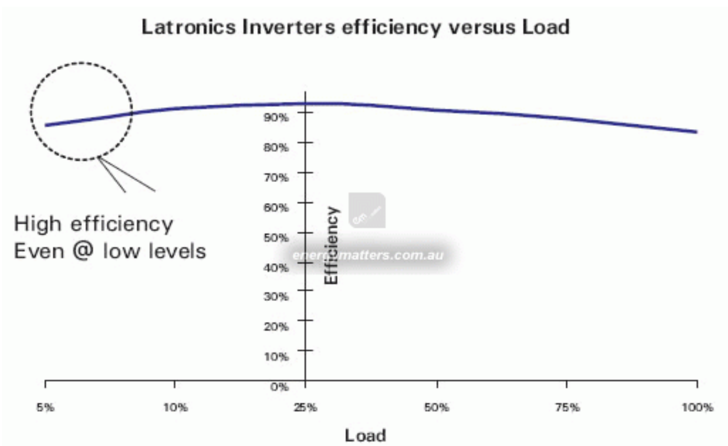
Electrical Characteristics	
Nominal DC Voltage	24 V
Continuous Power	400 W
½ Hour Rating	750 W
Surge Rating (5 seconds)	2000 W
Input Voltage Range	21 - 34 V
Standby Current	22 mA
Inverter ON – no load	0.31 A
Peak Efficiency	92 %
Output Voltage	230Vac +/- 4% (110Vac Available)
Output Waveform	True Sinewave
Total Harmonic Distortion	< 4 %
Output Frequency	50 Hz +/- 0.1%
Power Factor	All Conditions
Operating Temperature	-10° C to + 50° C
Autostart Sensitivity	0 – 20 W adjustable
DC to AC Isolation	3500 V
Protection Circuitry	Over temperature, Overload/Short Circuit, Battery Under voltage/Over voltage
Mechanical Characteristics	
Dimensions	260 mm x 160 mm x 100 mm
Weight	5.5Kg
Chassis	Powder coated 2mm Aluminium
AC Output Wiring	Single Power Outlet
Battery Leads	1m long with 10mm lugs

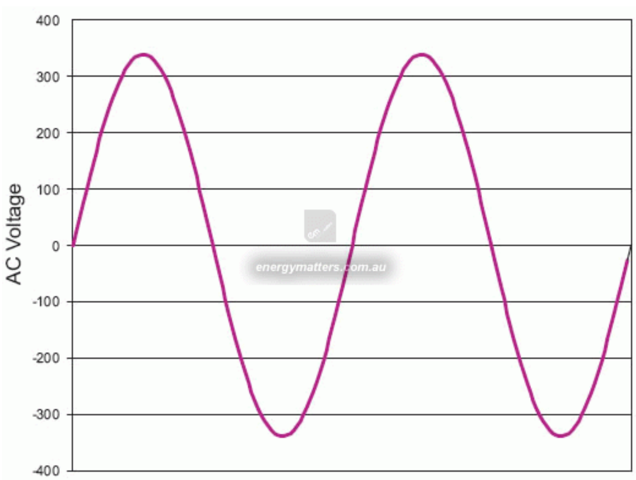
Quality and Safety

- A complete Australian made product, proudly designed and manufactured in Australia by a 100% Australian owned company.
- Manufactured by AS2279, AS3000, AS3100, EN55014, EN61000-4, CE & C-Tick standard.
- Rating: Specifications @ 25°C Ambient, Nominal Battery Voltage & Unity Power Factor

Additional pictures and graphs







جامعة النجاح الوطنية
كلية الدراسات العليا

"التقييم الفني و الاقتصادي لإنارة تجمعات صغيرة باستخدام أنظمة الخلايا الشمسية (PV) المركزية واللامركزية في فلسطين"

إعداد
بسام احمد عبدالحميد عبدالغني

إشراف
د. عماد بريك
أ. د. مروان محمود

قدمت هذه الأطروحة استكمالاً لمتطلبات درجة الماجستير في هندسة الطاقة النظيفة وترشيد الاستهلاك بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.
2008

التقييم الفني و الاقتصادي لإنارة تجمعات سكنية صغيرة باستخدام أنظمة الخلايا الشمسية (PV) المركزية واللامركزية في فلسطين "

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إشراف

د. عماد بريك

أ. د. مروان محمود

الملخص

إن بحث هذه الرسالة يشتمل على تطبيق نظام الخلايا الشمسي في إضاءة القرى الصغيرة و النائية باستخدام النظام المركزي أو اللامركزي.

يهدف هذا البحث الى اختيار أفضل تصميم و أفضل تشكيل لهذه الأنظمة وذلك على الأساس الاقتصادي (LCC) الذي يعطي اقل تكلفة في التكاليف العامة والإجمالية للعمر الافتراضي لكل نظام، مما يساعد في استقرار وثبات تشغيل النظام وان تمد في العمر الافتراضي لمكونات النظام وتقلل من تكلفة إنتاج الطاقة الكهربائية.

تم تطبيق هذا البحث على ثلاث قرى صغيرة و معزولة في محافظة طوباس وهي (قرى سلحب و ابزيق و يرزا) وقد تم اجراء تحليل و تقييم للنظامين المركزي واللامركزي لكل قرية على حدا، حيث تمت مراعاة عدد البيوت في كل قرية وكذلك المسافات بين البيوت ، وتم احتساب التكلفة الإجمالية لكل نظام (LCC) وتكلفة وحدة إنتاج الكهرباء ($/kWh) لكل حالة.

إن تصميم النظام المركزي يأخذ بعين الاعتبار عدد البيوت، طول المسافات بين البيوت وكذلك على الحمل الكهربائي الإجمالي لكل قرية، بينما تصميم النظام اللامركزي يعتمد فقط على الحمل الكهربائي لكل بيت.

من نتائج تطبيق البحث على قرى طوباس تبين أن التكلفة الإجمالية وتكلفة الوحدة الكهربائية للنظام اللامركزي اقل من النظام المركزي بـ 12.78% و 5.38% على التوالي، و

تبين أيضا أن الكفاءة الإجمالية للنظام اللامركزي تبلغ 11.59% ، وللنظام المركزي 10.89% ، ولكن هذه النتائج تعتمد على دراسة كل حالة على حدا.

تم تحليل تكلفة النظام اللامركزي باستخدام التيار المباشر DC للحمل الكهربائي في كل بيت، وفي هذه الحالة كانت تكلفة الكيلو واط ساعة هي 0.748 دولار أمريكي والتي هي اقل بـــ 17.3% من تكلفة الكيلو واط ساعة في حالة أن يكون الحمل الكهربائي لكل بيت يعتمـــد علـــى التيار الكهربائي المتردد AC.