An-Najah National University
Faculty of Graduate Studies

Optimal Operation Strategy and Economic Analysis of Rural Electrification of Atouf Village by Electric Network, Diesel Generator and Photovoltaic System

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Dedicated to………

My Mother
and
My Father Spirit

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Asma Yasin

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Optimal Operation Strategy and Economic Analysis of Rural Electrification of Atouf Village by Electric Network, Diesel Generator and Photovoltaic System

استراتيجية التشغيل الأمثل و التحليل الاقتصادي لانارة المناطق الريفية – قرية عطوف ، باستخدام أنظمة الخلايا الشمسية ،أنظمة الديزل ،وشبكات الكهرباء

أقر بأن ما اشتملت عليه هذه الرسالة انما هي نتاج جهدي الخاص ، باستثناء ما تمـت الاشارة اليه حيثما ورد ، وأن هذه الرسالة ككل ، أو أي جزء منها لم يقدم من قبل لنيـل أيـة 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:**
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Abbreviations

AC	Alternative current
ACSR	Aluminum conductor with steel reinforced
BOS	Balance of system
DC	Direct current
GS	Gaza Strip
GW	Giga watt
GWh	Giga watt hour
IEC	Israel electric corporation
km	Kilometer
kV	Kilovolt
kVA	Kilo volt ampere
kWh	Kilo watt hour
MW	Megawatt
NIS	New Israeli shekel
PARC	Palestinian agriculture relief committees
PCU	Power conditioning unit
PSH	Peak sun hour
PT	Palestinian Territories
PV	Photovoltaic
PVS	Photovoltaic system
RE	Renewable energy
TLS	Transmission line system
TWh	Terra watt hour
WB	West Bank

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Optimal Operation Strategy and Economic Analysis of Rural Electrification of Atouf Village by Electric Network, Diesel Generator and Photovoltaic System

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Abstract

This thesis describes the optimal operation and economic analysis of rural electrification of Atouf village by electric network, diesel generator and photovoltaic system, and also the design and testing of an 11.7 kWp PV system and summarizes its performance results after the first 6 months of operation. This system functions as a stand-alone power system used to supply electricity for Atouf village. The system is comprised of the following components. An array consist of PV modules produced from polycrystalline solar cell of 130W, making up a total peak power of 11.7 kW. In addition, there is one inverter of 7.2 kW, and an energy storage system of 120 kWh.

After the first 6 months of system operation from December 2007 to May 2008, it was found that all the components and the overall system had worked efficiently. In total, the system had generated during this period about 7596 kWh, average solar radiation in this period about 4.67kWh/m^2-day, daily input solar energy of the total system surface was 390.5kWh, and the average electricity production per day was 46.11kW. From the economical view point, photovoltaic energy system differ from conventional energy systems in that they have high initial cost and low operating costs. This study shows that the unit cost of the PV system is 2.69 NIS/kWh which is less than that of the diesel generator systems in Atouf village.

INTRODUCTION

Palestine has a large number of rural small villages far from the national electric grid. Electrical loads in such villages are mostly small and can be covered by means of photovoltaic generators which are economically more feasible than extending the electric network or using diesel electric generators. Since PV had been rarely used in Palestine, in this work we will investigate the potential of PV applications as in other countries and to demonstrate the reliability and feasibility of utilizing PV systems through presenting the testing results of a PV system need for rural electrification of an isolated village called Atouf.

The main objectives of this thesis are summarized in the following points:

- To investigate the potential of PV energy applications in Palestine and to demonstrate the reliability and feasibility of utilizing PV systems.
- Designing the PV power system for electrification of Atouf village respecting the local environmental conditions.
- To illustrate testing measurements to show how far the PV-power generation could be matched with load demands and battery state of charge.
- To provide full performance characteristics of the system in Atouf under all conditions.
- Finally, to provide Economic evaluation of supplying Atouf village by PV system, Diesel and IEC

Our research procedure are summarized in the following points:

- Theoretical background and literature review.
- Data collection about the potential of solar radiation in Palestine.
- Measurement of basic quantities in Atouf village-generator energy production and fuel use ,site electrical loads and other electrical parameters.
- Design the PV power system respecting the local environmental conditions.
- Illustrate testing results for Atouf electrical network to show far the PV-power generation could be matched with load demands and battery.
- Compare the performance and energy production costs of different system configurations.

First of all, the study begin with an introduction to the thesis, it gives information about objective, procedure and the main outline of the research.

The study consists of eight chapters. The first one concerns with the electricity sector in PT. In this chapter, we try to give an overview of the PT electricity sector and the fact that Israeli company IEC is considered the only source of electrical power in the PT. Then we attempt to throw light on the current situation of the electricity sector in the PT: production, consumption, and the electric power transmission grid. This chapter highlights the major problems of the electricity sector, especially the high distribution losses, high kWh price and electricity supply lack. Finally, we try to indicate the electrification of small villages in Palestine.

In the second chapter, the study shows potential of renewable energy in Palestine. This chapter shows the different sources of renewable energy that can be used to satisfy electricity and energy needs such as wind, biogas and solar energy. This chapter also gives an idea about sunshine and solar radiation in Palestine and the possibility of using it in electricity generation by using photovoltaic system.

The third chapter gives an information about the PV system. It consists of a definition of PV system, the advantages and disadvantages, types and components of PV system. This chapter also gives an idea about evaluation of photovoltaic systems in Palestine and the importance of using PV system in Palestine.

The fourth chapter contains a detailed analysis of partial or non-electrified villages in Palestine. This chapter illustrates a list of the non-electrified small villages in Palestine. Then we throw light on one of these villages as case study which is Atouf village. This chapter also gives an idea about location, living conditions, environmental data, and energy requirements of houses in Atouf village. Finally, it contains information about the source of electricity and the main electricity problems in the village.

The fifth chapter contains the performance analysis of existing diesel generator in Atouf and the cost of all components used in this system. In this chapter, we try to give an overview of the possibility to connect Atouf with IEC, and the full design of the transmission line and the total cost of the system.

The sixth chapter gives information about the system used in Atouf village with total selection of the all components of the PV system by determination the energy consumption in the village and also the average daily of solar radiation.

In the seventh chapter the study gives an implementation of Atouf PV system. This chapter shows installation of the PV-generator and the PV components such as battery, controller, inverter and wiring. This chapter also gives an idea about PV system cost.

Finally, the eighth chapter presents comparisons for the most important electricity generation systems, such as PV, transmission line, and diesel generator. The available data enable us to make comparisons in the cost of 1kWh production from these systems and it shows that the PV system is a good choice to provide Atouf with electricity. This chapter also provides a tariff structure for the PV-system in Atouf by using special device Energy Dispenser/Meter.

CHAPTER ONE

ELECTRICITY IN PALESTINE

As a result of several years of Israeli military occupation of the PT, the Palestinian economy suffers from major distortions and underdevelopment. The infrastructures of the WB and GS were greatly neglected by the Israeli Authorities. Under Israeli occupation, policies were employed which aimed to restrict the electrical production capacity of the PT.

The lack of an adequate infrastructure in the PT for nearly four decades has impeded any real growth on the energy front and caused chronic energy problems. There is a high unit price of energy when energy resources are either dwindling or non-existent.

Furthermore, the supply of conventional energy (electricity and petroleum products) is monopolized by the IEC, which creates an unrealistic price control of electricity, thus provoking energy shortages and the potential for future energy crises [1].

There are 63 localities in the PT which are not connected to the public electricity network. In general, the electricity sector is characterized by a relatively low level of electricity consumption; in 2005 the WB electricity consumption was estimated at 2138 GWh/year , while in the GS it was 1225 GWh/year , which is considered to be the lowest consumption rate in the region [2].

As noted, the Palestinian electricity sector suffers from many problems, such as high distribution losses it was estimated to be (10%-20%). The economic consequence of such a loss is estimated at 4.29

million US dollars per year, which in turn leads to a high price for kWh (between $0.13-0.5 kWh) [3].

However, following the Oslo Peace Agreement, the Palestinian Authority has performed many electrification and rehabilitation projects, such as the rehabilitation of 70% of the Gaza network and the northern of WB ($23 million, Norwegian aid) and electrification of isolated villages through Photovoltaic Systems such as Al-Kaabneh Village in WB,(150000$,Greenstar aid), but the current situation shows that the Palestinian energy sector is still dependent on Israel [1].

1.1. Electricity Production in the PT

The only Palestinian electricity production is from the Gaza power plant, with 140 MW of production total capacity which covers Gaza city and other surrounding areas. The Palestine Electric Company was established in 1999, with 33% of its assets for public shareholders and 67% for private shareholders and with cost of $150 million, Figure(1-1) [4].

Figure(1-1): Gaza power plant

The IEC is considered the monopoly of electricity production in WB with a main production capacity of 9.1 GW. Its main production plants are situated in Ashkilon and Hadera . In reality, the PT are completely dependant on the IEC for their electricity needs. Municipalities in the WB perform the role of electricity distribution companies [1].

At the end of 2006, two agreements were done, one with Egypt to supply Rafah (south of Gaza) by 33kV O.H line-17MW (connected), and the other agreement is with Jordan to supply Jericho in the WB by 33kV O.H line-20MW (under construction) [5].

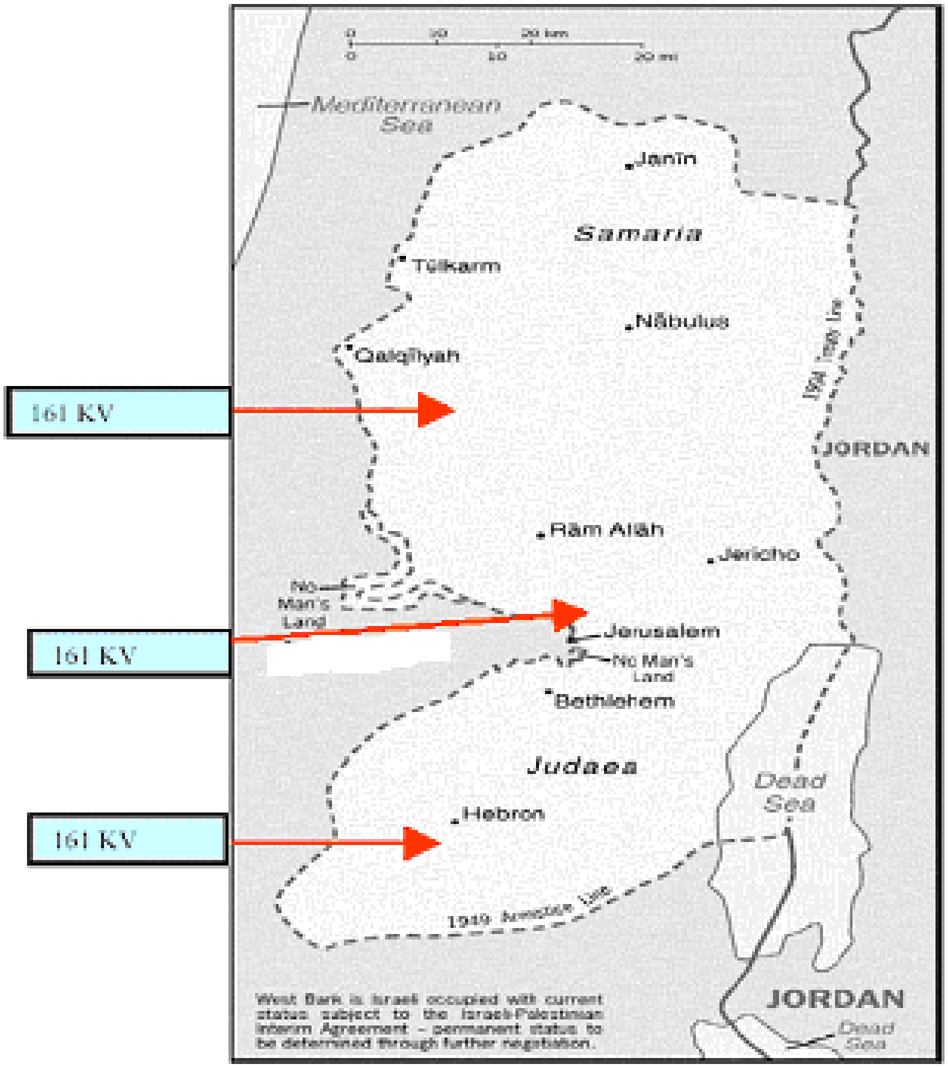
1.2. Electrical Grid System in the WB

The IEC supplies electricity to Palestinian villages adjacent to its overhead lines, under the influence of the political decisions taken by

Israeli authorities to suit their requirements without considering the needs of the villagers. There are three main lines in the WB and nine main lines in the GS (cf. Grid lines map(1-1) below). These lines were designated to supply colonies and military camps. During the last four decades, electrical installations had to be financed by the local population; this is why some rural villages located far from Jenin or Hebron have no electricity [1] .

The Israeli electricity network is a closed loop system of 2645km. The range of voltages of these networks is 400 volt, 6.6 kV, 11 kV and 33 kV. In addition there are 22 kV networks which the IEC sometimes used in their lines in the WB. There are 700 km of 11 & 6.6 kV networks, 400 km of 33 kV networks, 5000 km of 400 volt networks.

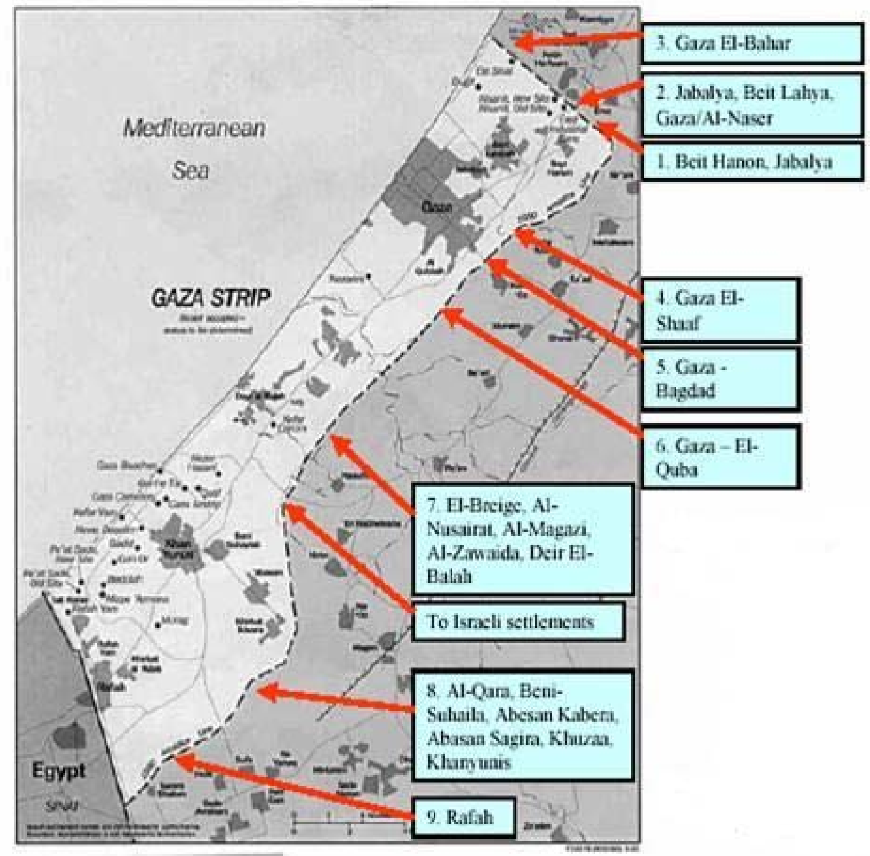
The electricity network is considered to be a serious problem for Palestine because it is characterized by high electricity loss in addition to frequent power cuts. Moreover, the inadequate network causes a supply shortage for the industrial sector, while the proportion of the cost of electricity is very high (nearly 35% of the operation cost)[1].



Map (1-1): Main IEC Feeders supply to WB

1.3. Electrical Grid System in GS

The IEC supplies the GS area with energy through eleven main feeders. After the Cairo Peace Agreement, two of these feeders' lines were assigned to supply energy to what formerly constituted the Israeli settlements in the Gaza Strip (Map 1-2)[1]:



Map (1-2): Main IEC Feeders supply to Gaza Strip

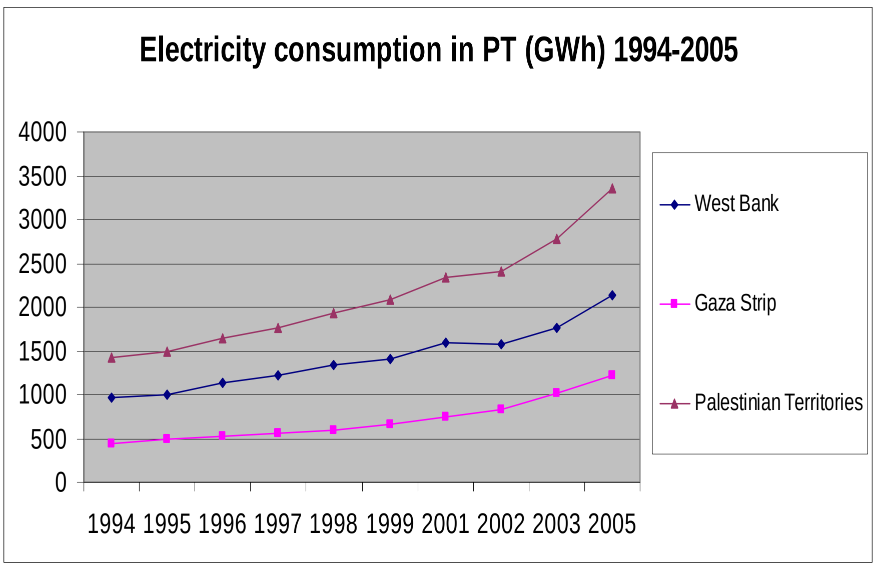
1.4. Electricity Consumption

Electricity consumption for the Palestinians is considered to be the lowest in the region, Table(1-1) show that electricity consumption per capita in 2006 was 675 kWh for Palestine compared to 5200kWh for Israel (8 times greater) [5].

Table(1-1): Electricity consumption per capita in Arab region

Country	Palestine	Israel	Jordan	Egypt	Lebanon
Consumption per capita (kWh/year) 2006	675	5200	1145	1050	2100
Average of Arab countries: 1445 kWh/capita/year					

Despite the economic and political conditions in Palestine , the trend analysis of electricity consumption in the WB and the GS show increased rates of consumption in recent years before and after the uprising, the following Figure(1-2) shows that [3]:

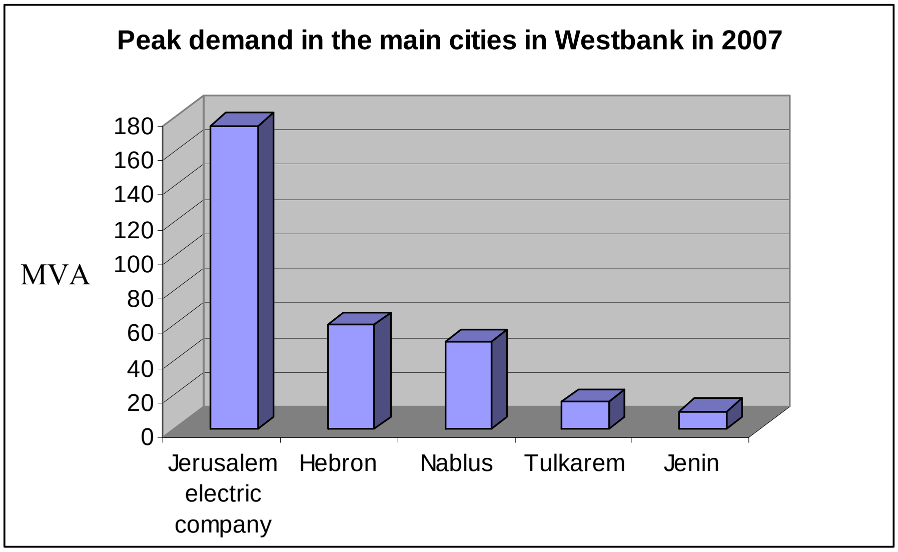


Figure(1-2): Electricity Consumption in PT

Peak demand

The peak demand in the PT was 294 MW in 1995 and jumped to 405 in 1999 (during the peace period following the Oslo Agreement). This tendency of increasing demand strongly slowed down during the second Intifada; a peak demand of 454 MW was recorded in 2001, which increased to only 496 MW in 2003. Two thirds of this demand for electricity comes from the WB [3].

Peak demand in Jerusalem Electric Company which includes Ramallah, Jericho, Jerusalem and Bait Lahem is high compared to other cities. The figure below shows peak demand for the main cities in WB (Fig.1-3) [6].



Figure(1-3): Peak demand in MVA in WB in the year 2007

1.5. Electrical Problems in Palestine

The electricity sector in Palestine suffers from many problems, these problems lies in that the sole source of electricity in the WB from the IEC, and these problems are:

1.5.1. Distribution losses

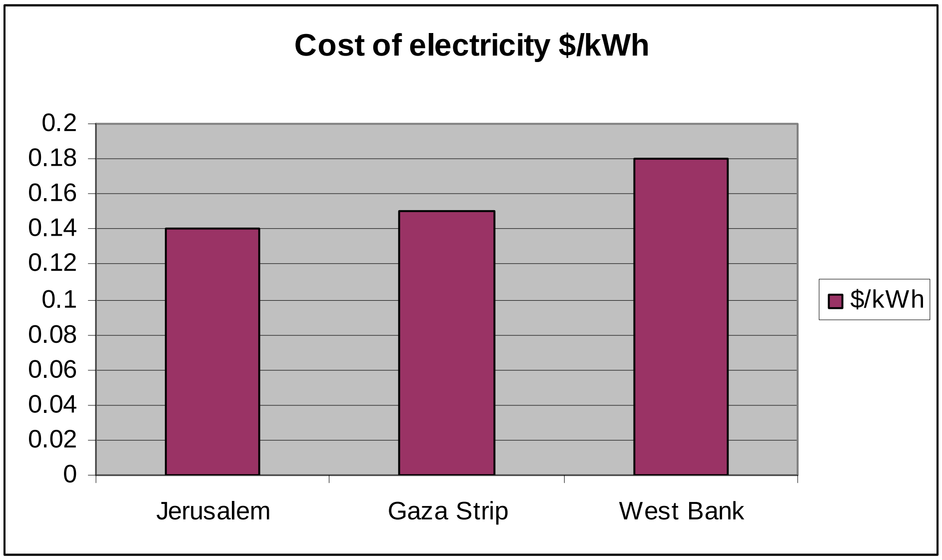
One of the main challenges for the electric rehabilitation plan is the distribution losses, which are considered as the highest in the region. Although the electricity supply is assured by the IEC, which uses the electric transmission and distribution network, no efforts were made to rehabilitate this network .While the electricity distribution loss in the PT is about 10% to 20% of the total energy injected, the minimum distribution losses in Israel is about (6-7)% [6].

1.5.2. High cost of energy

The fact that electricity production is monopolized by the IEC gives it the power to impose high prices. The IEC is thus able to discourage private manufacturing companies from competing with it by using small independent power stations at their factories. Municipalities in the PT collect the electricity bill from the final consumers. They determine the final price based on the IEC price plus a margin of 10% to cover salaries, maintenance and allow a profit margin[1].

The electricity price reached a very high level in WB (0.13-0.5)$/kWh; this is 3 times higher than the average price in Israel 0.07$/kWh [6].

In the year 2005 the cost of electricity reached 0.18 US $/kWh in WB, this value is very high compared with 0.15 US $/kWh in GS and 0.14 US $/kWh in Jerusalem, Figure(1-4) [7].



Figure(1-4): Cost of energy in PT in 2005

1.5.3. Lack of electricity supply

The IEC is considered the monopoly of electricity production in WB, Electricity is considered as the main source of energy. The connections to the electricity network have strongly increased during the last ten years. The percentage of households connected to the public electricity network in PT increased from 97.2% in July 1999 to 99.5% in July 2006. This is a misleading figure; in fact 93.7% of household in WB receive uninterrupted electricity services (24 hours a day, 7 days a week), Table(1-2) [8].

Table(1-2): The proportional distribution of the families in the Palestinian territories by region and the number of hours of service provided electricity, July 2006

Region	Number of hours of service provided Electricity			
	Less than 8 hours	8-23 hours	24 hours	Total
West Bank	2.1	4.2	93.7	100
West Bank-North	3.6	10.3	86.1	100
West Bank-Middle	0.7	0.0	99.3	100
West Bank-South	1.6	0.0	98.4	100
Gaza Strip	1.1	98.9	0.0	100

However, some 63 localities in the WB are not connected to a public electricity network, including 29 in the Hebron district and the probability of connecting them with high voltage grid in the near future is very poor due to financial and political situation, map(1-3) [9], and table(1-3) show the percentage of households that are not connected to electricity network in PT [10] .

Map(1-3): Percentage of households that are not connected to electricity network in the PT, July 2006.

Table(1-3): the percentage of households that are not connected to electricity network, July 2006.

Region	Main Electricity Source in the Housing Unit			
	Public Network	Private Generation	No Electricity	Total
Palestinian Territories	99.5	0.0	0.5	100
West Bank	99.3	0.1	0.6	100
North of West Bank	99.7	0.0	0.3	100
Middle of West Bank	99.7	0.0	0.3	100
South of West Bank	98.4	0.2	1.4	100
Gaza Strip	99.8	0.0	0.2	100

1.6. Electrification of Small Villages in Palestine

Palestine has a large number of remote small villages that lack electricity as shown in the last section and the probability of connecting them with high voltage grid in the near future is very poor due to financial and political situation. The daily average of energy demands in these villages are extremely low in the range of 0.5-3kWh per household[11].

The main electrical loads in these villages are represented in lightning, TV and refrigerators. Small diesel generators of power range from 3 to 7 kVA are widely used by different villagers to cover the power demands of their houses and sell the excess generated power at very high price [11] .

Usually the operation of these generators is limited on the night periods. The low voltage networks connecting these systems with consumers are mostly unprofessionally laid out, which makes these networks dangerous and accompanied with high power losses. In addition ,these small generators pollute strongly the environment, and are not reliable due to their frequent faults. The price of diesel fuel in Palestine is relatively high. Therefore ,utilizing of such generators does not represent a durable effective solution [11].

CHAPTER TWO

POTENTIAL OF RENEWABLE ENERGY IN PALESTINE

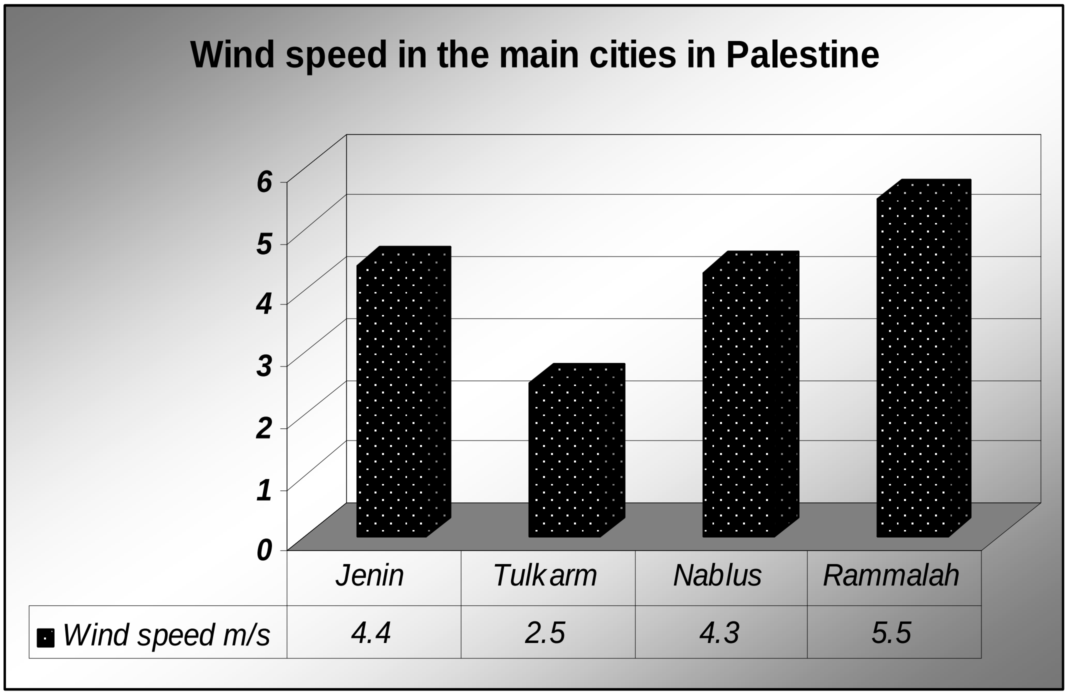
Renewable energy is energy that is derived from natural processes that are replenished constantly. In its various forms, it derives directly or indirectly from the sun, or from heat generated deep within the earth. Included in the definition is energy generated from solar, wind, biomass, geothermal, hydropower, ocean energy, bio-fuels and hydrogen derived from renewable resource [12].

The main renewable energy sources considered to have potential in Palestine are wind energy, biogas and solar energy.

2.1. The Wind Energy Potential in Different Areas in Palestine

Palestine can be considered as a country on moderate wind speed, coastal region (Gaza) has very low wind speed (2.5-3.5)m/s, hilly region have annual average(4-6)m/s and Jordan valley (Jericho) has very low wind speed(2-3)m/s [5]. The mean annual wind speed in Palestinian main cities are shown in Fig.(2-1) [6].

There are five modern meteorological stations were installed in the WB by Energy Research Center at An-Najah university, and the collected data from these stations shows that some areas in Palestine could have considerable wind energy potential for some application like water pumping [5].



Figure(2-1): Wind speed in Palestine

2.2. Biogas Potential

Biogas technologies were applied in some locations in Palestine for the purpose of gas production for cooking but not for electricity generation. The projects in this technology are summarized in the following :

1. Digester College of Agriculture \ Najah University: This Digester was built in mid-2000 at the College of Agriculture of An-Najah National University in Tulkarem cooperation with PARC. Digester is designed so that it can service a farm of about 15 cows can produce four cubic meters of biogas per day and about 700 liters per day of manure. But in Intifada this Digester was destroyed by the occupation forces [13].

2. Digester Jericho \ garden Babai: This Digester has been established in the spring in 1998 cooperation with PARC, the volume of

approximately 5 cubic meters can produce about cubic meters of biogas and 200 liters of manure. Digester used as a teaching garden for visitors to get acquainted with the digestion process is vital [13].

3. In Tulkarem \ Izbt Shufa: This Digester established cooperation with the PARC in a farm in the village of Izbt Shufa near Tulkarem. This Digester exists for this moment, but dormant since its inception and this image for digester after opening [4].

Figure(2-2): Izbt Shufa digester

2.3. Solar Energy in Palestine

Solar energy is expected to play a very important role in meeting energy demands in the near future. Since it is a clean type of energy with a diversity of applications, decentralized nature and availability, solar energy will represent a suitable solution for energy requirements especially in rural areas. It is important to state that the use of solar energy in rural regions will protect these area from pollution, since the use of solar home systems avoids large amounts of CO_2 emissions [14].

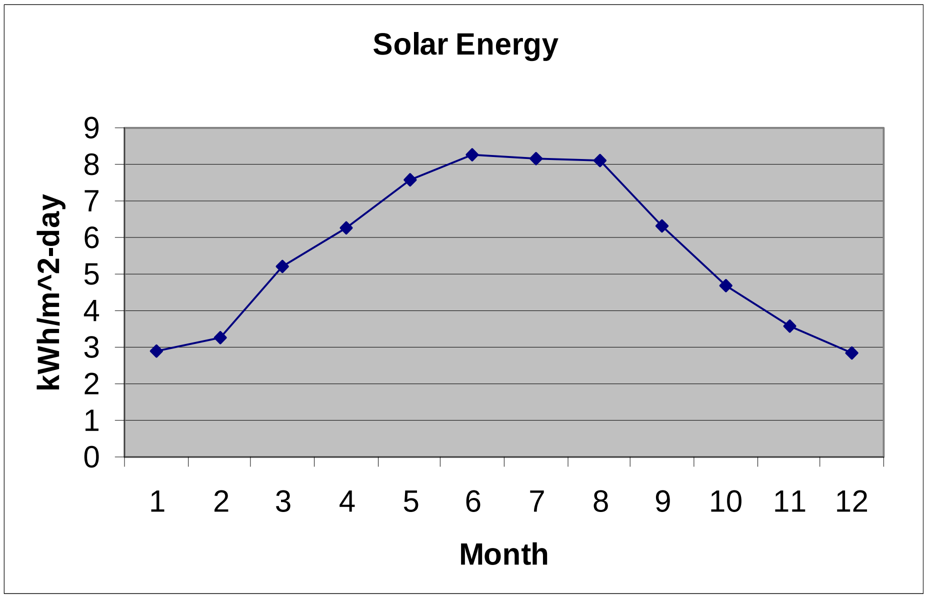
In Palestine, there are many remote small villages that lack of electricity, and it is possible to electrify these villages by using solar energy.

Solar Radiation

Palestine has a high solar energy potential, where average solar energy is between 2.63 kWh/m^2 per day in December to 8.5 kWh/m^2 per day in June, and the daily average of solar radiation intensity on horizontal surface (5.46 kWh/m^2 per day) while the total annual sunshine hours amounts to about 3000, these figures are very encouraging to use Photovoltaic generators for electrification of remote villages as it has been world wide successfully used [11].

The amount of radiation arrives at the WB differs from place to another. The amount of radiation decreases toward the West. This reduction is due to the cloud cover between the hills and the coastal plain. Solar radiation in the West Bank is at a highest in Jericho [11].

Fig.(2-3) show the solar radiation in Nablus city, solar radiation is reach $8kWh/m^2$ in June, July and August (Summer months)[6].



Figure(2-3): Solar energy for Nablus in 2005

Utilization of solar energy is very familiar to the Palestinian population and is used essentially for water heating.

CHAPTER THREE

PHOTOVOLTAIC SYSTEMS

Photovoltaic offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Because the source of light is usually the sun, they are often called solar cells. The word photovoltaic comes from "photo," meaning light, and "voltaic," which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight." Photovoltaic are often referred to as PV [15].

3.1. Advantages and Disadvantages of PV Systems

Many countries selected the PV systems for electrification of small villages for a variety of reasons. Some common reasons for selecting a PV system include [16]:

- Cost—when the cost is high for extending the utility power line or using another electricity-generating system in a remote location, a PV system is often the most cost-effective source of electricity.
- Reliability—PV modules have no moving parts and require little maintenance compared to other electricity-generating systems.
- Modularity—PV systems can be expanded to meet increased power requirements by adding more modules to an existing system.
- Environment—PV systems generate electricity without polluting the environment and without creating noise.

- Ability to combine systems—PV systems can be combined with other types of electric generators (wind, hydro, and diesel, for example) to charge batteries and provide power on demand.

As a developing technology, PV systems have also some disadvantages such as**[**17**]** :

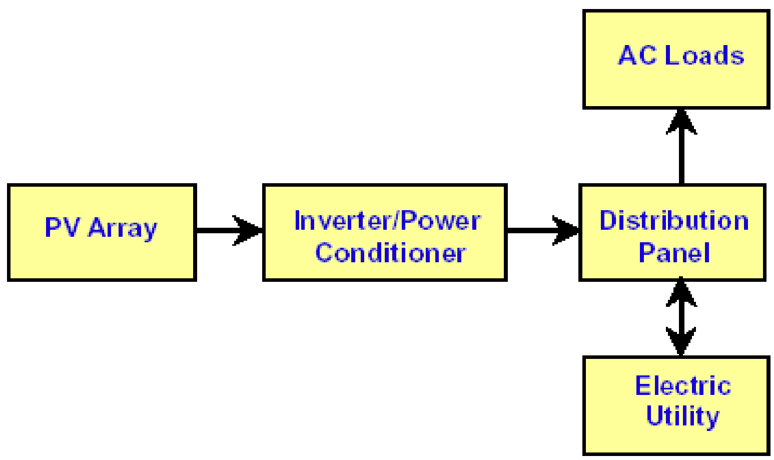
- Initial cost — PV systems have a high initial cost.
- Solar radiation — energy output from PV generator depends on sunlight levels which are variable and difficult to predict on a day to day basis.
- Energy storage — system more complex.
- Education — new technology for user.

3.2. Types of PV systems

Photovoltaic systems are generally classified according to their functional and operational requirements, their component configuration, and how the equipment is connected to the other power sources and electrical loads (appliances). The two principle classifications are Grid-Connected and Stand Alone Systems.

3.2.1. Grid connected or utility-interactive

PV systems are designed to operate interconnected with the electric utility grid. The primary component in grid-connected PV systems is the inverter, or power conditioning unit (PCU). A bi-directional interface is made between the PV system output circuits and the electric utility network, typically at an on-site distribution panel. This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back feed the grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility. The PCU converts the DC power produced by the PV array into AC power consistent with the requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized, figure(3-1) [18].



Figure(3-1): Diagram of grid-connected photovoltaic system.

3.2.2. Stand alone system

Stand-alone PV systems are designed to operate independent of the electric utility grid, and are generally designed and sized to supply certain DC and/or AC electrical loads. Stand-alone systems may be powered by a PV array only, or may use wind, an engine-generator or utility power as a backup power source in what is called a *PV-hybrid system*. Batteries are used in most stand-alone PV systems for energy storage. Figure (3-2) shows a diagram of a typical stand-alone PV system powering DC and AC loads. Figure (3-3) shows how a typical PV hybrid system might be configured [18].

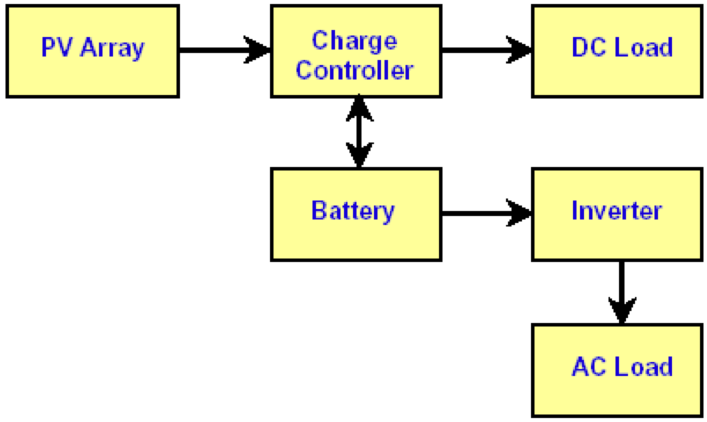


Figure (3-2): Diagram of stand-alone PV system with battery storage powering DC and AC loads

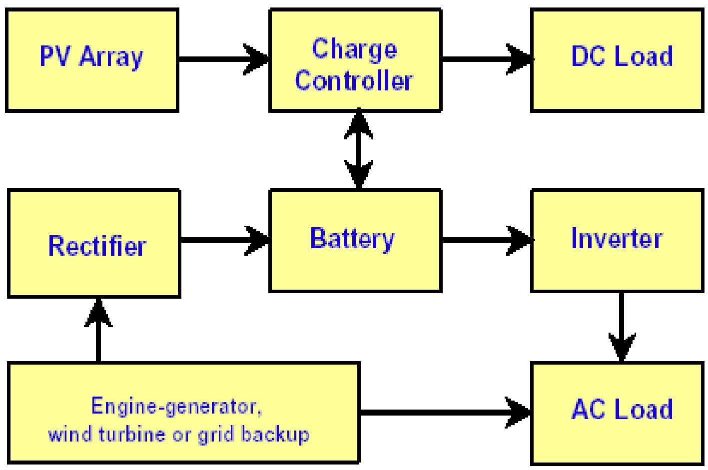


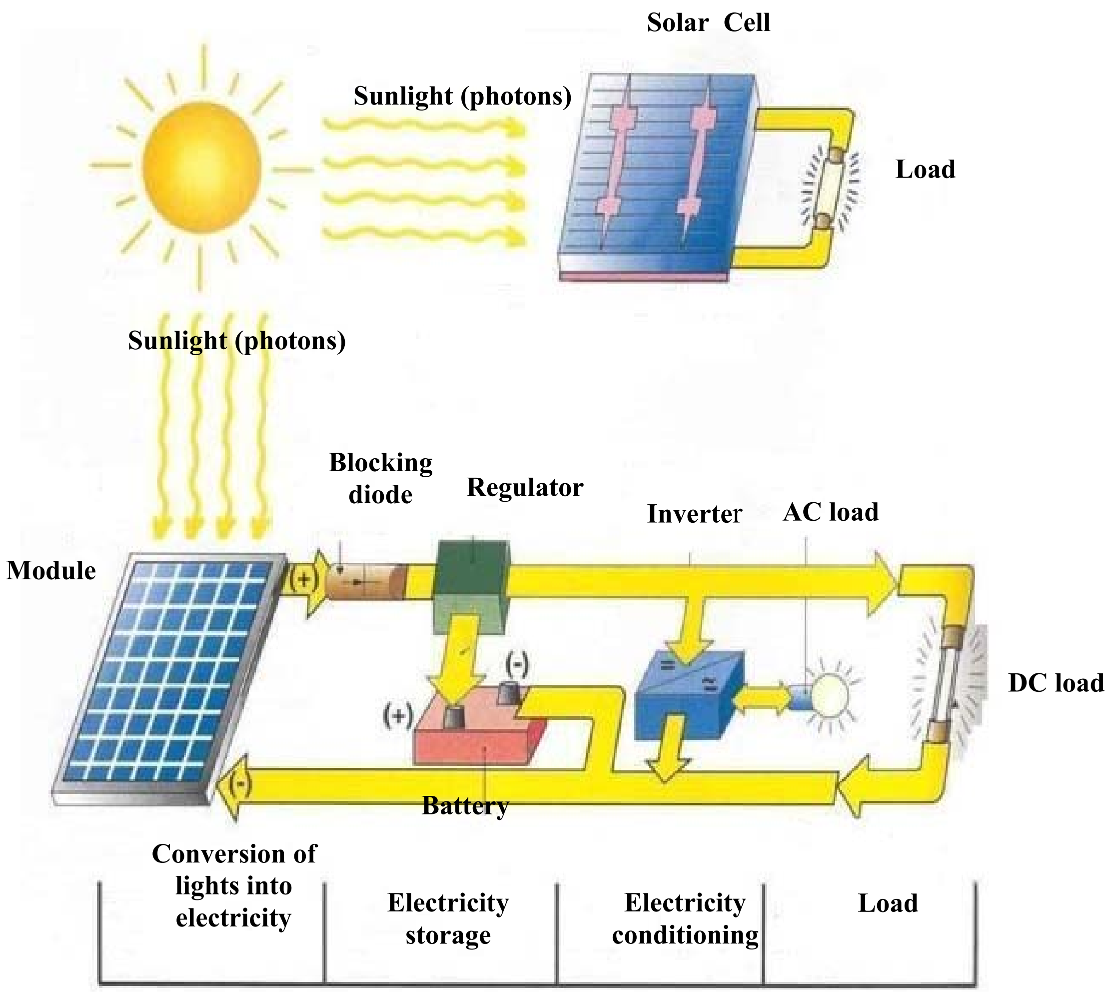
Figure (3-3): Diagram of photovoltaic hybrid system.

The simplest type of stand-alone PV system is a *direct-coupled system*, where the DC output of a PV module or array is directly connected to a DC load Figure(3-4). Since there is no electrical energy storage (batteries) in direct-coupled systems, the load only operates during sunlight hours, making these designs are suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems [18].

Figure (3-4): Direct-coupled PV system.

3.3. PV System Components

The specific components of PV system required depends on the functional and operational requirements for the system, and may include major components such as a *PV modules*, *DC-AC power inverte*r, *battery ban*k, system and battery *controlle*r, auxiliary energy sources and sometimes the specified *electrical load* (appliances). In addition, an assortment of *balance of system (BOS)* hardware, including wiring, terminations, over current, surge protection and disconnect devices, and other power processing equipment [18]. Figure(3-5) show a basic diagram of a photovoltaic system [4].



Figure(3-5): PV system components

1- PV modules

Cells are electrical devices a bout 1/100th of an inch thick that convert sunlight into direct current electricity through the photovoltaic effect, most cells produce approximately one-half of a volt [19].

To increase PV utility, dozens of individual PV cells are interconnected together in series or parallel in a sealed, weatherproof package called a module that convert sunlight instantly into DC electric power. When two modules are wired together in series, their voltage is doubled while the current stays constant. When two modules are wired in parallel, their current is doubled while the voltage stays constant. To achieve the desired voltage , modules are wired in series into what is called a PV panel [20] .

And to achieve the desired voltage and current, modules are wired in series and parallel into what is called a PV array [21], Figure(3-6) show Photovoltaic cells, modules, panels and arrays [18].

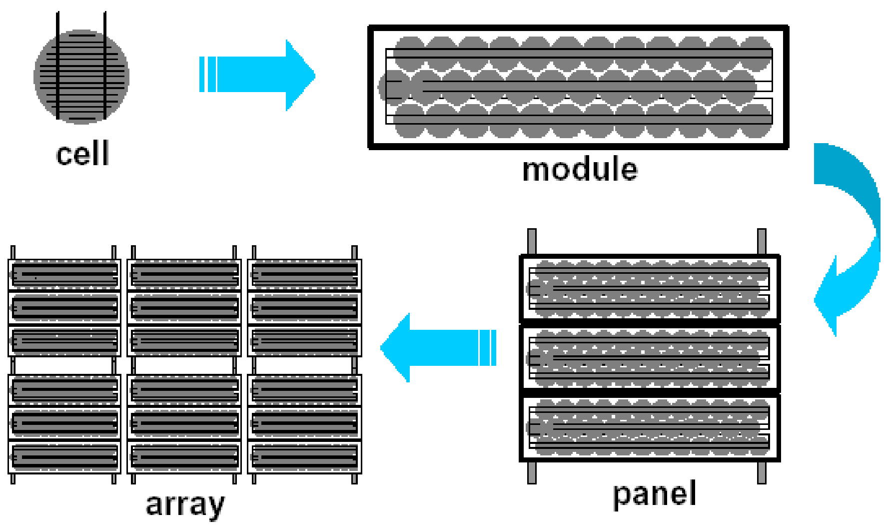


Figure (3-6): PV cell, module and array

Depending on the manufacturing process, most of modules can be of three types [21] :

1. Mono-crystalline Silicon.

2. Poly-crystalline Silicon.

3. Amorphous Silicon.

The first ones are the most efficient.

The total electrical energy output (wattage) of a PV module is equal to its output voltage multiplied by its operating current. The output characteristics of any given module are characterized by a performance curve called an I-V curve, that shows the relationship between current and voltage output [19].

Figure(3-7) below shows atypical I-V curve for KYOCERA photovoltaic modules (KC130GHT-2 high efficiency multi-crystal photovoltaic module) at standard test conditions $1000 W/m^2$ and 25^oC cell temperature [22], this condition is sometimes called " one sun " or " peak sun " passes through three significant points as illustrated in [23]:

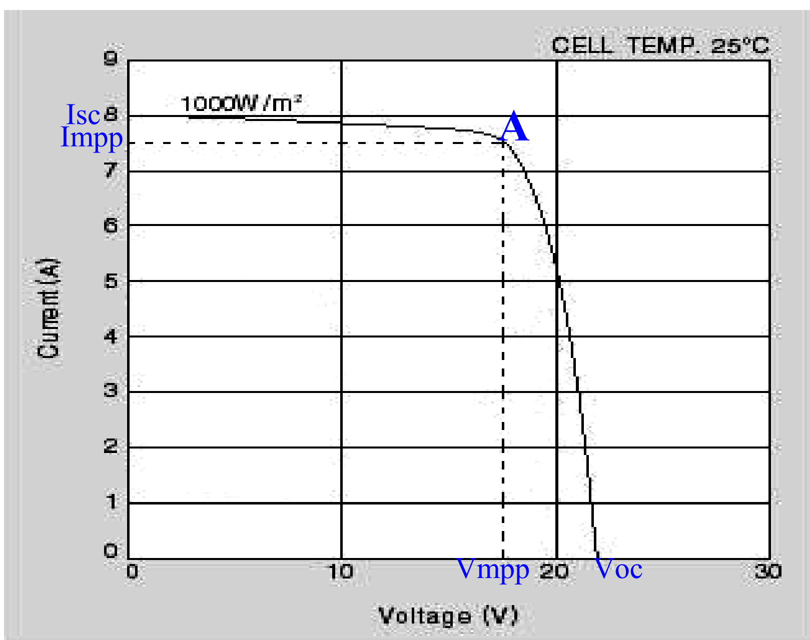


Figure (3-7): The I-V Characteristics of the PV module Kyocera KC130GHT-2

1. Short-Circuit Current (I_{sc}): occurs on a point of the curve where the voltage is zero. At this point, the power output of the solar cell is zero.

2. Open-Circuit Voltage (V_{oc}): occurs on a point of the curve where the current is zero. At this point the power output of the solar cell is zero.

3. Operation at Maximum Power : occurs at point A on the curve. The point A is usually referred to as the " knee " of the I - V curve.

When the module is operating in conditions less than one sun, the current output of the module is reduced as shown in Figure(3-8) below[19].

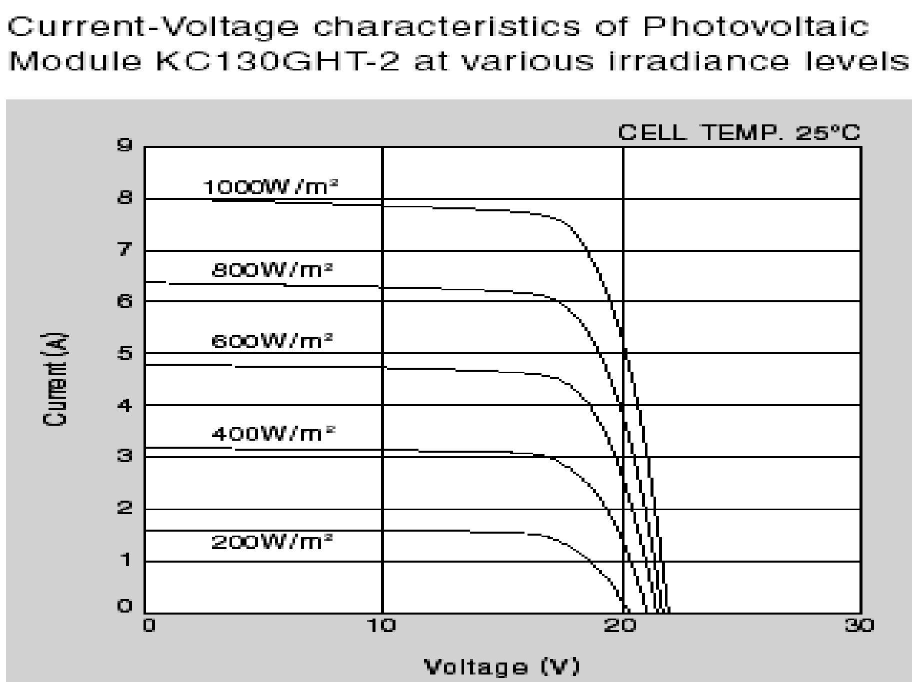


Figure (3-8): PV module I - V Characteristics at One Sun and less than one half Sun.

Module temperature affects the output voltage inversely and efficiency. Higher module temperatures will reduce the voltage by 0.04 to 0.1 volts for every one Celsius degree rise in temperature (0.04V/^{o}C to 0.1V/^{o}C). In Fahrenheit degrees, the voltage loss is from 0.022 to 0.056

volts per degree of temperature rise Figure (3-9). This is why modules should not be installed flush against a surface. Air should be allowed to circulate behind the back of each module so it's temperature does not rise and reducing its output [24].

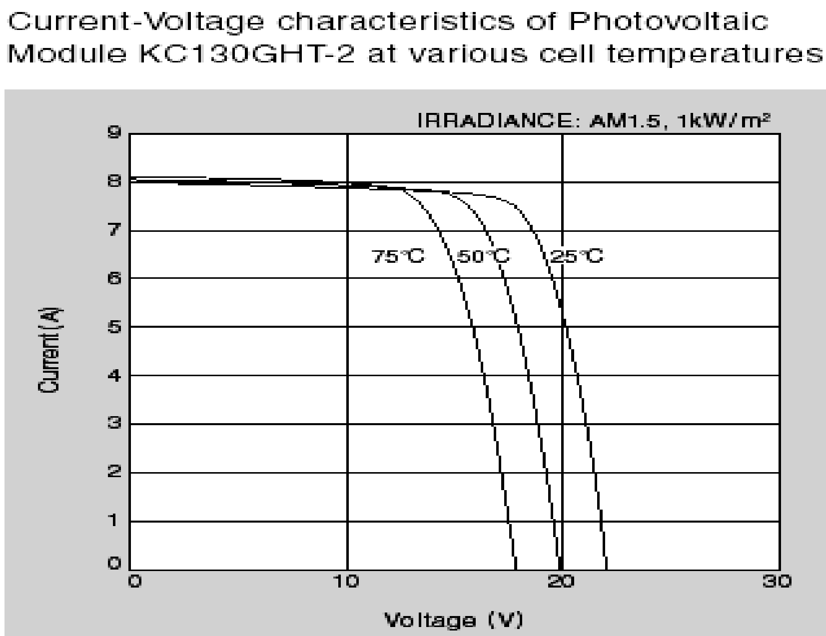


Figure (3-9):A Typical I-V curve for a module at 25°C (77°F), 50°C (122°F) and 75°C(167°F).

2- Diodes

Diode is a semiconductor device that allows electric current to pass in only one direction. In PV diodes may be used to stop modules from leaking battery current at night or during cloudy weather as blocking diodes, or to mitigate the effects of shading, or to bypass a failed module as Bypass diodes [19].

3- Charge controller

The charge controller is necessary to prevent the battery block from being overcharged by the array and from being overly discharged by the D.C loads [19].

There are four different types of PV controllers [19] :

1- **Shunt controllers**: are designed for very small systems, they prevent overcharging by shunting the battery when they are fully charged.

2- **Single stage controllers**: prevent battery overcharging by switching the current off when the battery voltage reaches a value called the charge termination set point. The array and battery are automatically reconnected when the battery reaches a lower value called the charge resumption set point.

3- **Multi-stage controllers**: these devices automatically establish different charging currents depending on the batteries state of charge. The full array current is allowed to flow when the battery is at a low state of charge. As the battery bank approaches full charge the controller dissipates some of the array power so that less current flows into the batteries.

4- Inverter

Converts DC power into standard AC power for use in the home, synchronizing with utility power whenever the electrical grid is distributing electricity [19] .

There are two categories of inverters [19] :

- The first category is synchronous or line-tied inverters which are used with utility connected PV systems.
- The second category is stand alone or static inverters which are designed for independent utility free power systems and are appropriate for remote PV installation .

Another classification for inverters is the type of waveform they produce, they are [19] :

- Square wave
- Modified sine wave
- True sine-wave

5- Battery

Batteries store direct current electrical energy in chemical form for later use. In PV system, the energy is used at night and during periods of cloudy weather .

A battery is charging when energy is being put in and discharging when energy is being taken out. A cycle is considered one charge-discharge sequence, which often occurs over a period of one day in residential PV systems . The following types of batteries are commonly used in PV systems [19]:

1- Lead-acid batteries

2- Liquid vented

3- Alkaline batteries

4- Nickel Cadmium

5- Nickel iron

The performance of storage batteries is described below[24]:

- **Amp-hour capacity**: the number of amp-hours a battery can deliver, is simply the number of amps of current it can discharge, multiplied by the number of hours it can deliver that current. System designers use amp-hour specifications to determine how long the system will operate without any significant amount of sunlight to recharge the batteries. This measure of "*days of autonomy*" is an important part of design procedures. Theoretically, a 200 amp-hour battery should be able to deliver either 200 amps for one hour, 50 amps for 4 hours, 4 amps for 50 hours, or one amp for 200 hours .

- **Charge and discharge rates**: If the battery is charged or discharged at a different rate than specified, the available amp-hour capacity will increase or decrease. Generally, if the battery is discharged at a slower rate, its capacity will probably be slightly higher. More rapid rates will generally reduce the available capacity. The rate of charge or discharge is defined as the total capacity divided by some number. For example, a discharge rate of C/20 means the battery is being discharged at a current equal to 1/20th of its total capacity. In the case of a 400 amp-hour battery, this would mean a discharge rate of 20 amps .

- **Temperature**: Batteries are rated for performance at 80°F. Lower temperatures reduce amp-hour capacity significantly. Higher temperatures result in a slightly higher capacity, but this will increase water loss and decrease the number of cycles in the battery life.

- **Depth of discharge :**This describes how much of the total amp -hour capacity of the battery is used during a charge-recharge cycle. As an example, "shallow cycle" batteries are designed to discharge from 10% to 25% of their total amp-hour capacity during each cycle. In contrast, most "deep cycle" batteries designed for photovoltaic applications are designed to discharge up to 80% of their capacity without damage. Even deep cycle batteries are affected by the depth of discharge. The deeper the discharge, the smaller the number of charging cycles the battery will last ,Figure(3-10) .

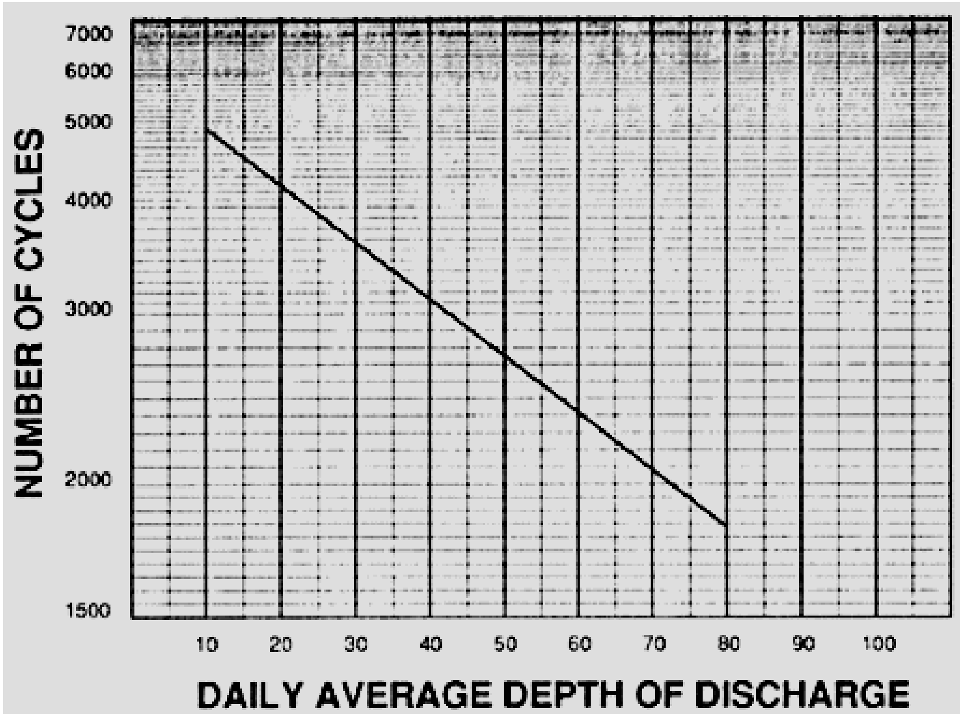


Figure (3-10):Number of cycles for different discharge depths

3.4. Evaluation of Photovoltaic Systems in Palestine

In Palestine, solar water heaters are used in more than 70% of houses [1]. Several PV applications were demonstrated totaling about 25 kWp mainly on home systems in villages, clinical refrigerators and communication systems [25].

Photovoltaic systems are not used as much as possible in Palestine due to financial and political situations, but there are some projects available in some location in WB, and these projects are:

1. Electrification of isolated villages through photovoltaic Systems (Al-Kaabneh Village, WB, Palestine) with eight large, sturdy 300-watt photovoltaic solar energy panels, provided by Americas, Figure(3-11) [26].

Figure (3-11): Photovoltaic solar energy panels in Al-Kaabneh Village

2. PV powered water pumping units :Decentralized PV generators with a total peak power of 65 kWp in remote villages as Ammoriah, Qariout [27].

3. Using solar energy for public lighting in Palestine (Wadi-Gaza Bridge), Figure(3-12) [28].

Figure (3-12): Utilizing solar energy for lighting of the Wadi Gaza Bridge.

3.5. The Importance of Using PV-System in Palestine

- **Palestine has a considerable number of remote small villages that lack electricity**— The probability of connecting these villages with high voltage grid in the near future is very poor due to financial and political situation it may be cheaper to generate their own power by PV systems rather than pay to extend transmission lines from the grid. Diesel, or gasoline generators, PV systems offer several advantages over transmission and diesel generators.

- **Cos**t— The price of diesel in Palestine is very high, this result in increasing of the price of electricity, and in most cases the villages could not pay for fuel, but a PV system is often the most cost-effective source of electricity.

- **Environmen**t—PV systems generate electricity without polluting the environment and without creating noise

CHAPTER FOUR

ANALYSIS OF PARTIAL OR NON-ELECTRIFIED VILLAGES IN PALESTINE- ATOUF VILLAGE

4.1. Analysis of Partial Electrified Villages in Palestine

Palestine has a number of remote small villages that lack electricity table(4-1),and the probability of connecting them with high voltage grid in the near future is very poor due to financial and political situation. About 63 localities in the West Bank are not connected to a public electricity network, including 29 in the Hebron district, diesel generator are used in these villages as electrical supply [29].

Table (4-1): Un-electrified Small Rural Villages in Palestine

	Village Name	District	أسم التجمع
		Jenin	
1	Khirbet Tanin		تنين
2	Al-Saaidah		السعايدة
3	Imreeha		إمريحة
4	Khirbet Sroog		خربة سروج
5	Aljameelat		الجميلات
6	Khirbet Al-mentar		خربة المنطار
7	Khirbet Masoud		خربة مسعود
8	Al-Kholgan		الخُلْجان
9	Khirbet Sabeen		خربة سبعين
10	Beer Al-Basha		بِير البَاشَا
11	Wadi Daook		وادي داعوق
12	Al-Zawya		الزاوِيَة
13	Mateqat Al-Heesh		منطقة الهيش
		Tulkarem	
14	Nazla Wasta		نزلة واستا
15	Khirbet Aqabah		خربة العقبة
		Nablus	
16	Shahdeh & Hamlan		شحدة وهملان
17	Zaatra		زعترة
		Hebron	
18	Emnezel		امنيزِل
19	Khirbet Ennab El Kaberah		عِنّاب الكَبِير
20	Khirbet Shwakeh		خربة شويكة
21	Khirbet Jala		خربة جالا
22	Um-Albatem		ام البطم
23	Hamroosh		حمروش
24	Al-Bqar		البقار
25	Groon Al-looz		جرون اللوز

	Village Name	District	أسم التجمع
26	Kinan Al-Nemr		قنان النمر
27	Al-Rawaeen (Imsfreh)		الرَواعِين (مسفرة)
28	Bereen		بيرِين
29	Jowe & Kfor Gool		جوي وكفر جول
30	Khirbet Dar Shames		خربة دير شمس
31	Al-Rakeez		الركيز
32	Khirbet Sarorah		خربة صاروره
33	Khirbet Asfa		خربة أصفى
34	Khirbet Al-Mqoorah		خربة المقعورة
35	Manteqet Shaab Al-Baten		منطقة شعب البطن
36	Quawees		قوا ويس
37	Khirbet Al-Tbaneh		خربة التبانة
38	Al-Rmadeen		الرَماضِين
39	Khirbet Al-mjaz		خربة المجاز
40	Mgair Al-Abeed		مغاير العبيد
41	Khirbet Al-Fkheet		خربة الفخيت
42	Khirbet Zanotah		خربة زنوتة
43	Khirbet Al-Kharabeh		خربة الخرابة
44	Khirbet Ghween		خربة غوين
45	Khirbet Al-Rahwa		خربة الرهوة
46	Arab Al-Forigat		عَرَب الفُرَيْجَات
		Bait Lahem	
47	Khalit Afaneh		خلة عفانة
48	Jeb El Theeb		جبة الذيب
49	Al-Azazmeh		العزازمة
50	Al-Rawaeen		الرَواعِين
		Al-Qudes	
51	Arab Al-Ghaleen		عَرَب الجَهَالين
		Jericho	
52	Al-Naby Mousa		النبي موسى
		Tubas	
53	Atouf		عاطوف
54	Ibzeeq		ابزيق
55	Salhab		سلحب
56	Al-Faresiah		الفَارِسِيَّة
57	Al-Maleh		المالِح
58	Khirbet Eazrah		خربة يزرة
59	Khirbet Homsah		خربة حمصة
60	Al-Hadediah		الحَدِيدِيَّة
		Qalqilia	
61	El Ramadeen El-shamaly		عرب الرماضين الشمالي
		Salfeet	
62	Rafaat		رَافات
		Ramallah	
63	Badew Al-Moaargat		بَدِو المُعَرَّجات

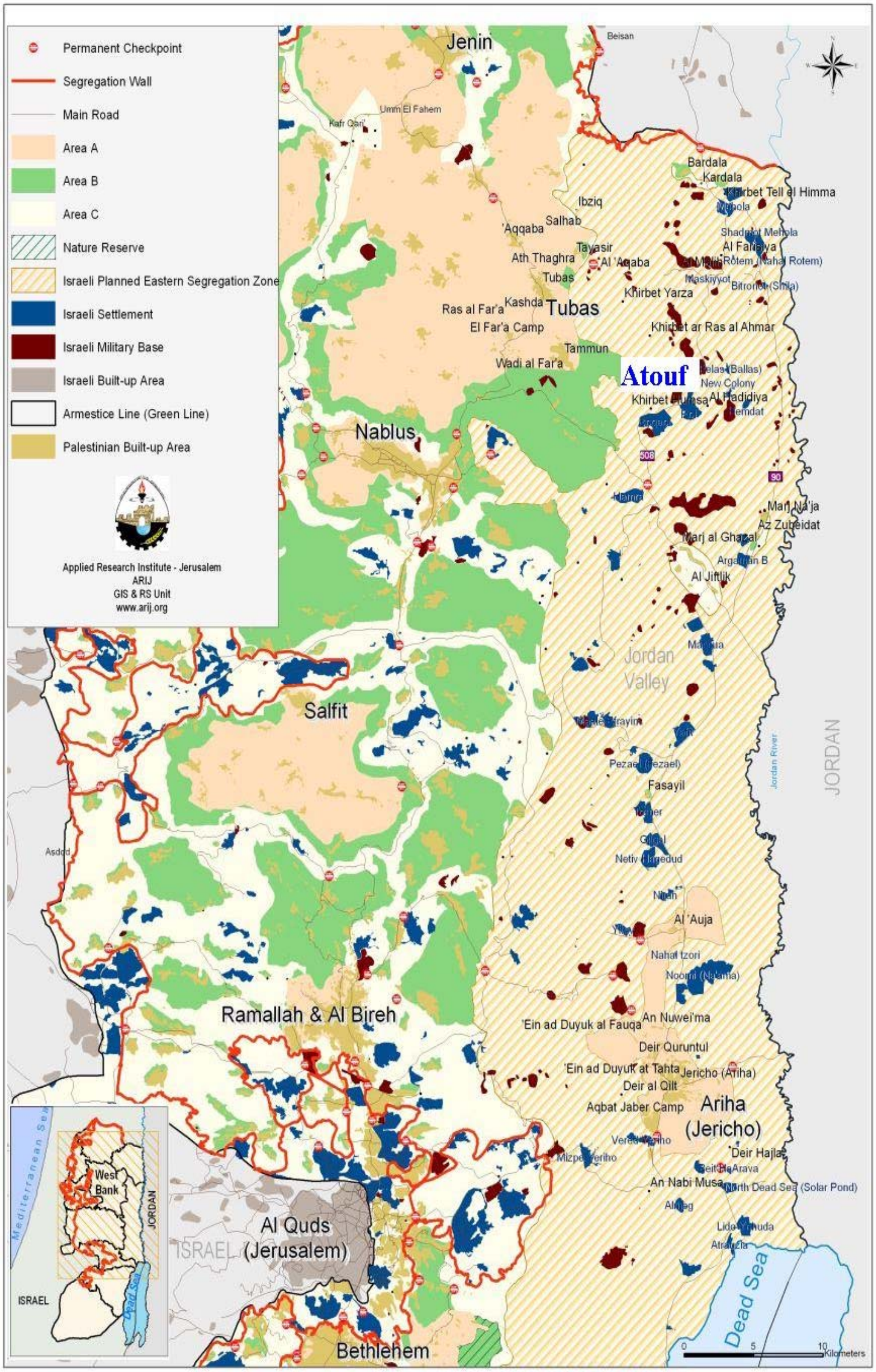
4.2. Case Study of Partial Electrified Villages - Atouf Village

Depending on a comprehensive assessment on partial and non-electrified villages in WB, Atouf was found to be one of the most appropriate villages to be subject to a techno-economic comparison study on electrification by grid connection, diesel generator and solar electric generators, Figure(4-1).

Figure(4-1): Atouf village

4.2.1. Location and living conditions

Atouf is located in the Jordan valley (West of Jordan valley) at the coordinates $32^{\circ}15^{/}$N and $35^{\circ}30^{/}$E and near Tamun town Map(4-1)[30]. Its inhabitants work mainly in farming and cattle breeding. Their number amount to about 200 living in 21 houses. A mosque ,clinic and school are available in Atouf. Drinking water is obtained from artesian wells in the village area.



Map(4-1): Location of Atouf village

The 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.

The village has no gas station and is 10 km far from the nearest high voltage grid (33kV) in Tamun town. Most houses of the village have solar water heaters on their roofs which is enough to cover the total daily hot water needs.

4.2.2. Environmental data

The solar radiation data has a great effect on the performance of photovoltaic (PV) systems. Fig.(4-2) shows the monthly values of solar energy [6].

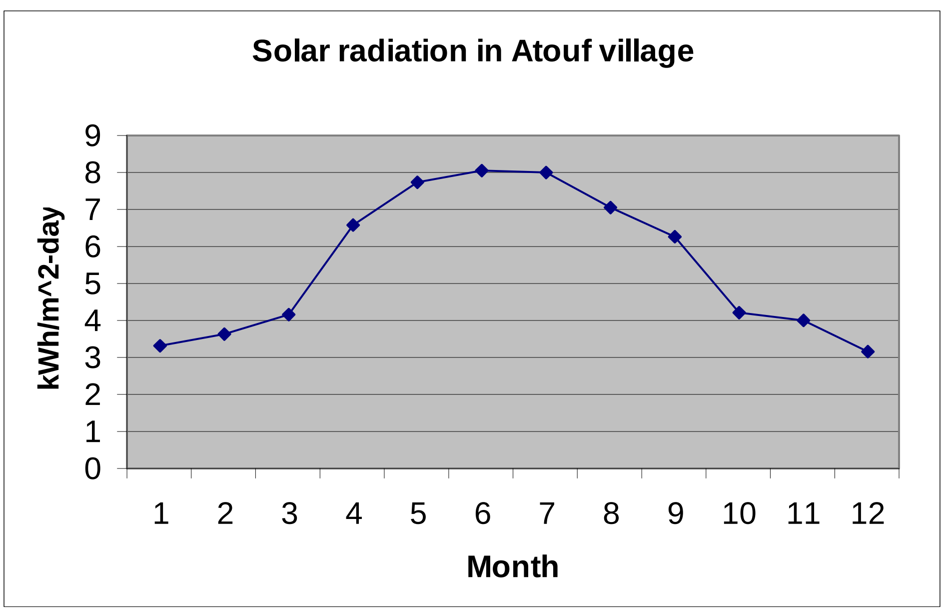


Figure (4-2) The monthly average value of solar energy in Atouf villages

It is clear from the figure that solar energy in this region is very high during summer months, where it exceeds 8kWh/m^2/day, while the lowest average intensity is during January with a value of 3.2kWh/m^2/day.

The village launches about 3000 sun shine hours per year. The annual average temperature amounts to 22^{o}C while it exceeds 37^{o}C during summer months [6].

4.2.3. Energy requirements of a house in Atouf village

The electrical load in the village is mainly concentrated on the night period since the population work during the day in the agriculture fields and cattle pasture.

The main electrical loads in the village are: house hold appliances (lighting, TV, refrigerator, radio, washing machine and fan), street lighting (sodium lamps), school appliances(lighting, educational TV and lab equipment). The electrical loads in all houses are specified in Table(4-2), in school Table(4-3), in clinic Table(4-4), and in mosque Table(4-5).

Table(4-2): Electrical loads in each houses in Atouf village

Type of appliances	**1- Abed**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	2	60	3	360
Efficient lamp	9	40	8	2880
Fridge	1	225	15	3375
TV	2	120	20	4800
Mobile charger	1	5	5	25
Lamp charger	1	5	5	25
Total		**455**		**11456**
Type of appliances	**2- Rabah**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	1	60	15	900
Efficient lamp	1	40	20	800
TV	1	120	20	2400
Washing machine	1	120	20	2400
Total		**340**		**6500**
Type of appliances	**3- Jamal**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	1	60	6	360
Efficient lamp	3	18	20	1080
Fridge	1	225	15	3375
TV	1	120	20	2400
Pump	1	1100	3	3300
Lamp charging	1	5	5	25
Washing machine	1	100	3	300
Total		**1628**		**10840**
Type of appliances	**4- Omar**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	2	60	6	720
Efficient lamp	2	15	20	600
Fridge	1	225	25	5625
TV	1	250	15	3750
Mobile charger	1	5	6	30
Milk machine	1	550	2	1100
Total		**1105**		**11825**

Type of appliances	**5- Mohamed**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	3	60	6	1080
TV	2	225	10	4500
Washing machine	1	325	5	1625
Total		**610**		**7205**
Type of appliances	**6- Abed Algani**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp	5	20	14	1400
Fridge	1	225	21	4725
TV	1	225	15	3375
Lamp charging	1	5	15	75
Washing machine	1	250	3	750
Battery charger	1	60	8	480
Total		**785**		**10805**
Type of appliances	**7- Naji Yousef**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp	2	40	21	1680
TV	1	225	20	4500
Mobile charger	1	5	15	75
Total		**270**		**6255**
Type of appliances	**8- Tamam**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	2	60	10	1200
Efficient lamp	2	20	20	800
Mobile charger	1	5	5	25
Washing machine	1	325	3	975
Total		**410**		**3000**
Type of appliances	**9- Mohamed Mostafa**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	3	60	20	3600
TV	2	225	20	9000
Washing machine	1	325	4	1300
Total		**610**		**13900**
Type of appliances	**10- Rasheed**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	1	60	5	300
Efficient lamp	1	40	7	280
Efficient lamp 2	3	20	14	840
Fridge	1	225	20	4500
TV	1	200	20	4000
Pump	1	750	2	1500
Mobile charger	1	5	5	25

Lamp charger	2	5	2	20
Washing machine	1	200	4	800
Battery charger	1	60	10	600
Receiver	1	100	15	1500
Total		**1665**		**14365**
Type of appliances	**11- Naji Hesein**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	3	60	8	1440
Efficient lamp 2	6	20	15	1800
Fridge	1	225	22	4950
TV	1	200	21	4200
Pump	1	750	2	1500
Mobile charger	2	5	7	70
Washing machine	1	200	7	1400
Total		**1460**		**15360**
Type of appliances	**12- Jamal Khader**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp 2	3	20	21	1260
TV	1	200	21	4200
Pump	1	370	4	1480
Mobile charger	1	5	7	35
Total		**595**		**6975**
Type of appliances	**13- Naeem Mostafa**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp	2	40	11	880
Efficient lamp 2	3	20	15	900
Fridge	1	225	20	4500
TV	1	200	21	4200
Pump	1	750	5	3750
Mobile charger	1	5	7	35
Washing machine	1	200	5	1000
Total		**1440**		**15265**
Type of appliances	**14-Khair Allah**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp	3	40	16	1920
TV	1	225	21	4725
Washing machine	1	200	7	1400
Total		**465**		**8045**
Type of appliances	**15- Fayad Bani Audeh**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	3	60	14	2520
TV	1	225	21	4725
Total		**285**		**7245**

Type of appliances	16- Maher Aeid			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp	2	40	18	1440
Efficient lamp 2	1	15	21	315
TV	1	225	21	4725
Washing machine	1	200	7	1400
Total		**480**		**7880**
Type of appliances	**17- Aaref Abed**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	2	60	14	1680
Efficient lamp	1	40	14	560
Fridge	1	200	21	4200
TV	1	225	20	4500
Mobile charger	1	5	7	35
Receiver	1	100	21	2100
Total		**630**		**13075**
Type of appliances	**18- Waleed**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp 2	2	18	21	756
Fridge	1	225	21	4725
TV	1	200	18	3600
Pump	1	750	7	5250
Ups lamp	1	20	7	140
Total		**1213**		**14471**
Type of appliances	**19- Khdair**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp 2	2	20	18	720
Fridge	1	200	21	4200
TV	1	200	21	4200
Lamp charger	1	20	7	140
Receiver	1	100	15	1500
Total		**540**		**10760**
Type of appliances	**20- Khalid Yousef**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	2	60	18	2160
Efficient lamp 2	1	20	18	360
Fridge	1	200	21	4200
TV	1	225	20	4500
Lamp charger	1	5	7	35
Washing machine	1	200	8	1400
Total		**710**		**12655**
Type of appliances	**21- Khader**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	1	60	12	720

Efficient lamp	2	15	21	630
Fridge	1	225	21	4725
Mobile charger	1	5	8	40
Washing machine	1	325	5	1625
Battery charger	2	60	8	960
Total		**690**		**8700**

Table(4-3): Electrical loads in Atouf school

Type of appliances	**School**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Fridge	1	225	7	1575
Pump	1	350	8	2800
Battery charger	1	60	7	420
Computer	1	100	14	1400
Copy machine	1	200	7	1400
Total		**935**		**7595**

Table(4-4): Electrical loads in Atouf mosque

Type of appliances	**Mosque**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Efficient lamp	4	36	14	2016
Pump	1	350	4	1400
Copy machine	1	200	2	400
Fans	3	200	3	1800
Total		**786**		**5616**

Table(4-5): Electrical loads in Atouf clinic

Type of appliances	**Clinic**			
	Number	Power (W)	Hour/week	Energy (Wh/week)
Incandescent lamp	3	120	5	1800
Computer	1	100	4	400
Refrigerator	1	100	8	800
Total		**320**		**3000**

Street lighting used in Atouf village is sodium lamps see Fig.(4-3), the energy consumption from street lighting 4000Wh/day.

Fig(4-3): Street lighting (Sodium lamps) in Atouf village

4.2.4. Electricity consumption in Atouf village

Atouf village use Diesel Generator in their Electricity production, the operating hours of the Generator is about 5 hours, the electrical load in the village is mainly concentrated on the night period, so electricity consumption in Atouf village is not high as in other villages, the average electricity consumption per month is about 1346 kWh ,Fig.(4-4) shows the electricity consumption in Atouf village .

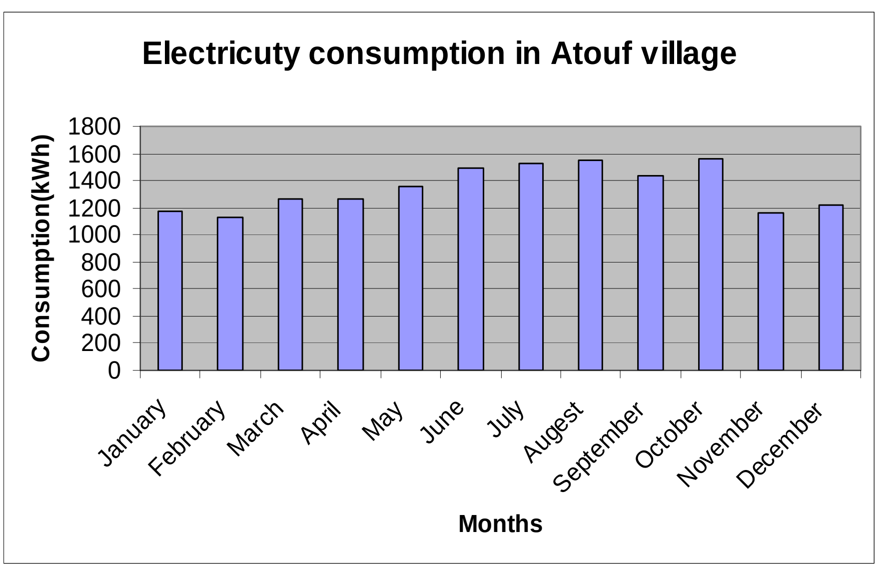


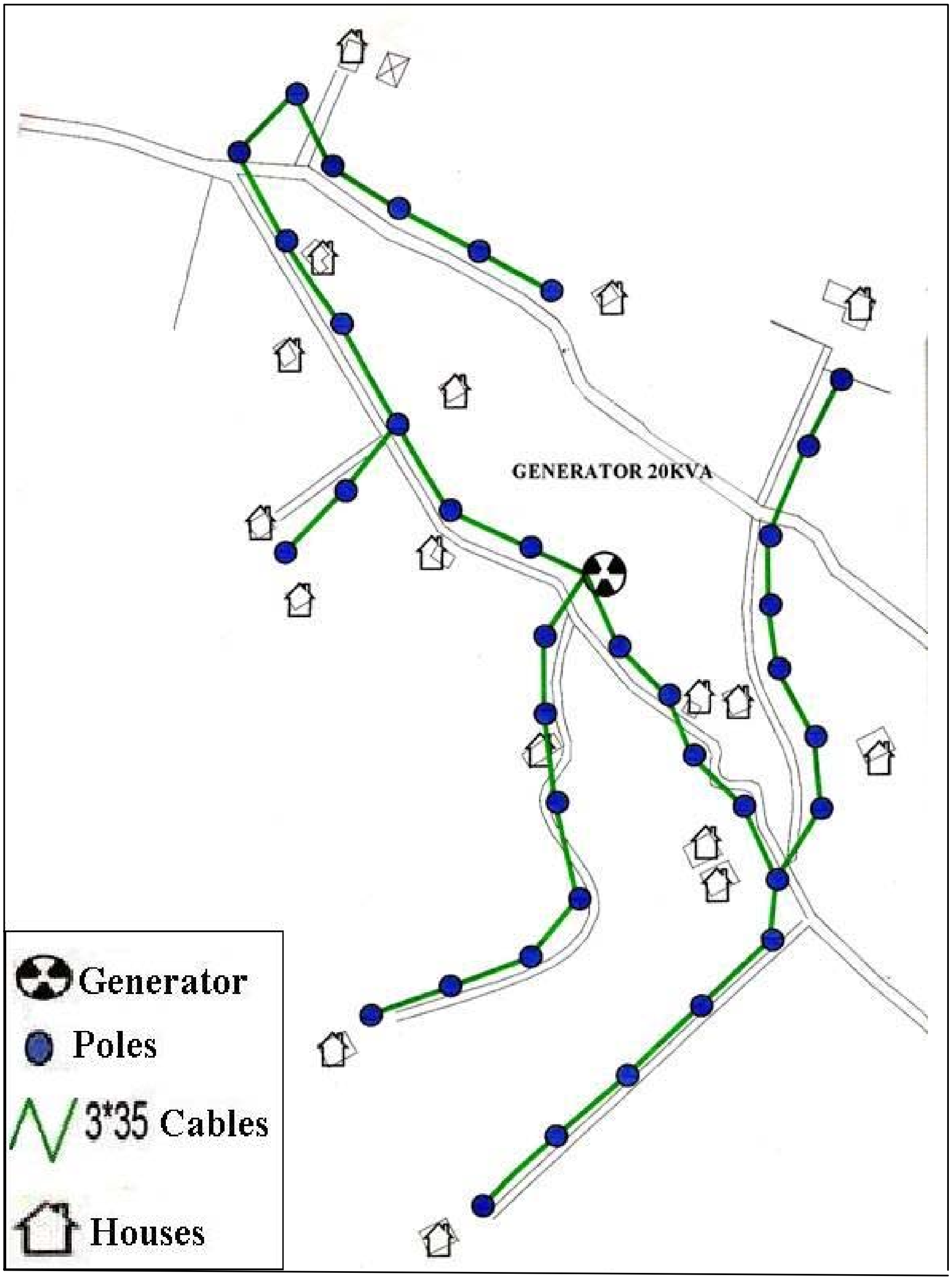
Figure (4-4): Monthly electricity consumption in Atouf village

4.3. Electrical Source in Atouf Village

Electrical source in Atouf village consists of Daewoo diesel generator Figure(4-5), and low voltage network that made up of poles and cables, this network connects diesel generator with consumers, Map(4-2) [3] and Fig.(4-6).

Fig.(4-5): Diesel generator used in Atouf village

Fig.(4-6) : Electrical network in Atouf village.



Map.(4-2) : Electrical network in Atouf village.

4.4. Electrical Problems in Atouf Village

- Diesel generators with 20kVA capacity are used in Atouf village to cover the power demands in Atouf houses .Usually the operation of the generator is limited on the night periods and the operating time is a bout 5hours, and this term is not enough to do all the household chores in the village or even to watch television.
- In addition ,diesel generators pollute the environment, and are not reliable due to their frequent faults.
- The price of diesel in Palestine is very high, and the generator requires approximately 14 liters of diesel in a day even works, and in most cases the village could not pay for fuel.
- The price of electricity in Atouf village is very high, people in village pay 1NIS for the first 30kWh, then pays 1.5 NIS for above.

CHAPTER FIVE

THE PERFORMANCE ANALYSIS OF EXISTING DIESEL GENERATOR AND POSSIBILITY TO CONNECT ATOUF WITH ISRAEL ELECTRICAL NETWORK (IEC)

5.1. Performance of the Existing Diesel Generator

Diesel generator are used in Atouf village to provide it with electric power, usually ,these generators require high running cost, frequent maintenance and they pollute the environment.

Atouf village use diesel generator with 20kVA/16kW capacity, three phase output AC voltage (3X380V), power factor of 0.85,and size of solar tank 700 liter, Figure(5-1).

Figure(5-1): Diesel generator used in Atouf village

Diesel generator used in Atouf village require high running cost, maintenance, Oil and filter changing table(5-1) ,and require high cost of diesel, diesel consumption costs 27090.25NIS/year, table(5-2)[6].

The total cost of the diesel generator system is shown in Table(5-3), salvage value is taken about 15% from the diesel generator cost.

Table(5-1): Diesel generator maintenances

	Life Time	Unit price (NIS)
Diesel generator	13years	78000
Battery	2 years	250
Oil and Filter	250 working hours	240
Diesel filter	500 working hours	70
Air filter	1000 working hours	60

Table(5-2): Average diesel consumption in the year 2006

Month	Average Diesel Consumption 2006	Operating Hours	Cost (NIS/liter)
January	399.9 Liters/month	5	5.5
February	364 Liters/month	5	5.5
March	434 Liters/month	5	5.5
April	420 Liters/month	5	5.5
May	409.2 Liters/month	5	5.5
June	396 Liters/month	5	5.5
July	409.2 Liters/month	5	5.5
August	409.2 Liters/month	5	5.5
September	396 Liters/month	5	5.5
October	434 Liters/month	5	5.5
November	420 Liters/month	5	5.5
December	434 Liters/month	5	5.5

Table(5-3): Diesel generator system cost

No.	Components	Price (NIS)
1.	Diesel generator	78000
2.	Diesel	27090.25NIS/year
3.	Oil and filter	8640NIS/year
4.	Diesel filter	1260NIS/year
5.	Air filter	540NIS/year
6.	Battery	125NIS/year
7.	Salvage value	11700

5.2. Transmission Line System (TLS)

Transmission lines system are designed to transport large amounts of electric power, usually expressed in watts or kilowatts, over long distances. The voltage at which these lines operate may range from few thousand volts to a value of 750kV.

In general ,if the transmission voltage is increased, the volume of conductor material required is reduced, and it may remembered that as the transmission voltage is increased, the cost of insulating conductors, cost of transformers, switch-gear and other terminal apparatus, also increases [11].

The primary distribution voltage in the area of Atouf is 33kV and it is in Tamun town.

5.2.1. Selection of transmission line

The principle elements of the medium voltage transmission line are:

1- **Supports**: which are generally steel tower or trusses and provide support to the conductors [31]. To calculate the number of needed towers and trusses, assume that the span equals 65m, and the distance between Atouf village and the nearest tower of 33kV is 10km, then:

   Number of needed towers and trusses =10000m/65m = 154.

   Then, take number of trusses = 154 x 3 / 4 = 115 trusses with 12m length and the rest is for towers, 39 towers with 12m length.

2- **Conductors**: which carry electric power from the sending end to the receiving end, the usual material is aluminum reinforced with steel [31].

To calculate the conductor length assume that sag equals 10%, then 33km from ACSR $50mm^2$ for three phase lines, and 11km from ACSR $35mm^2$ for neutral line will be taken.

3- **Insulators**: which are attached to supports and insulate the conductors from the ground [31] .

Number of Insulators for towers (6 insulators) = 39 x 6 = 234 insulators.

Number of Insulators for trusses (3 insulators) = 115 x 3 = 345 insulators.

4- **Cross arms**: which provide support to the insulators.

Arms for towers = 39, Arms for trusses = 115.

5- **Step-up and step-down transformers** at the sending and receiving ends respectively, 150kVA transformer capacity will be selected to provide Atouf village with electricity.

6- **Protective devices**: such as ground wired, circuit breaker and isolator switch.

7- **Number of Adiabatic climbed** to the towers and trusses are 154.

5.2.2. Transmission line system cost

The local costs of main system components in detail with the total cost of accessories and works are illustrated in table(5-4) [3].

Table(5-4): Transmission line cost

Component material or work	Quantity	Unit price (NIS)	Total price(NIS)
Tower 12m length	39	5516	215124
Truss 12m length	115	3940	453100
Conductor ACSR $50mm^2$	33000m	17730	585090
Conductor ACSR $35mm^2$	11000m	2.5	275000
Strength insulators for towers	234	347	81132.5
Pin insulators for trusses	345	276	95151
Cross arms	154	552	84946
Earthing electrodes $3x50mm^2$	154	78.8	12135
Isolator switch	1		10530
Transformer 150KVA	1		32000
Distribution board	1		14000
Obstacles for tower climb	154		13500
Mechanical parts, insulation material and various accessories	74		24270
Total			1,895,979.5

The needed maintenance cost for TLS and distribution transformer during the life time of the system, which assume to be 25 years, is about 2% of the total TLS cost.

This means that the yearly maintenance cost (Cm) is

Cm = (0.02 x 1895979.5) / 25 = 1516.8 NIS/year.

Salvage value is taken about 15% from the transmission line system cost and it is obtained as follow:

Salvage = 15% x 1,895,979.5 = 28439.693NIS.

CHAPTER SIX

SELECTION OF PHOTOVOLTAIC SYSTEM FOR ATOUF VILLAGE

6.1. Selection Specifications

The selection investigates the method of choosing alternate generation capacity to provide electricity to remote villages such as Atouf village. Diesel generator used to supplement the output of the PV array when there is a large discrepancy between month-to-month system need versus month-to-month PV generation capacity.

If installation of a PV array to meet minimum sun availability results in significant excess generation for a number of month, then much of the PV output is wasted. In such cases, it often makes better economics sense to use a generator to supplement the PV output during the months of low output and size the PV to meet most of the needs during months of higher peak sun.

There are a significant cost increase between sizing a PV system to provide 95% of system electrical needs versus providing 99% of system needs. Hence, use of a generator for increasing system availability from general to critical may also be cost effective [19].

PV system is a good solution to provide the remote villages such as Atouf village with electricity, with a combination of diesel generator.

The electrical load in the village is mainly concentrated on night period, the main electrical loads are TV, radio, washing machine, lighting and refrigerator.

All loads will be 220V AC as in typical residence, except that energy efficiency has been taken into account in the selection if the loads, for example, a high efficiency refrigerator has been selected and all lighting will be fluorescent.

The goal of the design is to arrive at a combination of PV and diesel generator energy production that will result in the lowest or at least acceptable LCC.

6.2. Selection Implementation

Since the generator is available for PV system backup, it may seem unnecessary to incorporate batteries into the system. However, for generators to operate efficiently, they need to run at close to 90% of their output capacity. Operation of a generator at a small fraction of capacity will result in significant decrease in efficiency. Hence, batteries are used so the generator can charge them at a rate close to its capacity [19].

Since charging batteries too quickly tends to result in an inefficient charging process, the generator/battery system should be sized so the generator will take at least 5 hours to charge the batteries. Actually, these criteria are not necessarily inconsistent, since the batteries will not normally be charged from full discharge to full charge. Normally the generator will charge the batteries from about 20% to about 70%. Charging the batteries from 20% to 70% in 5 hours requires a charging rate of C/10 [19].

The bottom line, then, for batteries, is to provide few days of storage so the charging rate will not be excessive. More storage will normally result in some what lower use of the generator, since the generator will not necessarily need to back up the PV array in the event of cloudy weather for few days. Longer storage times may be desirable in areas where summers have periods of sunny days followed by periods of cloudy days. In general, fewer batteries will be used in a hybrid system since the diesel generator will supplement the sun. Choice of the number of autonomy for the system, however, becomes more dependent on other factors, such as how long it may take to implement emergency repairs on the generator.

After loads and batteries are selected, then the array size are calculated. Then controllers, inverter, fuses, and wires are selected.

6.3. Determination of Average Daily PV System Load

Table(6-1) summarized the energy consumption for the residences by month. All loads are 220V AC loads and the input of the inverter will be 48V DC rather than 12V DC in order to reduce the PV array current output requirements, thus reducing wire size from array to inverter. Note that the same number of modules will still be required, since the same total power must be produced by the array.

Table(6-1): Energy consumption in Atouf village

Month	Consumption(kWh)
January	1171
February	1126
March	1269
April	1267
May	1361
June	1487
July	1524
August	1554
September	1441
October	1565
November	1165
December	1216
Total	16146

The daily load energy consumption for Atouf village is about 44.24kWh.

The electrical loads in the village are small appliances such as TV, radio, washing machine, lighting and refrigerator, as was noted in chapter 5. All loads will be 220V AC as in typical residence, except that energy efficiency has been take into account in the selection of the loads. For example, a high efficiency refrigerator has been selected and all lighting will be fluorescent.

6.4. The Average Daily of Solar Radiation Intensity

Atouf has a high solar energy potential, where the daily average solar radiation intensity is 5.4 kWh/m^2, and the peak sun hours (PSH) equal 5.4.

6.5. Selection of the PV-Generator

The most appropriate PV power system to cover such a load is illustrate in Figure(6-1).

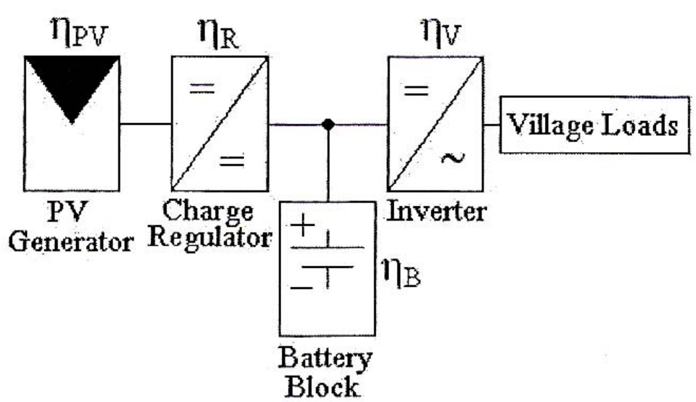


Figure (6-1): PV power system of Atouf village

The peak power of the PV generator (P_{Pv}) is obtained as follows[32]:

$$P_{pv} = \frac{E_L}{\eta_R \times \eta_B \times \eta_V \times PSH} S_f \qquad 6\text{-}1$$

Where E_L is daily energy consumption = 44.24kWh, the peak sun hours PSH= 5.45, the efficiencies of the system components (η_v = 0.93 ,η_R = 0.95 η_B = 0.9) and the safety factor for compensation of resistive losses and PV-cell temperature losses S_f = 1.15, by substituting these value in Eq.(6-1), then the peak power of PV generator is:

P_{PV} = 11.7 kWp.

6.6. Selection of the Battery Block

The storage capacity of battery block for such system is considerably large. Therefore, special lead-acid battery cells (block type) of long life time (> 10 years), high cycling stability rate (>1000 times), and capability of standing very deep discharge is selected.

The number of days of autonomy required for critical need applications depends on the location of the system. In locations with relatively high average insolation, even during the worst part of the year, less storage is needed. The number of days of autonomy required for Atouf village is 1.5 days.

The next choice is to determine the type of batteries to use and the allowable depth of discharge. In this design, deep discharge batteries allowing 80% discharge are not unreasonable, since under most conditions, the batteries will not discharge nearly this amount. Hence, the battery life will be relatively long. Battery size is thus determined from[33]:

$$C_{Ah} = \frac{1.5 \times E_L}{V_B \times DOD \times \eta_B \times \eta_V} \qquad 6\text{-}2$$

$$C_{wh} = C_{Ah} V_B \qquad 6\text{-}3$$

Where V_B and η_B are voltage and efficiency of battery block, while DOD is the permissible depth of discharge rate of a cell. Assuming realistic values of η_B=0.9, DOD=0.66 and V_B=48V, by substituting these value in Eq.(6-2) and Eq.(6-3), then:

$$C_{Ah} = \frac{1.5 \text{ X } 44240}{48 \text{ X } 0.66 \text{ X } 0.9 \text{ X } 0.93} = 2500 \text{ Ah}$$

$$C_{wh} = 2500 \text{ X } 48 = 120 \text{ kW h.}$$

Lead acid battery are typically design to take 10 hours from zero charge to full charge. Hence , if 10 hours times the PV charging rate in amperes exceeds the battery capacity in AH, it means the PV array is capable of fully charging the batteries in less than 10 hours[33].

Once the battery capacity is determined, the number of batteries required for the system is determined by dividing the total capacity require by the capacity of a single battery.

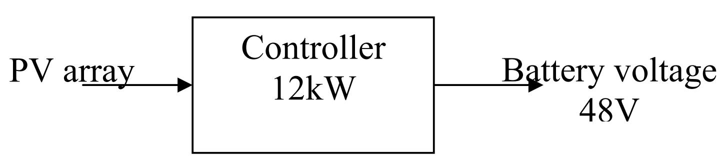
Number of batteries = 24, connected in series to achieve the desired voltage system which is 48V.

6.7. Selection of Charge Regulator (Controller)

The battery charge controller is chosen to maintain a longer lifetime for the batteries. It control battery charge and discharge by both the PV array and the generator. It provide a starting signal/voltage for the generator when the batteries have discharged to a present level and shut down the generator when the batteries reach a present level of charge.

Input/output ratings of controller are fixed by the output of the PV array and V_B, figure(6-2). It has to be capable of carrying the short circuit current of the PV.

Controller sizing = Module short circuit x modules in parallel x 1.25 (factor of safety).



Figure(6-2): Charge controller specifications

Thus, in this case, it can be chosen to handle 1.25xIs.c of the array and to maintain the system voltage in the range of 48V, the appropriate rated power is 12kW.

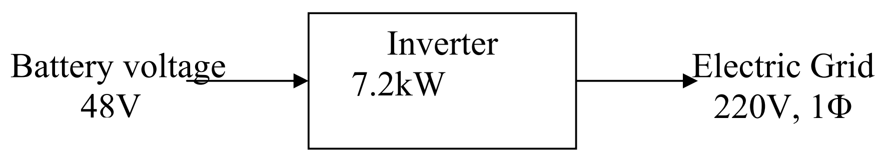
6.8. Selection of DC/AC Inverter

The inverter has to be capable of handling the maximum expected power of AC loads. The input of inverter have to be matched with the battery block voltage which is 48V while its output should fulfill the specifications of the electric grid of the village which is 220V, 1Φ.

The maximum inverter to load current is found by dividing the total load power by the system voltage.

Inverter to load current = 7.2kW / 220V = 32A.

The specifications of inverter will be 7.2kW, $48V_{DC}$, and $220V_{AC}$, figure(6-3).



Figure(6-3): Inverter specifications

CHAPTER SEVEN

IMPLEMENTATION OF ATOUF PV-SYSTEM

7.1. Installation of the PV System

To install the PV system ,a poly-crystalline PV module type Kyocera KC130GHT-2 is used in this system with the following specifications in table(7-1) and appendix(1) [34].

Table (7-1): Specification of Kyocera KC130GHT-2 module at standard conditions.

Electrical Date	
Maximum Power	130W
Maximum Power Voltage	17.6V
Maximum Power Current	7.39A
Open Circuit Voltage (Voc)	21.9V
Short Circuit Current(Isc)	8.02A
Area	$0.9291m^2$

Then the number of the necessary PV modules (N_{PV}) is obtained as:

$$Npv = \frac{P_{pv}}{P_{mpp}} = 90 \text{ PV modules} \qquad 7\text{-}1$$

Thus, 90 modules are used to supply the houses with the required energy. The modules can be connected to give the desired (operating) voltage which is between (48-53)V see figure(7-1), so the number of series modules are obtained as follow:

Number of modules in series = 48 / 17.6 = 2.7 modules

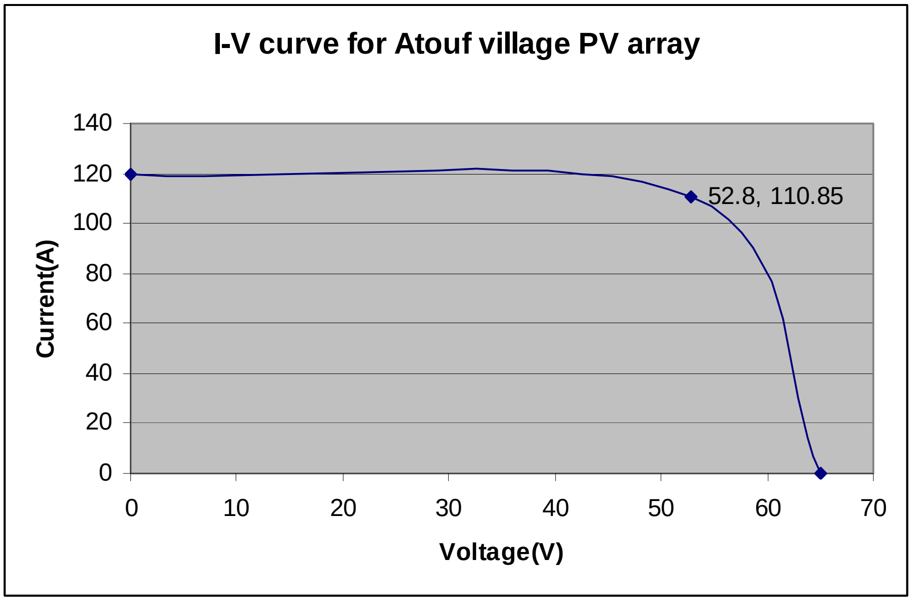


Figure (7-1): I-V curve for Atouf village PV array in at standard condition

The modules connected in parallel group of three in series to produce operating system voltage $48V_{DC}$. Two array will be used, each array consist of 45 modules, each 3 modules will be connected in series to built 15 parallel strings. The arrays connected in parallel to produce $48V_{DC}$.

In this system, three source-circuit combiner boxes in each array are used to balance the PV supply between the two arrays to the charge controllers, figure(7-2). Since there will be a total of fifteen source circuits, five circuits will be connected to each combiner box. Since $I_{S.C}$ of each of the source circuits is 8.02A, and since 156% of 8.02A is 12.53A, the source circuits will be fused at 15A.

Figure (7-2): Combiner box

The total area of PV array are:

$$Apv = 45 X 0.9291 = 42m^2.$$

7.2. Installation of the PV Components

1- Block battery

To install the capacity of the storage battery in Atouf village, VARTA block battery type with V_N= 2V see figure(7-3), 24 battery cells (each cell rated at 2V/2500Ah) have to be connected in series to build a battery block of an output rated at 48 V_{DC} /2500 Ah see figure(7-4).

Figure (7-3) : VARTA block battery

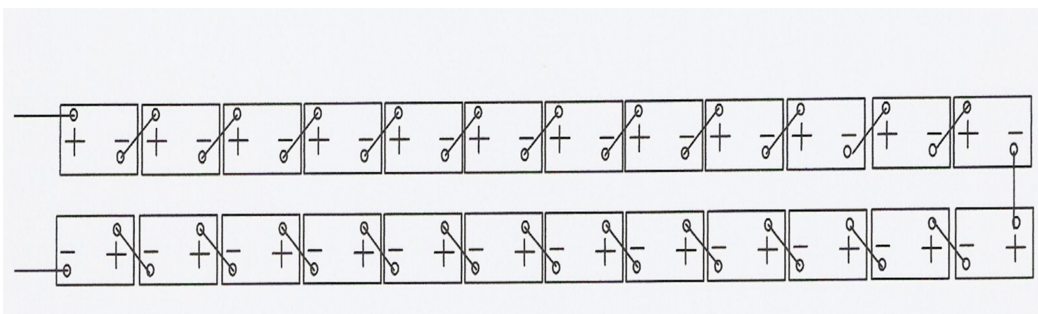


Figure (7-4) : Battery connection

2- Controller

To select the correct controller, maximum currents to and from controller need to be identified. The maximum array-to-controller current is given by 125% of the short circuit array current, to account for possible cloud focusing, then controller size is obtained by:

Controller sizing = Module short circuit x modules in parallel x 1.25 (factor of safety)= 8.02 x 15 x 1.25 = 150A x 2 array = 300A

Thus, in this case, it can be chosen to handle 300A of the array and to maintain the system voltage in the range of 48V, the appropriate rated power is 12kW, table(7-2) and figure(7-5) show the specifications and type of the charge controller that installed in Atouf village.

Table (7-2): The specifications of the charge controller

Regulator Type: Cod 675RM000005 Mod TAPSRM480	
Input	**Output**
52V	**48V**
240A	**250A**
Rated power (VA) = 12000W	

Figure (7-5): Battery charge regulator

3- Inverter

The maximum output current of the inverter is found by dividing the total load power by the system voltage.

The specifications of the inverter will be 7.2kW, $48V_{DC}$, and $220V_{AC}$, see table(7-3) and figure(7-6) .

Table(7-3) :The specifications of inverter in Atouf village

Inverter type: Cod6750M000005 Mod TApS0M2300	
Input	**Output**
48V	**230V**
150A	**31A**
Rated power (VA) = 7200W	

Figure(7-6):Inverter

7.3. Wiring and Installation

The next step in the selection is to decide what loads will be on which circuits and then compute the proper wire sizes to limit voltage drop to the loads. Proper wire sizing depends on the current to be carried by the wire, but, at low voltages, primarily on the length of the wire and the resulting voltage drop.

To determine wire sizes for the array, it is necessary to recognize that under certain unusual conditions, it is possible for the reflection from cloud to focus the sunlight on an array. This phenomenon requires that the wire be able to carry the array current as enhanced by cloud focusing. To allow for cloud focusing the array short circuit current is multiplied by 1.25 to obtain the maximum current from array to controller. This maximum array current is then multiply by another factor of 1.25 as required for continuous requirement, and wire sizes are then chosen to meet this ampacity requirements. The wiring of PV source circuits and PV output circuits must thus be capable of carrying 156% of the short circuit current of either the source circuit or output circuit, whichever is applicable [19].

Since there will be a total of fifteen source circuits, five circuits will be connected to each combiner box. Since $I_{S.C}$ of each of the source circuits is 8.02A, and since 156% of 8.02A is 12.53A, and in order to keep the voltage drop in source circuit below 2%, so $4mm^2$ is the appropriate wire size between arrays and to combiner box.

With five source circuits combined in each source circuit combiner box, the PV output circuit current from each combiner box will be 125% of 5xIs.c, or 50.13A. The wire must be size to handle 125% of this current, since the circuit must be rated for continues duty. Thus, the ampacity of the PV output circuits must be at least 62.66A. With two array used in the village, in order to keep the voltage drop below 2% in the nearest array which lies about 15m from charge controller $16mm^2$ is the appropriate wire size, and also to keep in below 2% in the farthest one $35mm^2$ is the appropriate wire size. These circuits are inside at ground level, and it is XLPE type.

The rated inverter output circuit current is the rated inverter output power divided by the system AC voltage, which is 31A, so the wiring from inverter output to the point of utility connection must have a minimum ampacity of 125% of this value, or 42A, so $10mm^2$ is the appropriate wire size from inverter to the panel load.

The battery to inverter current is the rated inverter output power divided by the system DC voltage which is 150A, and the charge controller to battery current is the rated power of the charge controller divided by the system DC voltage, which is 250A, table(7-4) shows the wire sizes required for the PV system.

Table (7-4): Summary of PV circuits wiring for Atouf village system

Wire Location	Wire size (mm^2)
Array to combiner box	4
Combiner box to controller	16 for the nearest array
Combiner box to controller	35 for the farthest array
Inverter to panel load	10

8.4. Protection of the System

All fuses or circuit breakers used must be rated for DC use if they are to be used on DC. Fuses or circuit breaker in the line to the battery system must be located close to the batteries in order to provide protection to both the batteries and the wiring from battery to inverter. Since short-circuit battery currents may exceed 5000A, battery over-current protection must have high interrupting capacity [19]. Table(7-5) shows the fuses size required for the PV system.

Table(7-5): Summary of PV circuits fusing for Atouf village system

Wire Location	Fuse size
Array to combiner box	15A
charge controller to battery	250A
Inverter to panel load	50A

7.5. Complete System Installation

Figure(7-7) shows the connections of the two arrays with combiner box and with charge controller, figure(7-8) shows the complete system with wiring and fusing installation, and distribution board shown in figure(7-9).

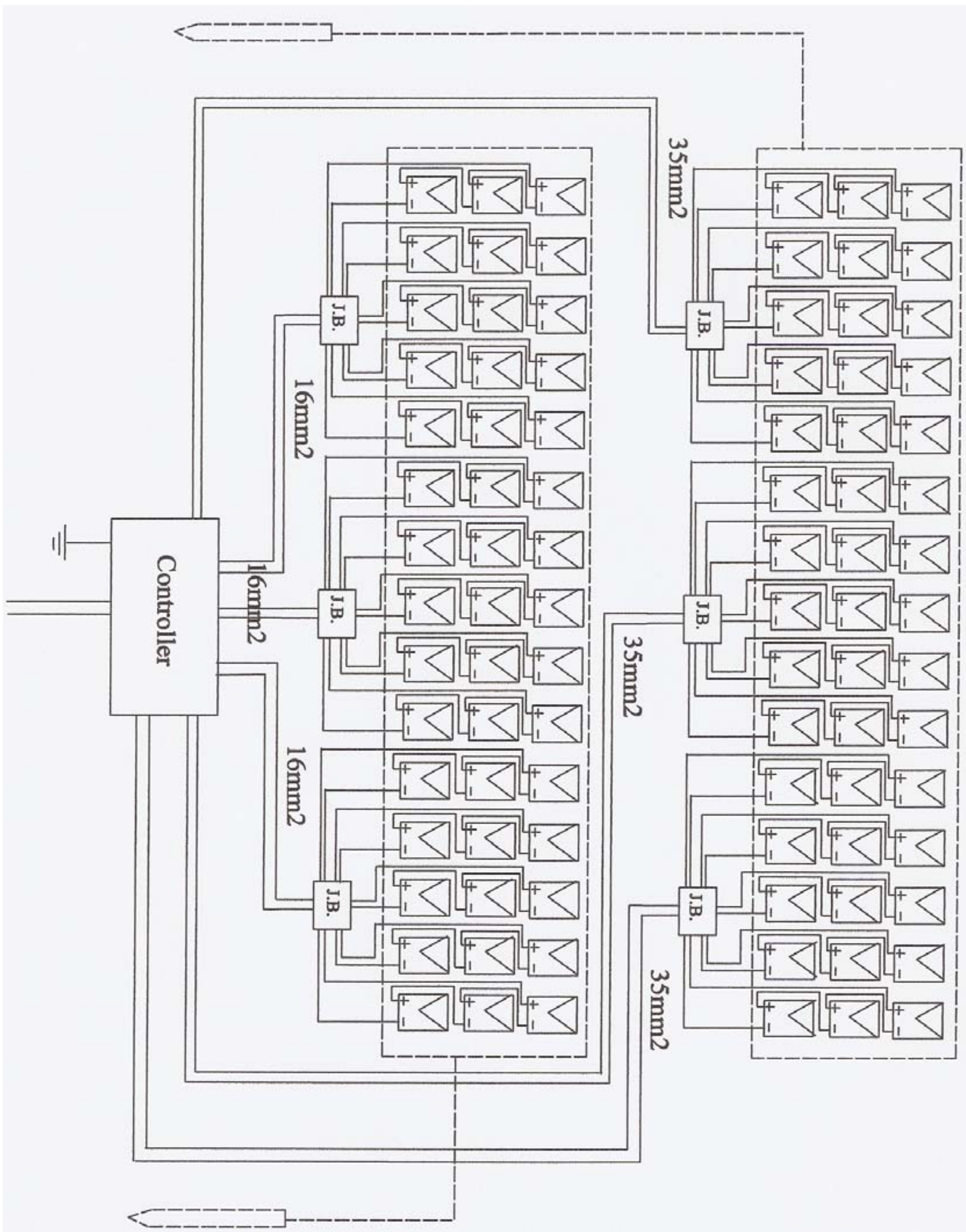


Figure (7-7): The connections of arrays with combiner box and charge controller.

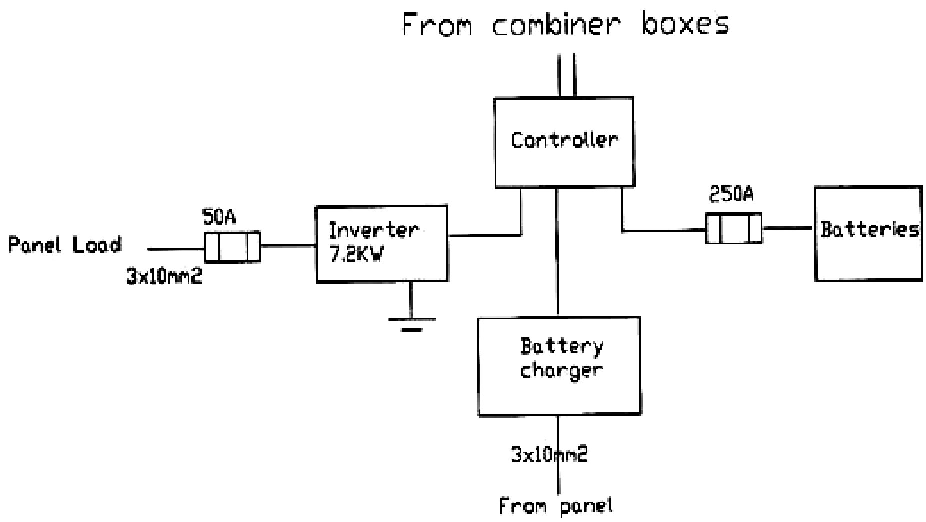


Figure (7-8): The complete system with wiring and fusing installation.

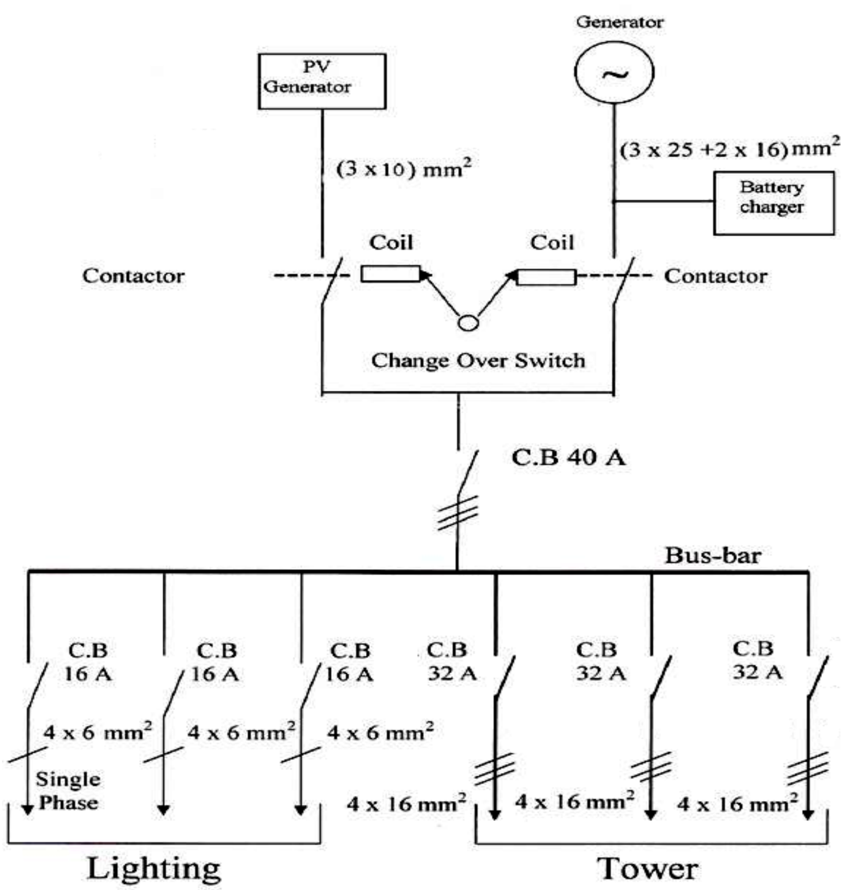


Figure (7-9): Distribution board.

7.6. PV System Cost

The associated cost of the components, materials and installation of the PV system are listed in Table(7-6) [6].

Table(7-6): Cost of components, materials and installation of PV system

Component material or work	Quantity	Price(NIS)	Life time(Year)
PV-module Kyocera	11.7 W	176000	25
Battery cells	24	97600	12
Charge regulator	1	16000	25
Inverter	1	21200	25
Mechanical parts, installation material and various accessories		55000	
Total		365800	

The needed maintenance cost for PV system during the life time of the system, which assume to be 25 years, is about 2% of the total PV system cost.

This means that the yearly maintenance cost (Cm) is

Cm = (0.02 x 365800) / 25 = 292.64 NIS/year.

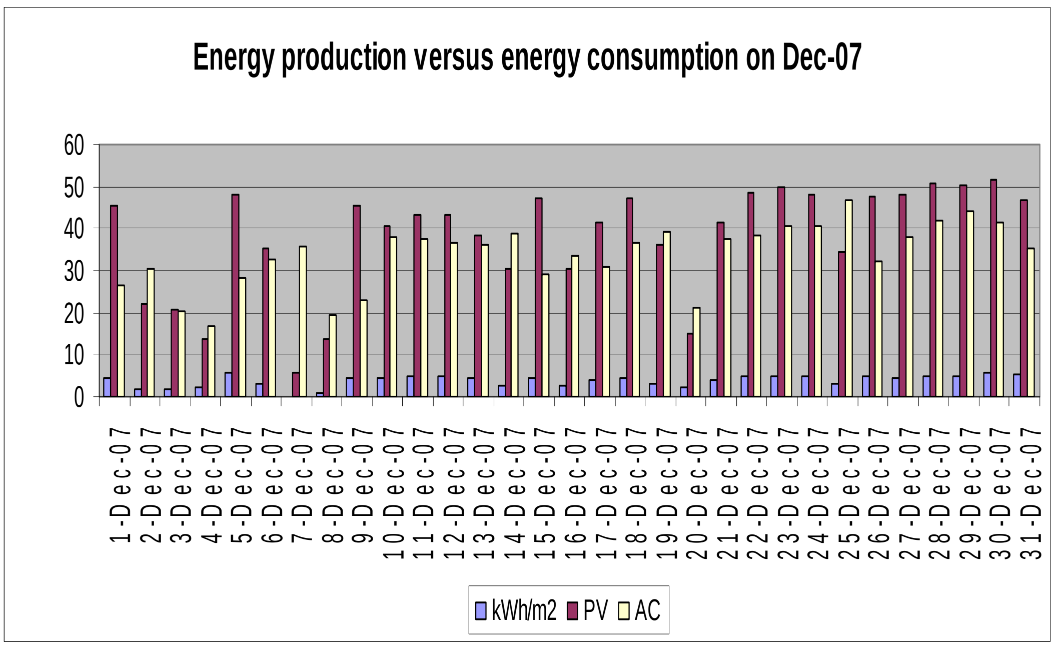
Salvage value is taken about 15% from PV system cost and it is obtained as follow:

Salvage = 15% x 365800= 54870NIS.

7.7. Performance Analysis of Operating PV System in Atouf Village

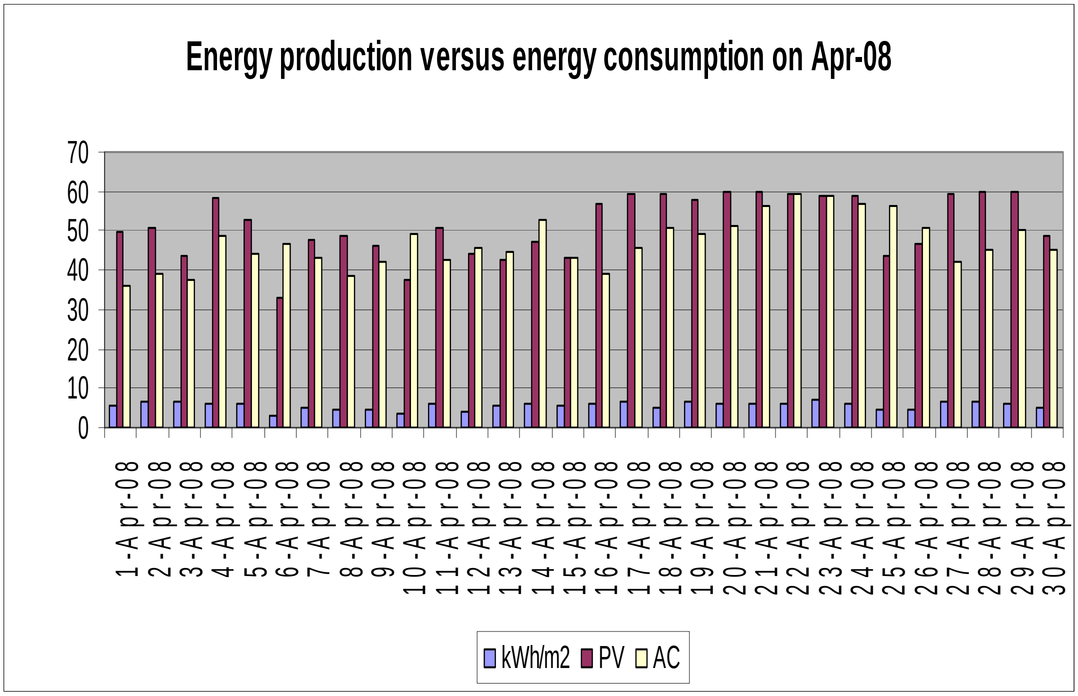
In this section, the relation of daily energy production and daily energy consumption for three different cases of solar irradiation is considered, determined by the average daily solar radiation during 1-Dec-07 to 21-May-08. Firstly, sunny day means that the average daily solar irradiation is higher than $5kWh/m^2$. Secondly, semi-cloudy day means that the average daily solar irradiation is between 3kWh/m^2 and 5kWh/m^2 and thirdly, cloudy day means that the average daily solar irradiation is lower than 3kW/m^2.

In case of sunny day, for example on the day of 30-Dec-07, see Figure(7-10), the average solar irradiation was about 5.89kWh/m^2 that produced the energy about 51.77 kWh, is higher than the approximated daily energy consumption by about 10.44 kWh.



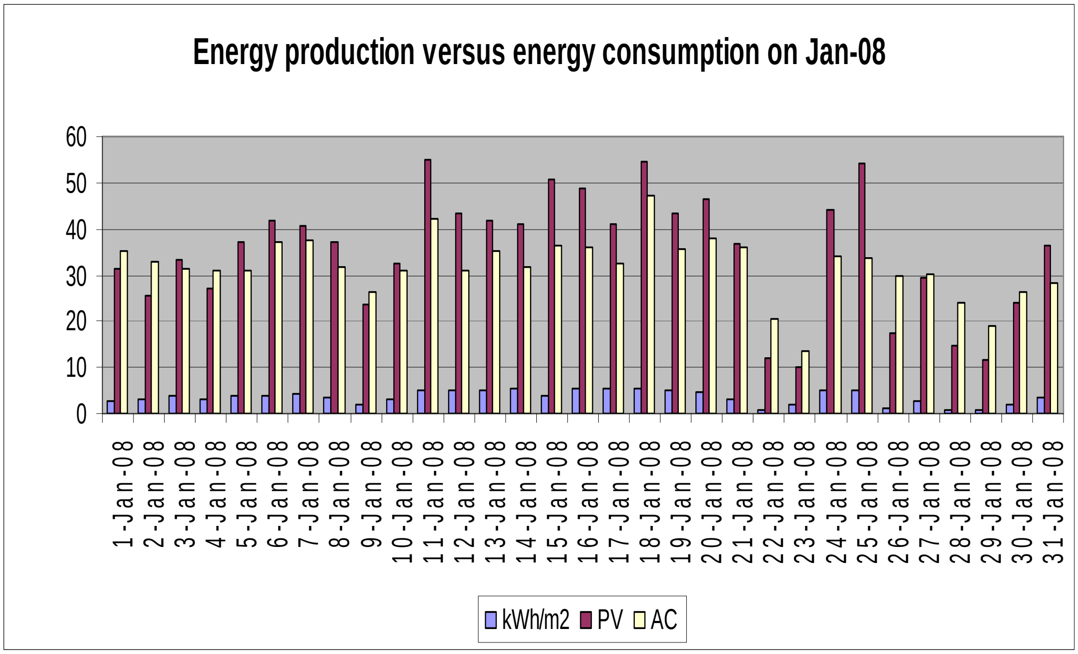
Figure(7-10): The energy production versus energy consumption on Dec-07.

But on the day of 17-Apr-08 see Figure(7-11) the average solar irradiation was about 6.53kW/m^2, that produced the energy about 59.314 kWh, is higher than the approximated daily energy consumption by about 13.8 kWh. Normally this surplus energy will be charged to battery, but in case where the battery is fully charged this surplus energy will be unutilized. These results confirmed the advantage of using this surplus energy to share with the other energy demand sources.



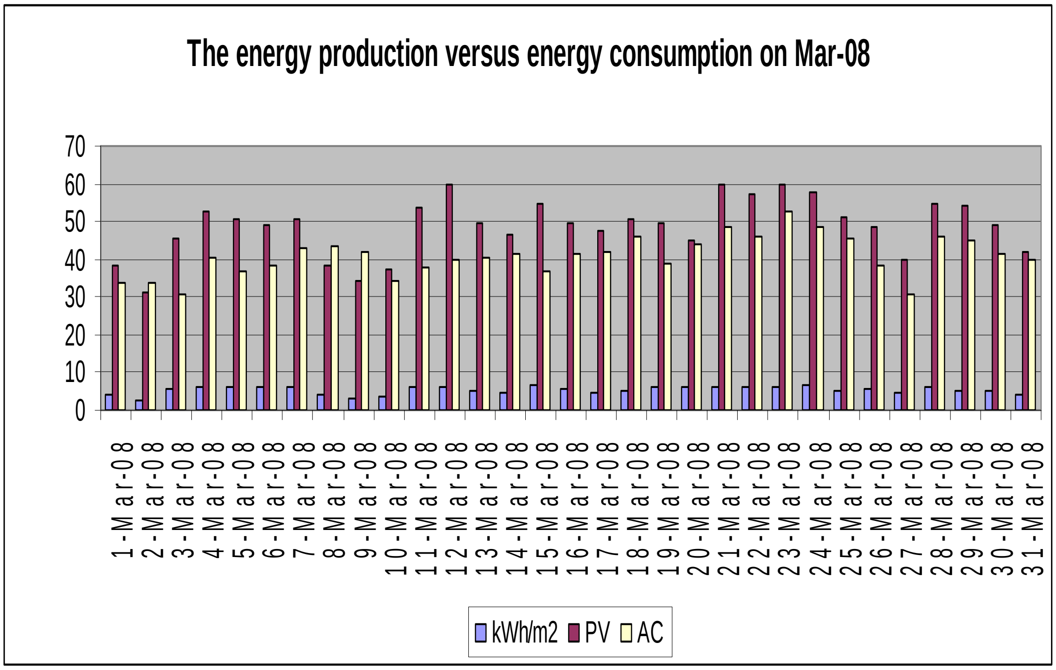
Figure(7-11): The energy production versus energy consumption on Apr-08.

In case of semi cloudy day, for example on the day of 21-Jan-08 see Figure(7-12) the average solar irradiation was about 3.15kW/m^2, that produced the energy about 36.695 kWh, was slightly higher than the approximated daily energy consumption by about 0.81 kWh.



Figure(7-12): The energy production versus energy consumption on Jan-08

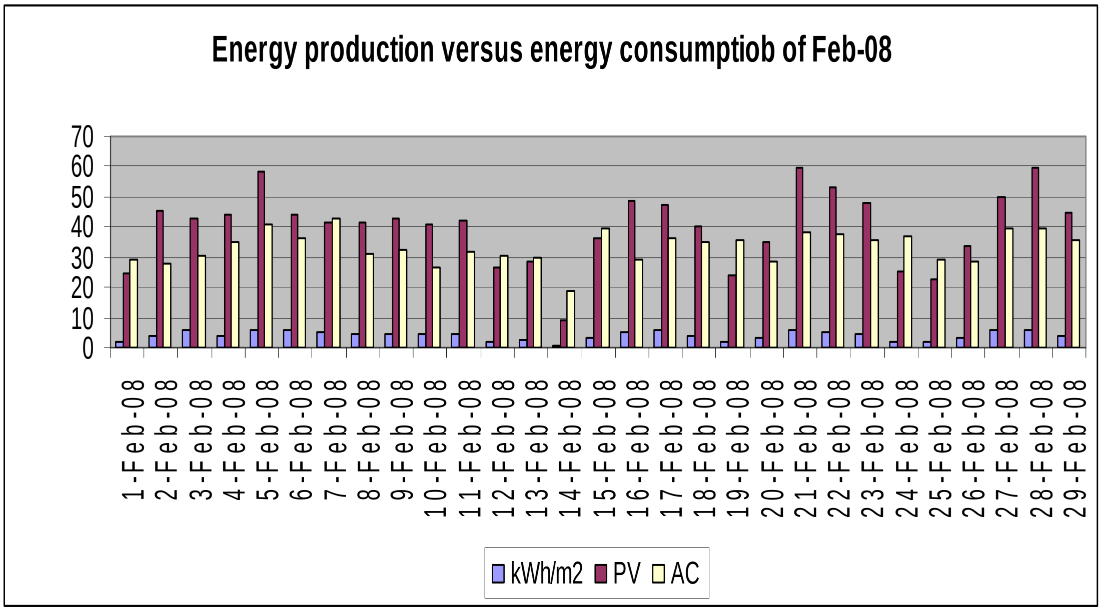
But on the day of 10-Mar-08 see Figure(7-13) the average solar irradiation was about 4.12kW/m^2, that produced the energy about 38.486 kWh, was slightly higher than the approximated daily energy consumption by about 4.6 kWh, This case is similar to a pure stand-alone system where the input energy is supplied from two sources, PV generator and battery. This is good for battery life, which can be charged and discharged with the deep cycle.



Figure(7-13): The energy production versus energy consumption on Mar-08

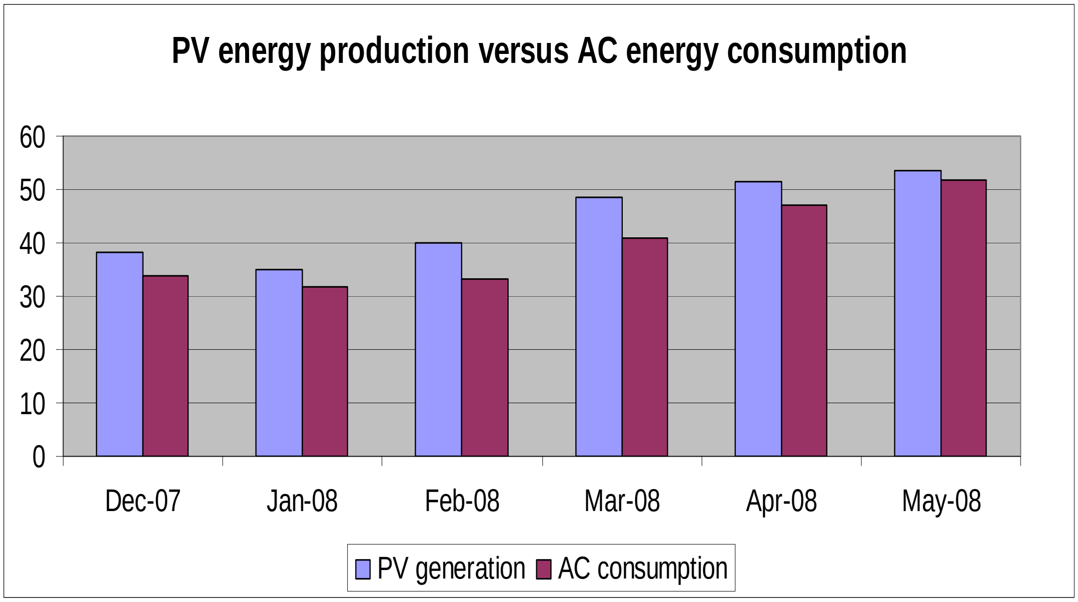
In case of cloudy day, for example on the day of 14-Feb-08, see Figure(7-14), the average solar irradiation about 0.43kW/m^2 that produced the energy about 9.156kWh, is less than the approximated daily energy consumption by about 9.33kWh, but on the day of 06-Apr-08, see Figure(7-11), the average solar irradiation about 2.96kW/m^2 that produced the energy about 32.778kWh, is less than the approximated daily energy consumption by about 13.64kWh.

In this case, the PV stand-alone power system may be inadequate because even with battery backup, the power supply system can fail if the weather remains continuously cloudy for many days. However, this situation can be overcome by using energy from the other supply sources (Diesel generator).



Figure(7-14): The energy production versus energy consumption on Feb-08

Finally, as shown during the first 6 months of operation, the PV system had worked effectively, the average of electricity production per day is 46.11kWh. It ranged from 38.09kWh (December 2007) to 51.5kWh (May 2008). The system performance evaluation is shown in Figure(7-15) this figure shows the monthly average daily potential PV energy and the average daily energy consumption of this system.



Figure(7-15): The PV energy generation versus energy consumption during Dec-07 to May-08 .

CHAPTER EIGHT

ECONOMIC EVALUATION OF SUPPLY ATOUF VILLAGE BY PV SYSTEM COMPARING WITH DIESEL OR IEC

8.1. The Cost of 1kWh Producing from PV and Other Systems

8.1.1. PV system

From the economical view point, photovoltaic energy system differ from conventional energy systems in that they have high initial cost and low operating costs. The price of the PV system and its installation are important factors in the economics of PV systems. These include the prices of PV modules, storage batteries, the control unit, the inverter, and all other auxiliaries. The cost of installation must be taken into consideration.

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

1- The lifecycle of the system components will be considered as 25 years except for the batteries, which will be considered to have lifetime of 12 years .

2- The interest rate is about 10%.

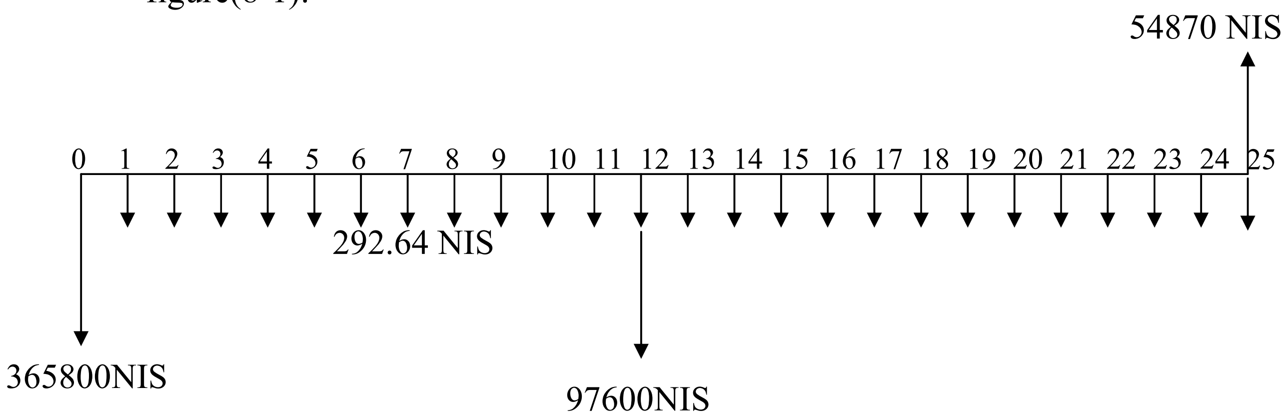
The initial cost of the PV system = PV array cost + first group of batteries cost + inverter cost + controller cost + installation cost.

The initial cost of the PV system = 176000 + 97600 + 16000 + 21200 + 55000

= 365800 NIS.

The annual maintenance and operation cost is about 2% of initial cost which is equal to 292.64 NIS/year, salvage value after 25 years is taken about 15% from initial cost and it is equal to 54870NIS, see page(91), and cost of second group of batteries after 12 years is equal to 97600NIS.

The life cycle cost of PV system is obtained by drawing cash flow as in figure(8-1):



Figure(8-1): Cash flow of PV system.

To calculate the equivalent uniform annual series A of cash flow in figure(8-1) which include randomly placed single amounts and uniform-series amounts, the most important fact to remember is to first convert everything to a present worth or a future worth. Then the equivalent uniform series is obtained with appropriate A/P or A/F factor [35].

The life cycle cost of PV system = initial cost of PV system + present worth of maintenance and operation – present worth of salvage value + present worth of second group of batteries.

The life cycle cost of PV system = $365800 + 292.64(P / A_{i,n}) - 54870 (P / F_{i,n}) + 97600(P / F_{i,n})$.

- The term $A (P / A_{i,n})$ is called the uniform-series present worth factor. This expression determines the present worth P of an equivalent uniform annual series A which begins at the end of year 1 and extends for n years at an interest rate i ,and (P/A) can be found by eq.(8-1) [35]:

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad i \neq 0 \qquad 8\text{-}1$$

- The term F (P / F $_{i,n}$) is known as the single-payment present-worth factor, or the P/F factor. This expression determines the present worth P of a given future amount F after n years at interest rate i , and (P/F) can be found by eq.(8-2) [35]:

$$P = F\left[\frac{1}{(1+i)^n}\right] \qquad 8\text{-}2$$

In order to simplify the routine engineering economy calculations involving the factors, tables of factors values have been prepared for interest rates from 0.25 to 50% and time period from 1 to large n values, depending on the interest value 10% and interest table in appendix(1), present worth can be solved as follow [35]:

PW = 365800 + 292.64(P / A $_{i,n}$) – 54870(P / F $_{i,n}$) + 97600 (P / F $_{i,n}$).

PW = 365800 + 292.64(P / A $_{10\%,25}$) – 54870(P / F $_{10\%,25}$) + 97600 (P / F$_{10\%,12}$).

The factors in the above equation is taken from appendix(1):

PW = 365800 + 292.64 x 9.0770 – 54870 x 0.0923 + 97600 x 0.3186

= 394487.2 NIS.

Then the equivalent annual worth AW is obtained with appropriate A/P, as follow:

AW = PW $(A / P_{i,n})$ = 394487.2 $(A / P_{10\%,25})$.

- The term P $(A / P_{i,n})$, called the capital-recovery factor, or A/P factor, yields the equivalent uniform annual worth A over n years of a given investment P when the interest rate is i ,and (A/P) factor solved by using eq.(8-3) [35]:

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \qquad 8\text{-}3$$

From appendix(1), the term $(A / P_{10\%,25})$ is equal to 0.11017, then:

AW = 394487.2 $(A / P_{10\%,25})$ = 394487.2 x 0.11017 = 43460.655NIS.

The life cycle output energy = 16147.6 kWh/year, see table(6-1).

The cost of 1 kWh from the PV generator = 43460.655NIS / 16147.6 kWh

= 2.69 NIS/kWh.

8.1.2. Diesel generator

It is important to estimate the life cycle cost of Diesel generator system that exist in Atouf village. This will give an indication of the difference in energy cost between PV system and Diesel generator systems.

To estimate the diesel generator life cycle cost, there are some assumption:

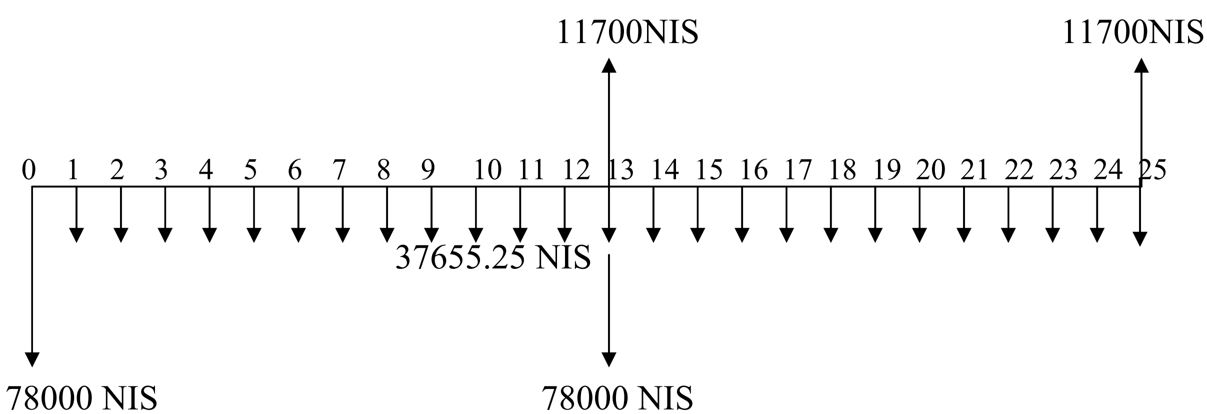
1- Diesel generator cost which is 78000NIS, life time 13years.

2- Total Annual maintenances cost 37655.25NIS. see table(5-3).

3- Salvage value cost 11700NIS every 13years.

4- The interest rate is about 10%.

The life cycle cost of Diesel generator system is obtained by using cash flow in figure(8-2):



Figure(8-2): Cash flow of diesel generator

The life cycle cost of diesel generator = initial cost of diesel generator + present worth of maintenance, operation and oil changing + present worth of second diesel generator – present worth of salvage value after 13 years – present worth of salvage value after 25 years.

The life cycle cost of PV system = 78000 + 37655.25(P / A $_{i,n}$) + 78000 (P / F $_{i,n}$) – 11700(P / F $_{i,n}$) – 11700 (P / F $_{i,n}$).

PW = 78000 + 37655.25(P / A $_{i,n}$) + 78000(P / F $_{i,n}$) – 11700(P / F $_{i,n}$) – 11700(P / F $_{i,n}$).

PW = 78000 + 37655.25(P / A $_{10\%,25}$) + 78000(P / F$_{10\%,13}$) – 11700(P / F$_{10\%,13}$) – 11700(P / F$_{10\%,25}$).

The factors in the above equation is taken from appendix(1):

PW = 78000 + 37655.25 x 9.0770 + 78000 x 0.2897 – 11700 x 0.2897 – 11700 x 0.0923.

PW = 437923.9 NIS.

Then the equivalent annual worth AW is obtained with appropriate A/P, as follow:

AW = PW (A / P $_{i,n}$) = 437923.9 (A / P $_{10\%,25}$).

From appendix(1), the term (A / P $_{10\%,25}$) is equal to 0.11017, then:

AW = 437923.9 (A / P $_{10\%,25}$) = 437923.9 x 0.11017 = 48246.1NIS.

The life cycle output energy = 16147.6 kWh/year, see table(6-1).

The cost of 1 kWh from the diesel generator = 48246.1NIS / 16147.6 kWh

= 2.98 NIS/kWh.

8.1.3. Transmission line system

The price of the transmission system and installation are important factors in the economics of transmission line system. The life cycle cost will be estimated as follows:

1- The life cycle of the system components will be considered as 25 years.

2- The interest rate is about 10%.

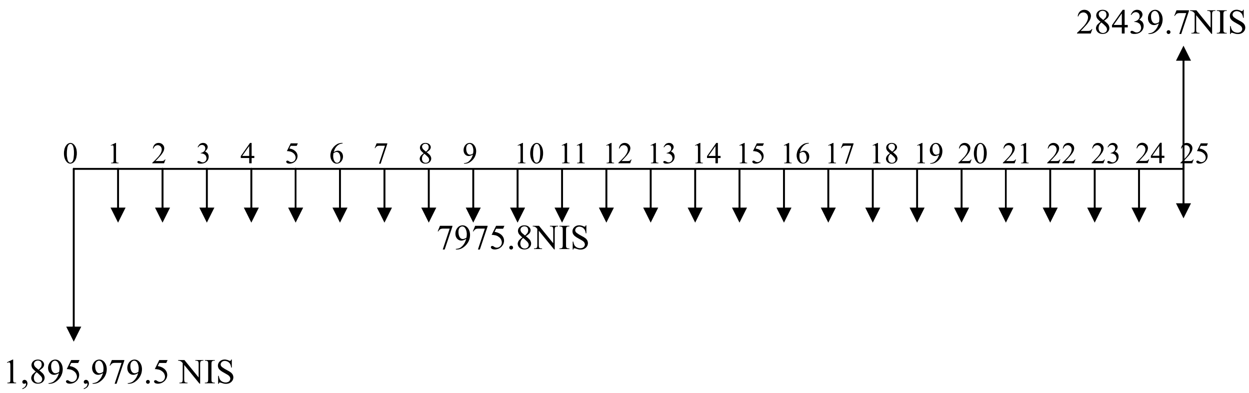
3- Initial cost of the TLS including civil works and installation is 1,895,979.5NIS, see table(5-4).

4- The annual maintenance and operation cost is about 2% of initial cost which is equal to 1516.8 NIS/year, salvage value after 25 years is taken about 15% from initial cost and it is equal to 28439.7NIS, see page(69).

5- Annual cost of energy from IEC is taken as running cost, it is equal to energy consumption multiply by cost of 1 kWh from IEC, thus it is equal to 16147.6 x 0.4 = 6459NIS.

6- The annual maintenance and operation cost + Annual cost of energy from IEC is equal to 7975.8 NIS.

The life cycle cost of TLS system is obtained by using cash flow in figure(8-3):



Figure(8-3): Cash flow of transmission line system

The life cycle cost of transmission line system = initial cost of TLS + present worth of maintenance and cost of energy from IEC – present worth of salvage value after 25 years.

The life cycle cost of PV system = 1,895,979.5 + 7975.8(P / A $_{i,n}$) – 28439.7(P / F $_{i,n}$).

PW = 1,895,979.5 + 7975.8(P / A $_{i,n}$) – 28439.7(P / F $_{i,n}$).

PW = 1,895,979.5 + 7975.8(P / A $_{10\%,25}$) – 28439.7(P / F$_{10\%,25}$).

The factors in the above equation is taken from appendix(2):

PW = 1,895,979.5 + 7975.8 x 9.0770 – 28439.7 x 0.0923.

PW = 1965751 NIS.

Then the equivalent annual worth AW is obtained with appropriate A/P, as:

AW = PW (A / P $_{i,n}$) = 1965751 (A / P $_{10\%,25}$).

From appendix(1), the term (A / P $_{10\%,25}$) is equal to 0.11017, then:

AW = 1965751 $(A / P_{10\%, 25})$ = 1965751 x 0.11017 = 216566.79 NIS.

The life cycle output energy = 16147.6 kWh/year, see table(6-1).

The cost of 1 kWh from the TLS = Fixed cost + Running cost

= 216566.79 NIS / 16147.6 kWh + 0.4

= 13.4 + 0.4 = 13.8 NIS/kWh.

Cost of energy in transmission line system is very high compared with diesel generator and PV systems, this high is due to the small loads in Atouf village. The TLS is very important in the future, it will be used to supply other villages or factories located near Atouf village.

This study shows that the life cycle cost of the PV system is less than that of the diesel generator systems in Atouf village, table(8-1) show cost of 1kWh for PV, diesel generator and transmission line systems.

Table (8-1): Summary of cost of 1kWh for different type of systems

Type	Cost of 1 kWh (NIS)
PV system	2.69
Diesel generator system	2.98
Transmission line system	13.8

In any case, PV systems are clean and renewable sources of energy; they do not cause pollution of any type during their use. On the other hand, diesel generators cause noise and produce gases and smoke.

8.2. Rate of Return for the PV System

Rate of return (ROR) is the rate of interest paid on the unpaid balance of borrowed money, or the rate of interest earned on the un-recovered balance of an investment, so that the final payment or receipt brings the balance to exactly zero with interest considered [35]. The ROR is expressed as a percent per period, for example, i=10% per year.

To estimate rate of return for the PV system, there are some assumption:

1- Initial cost of the PV system 365800NIS.

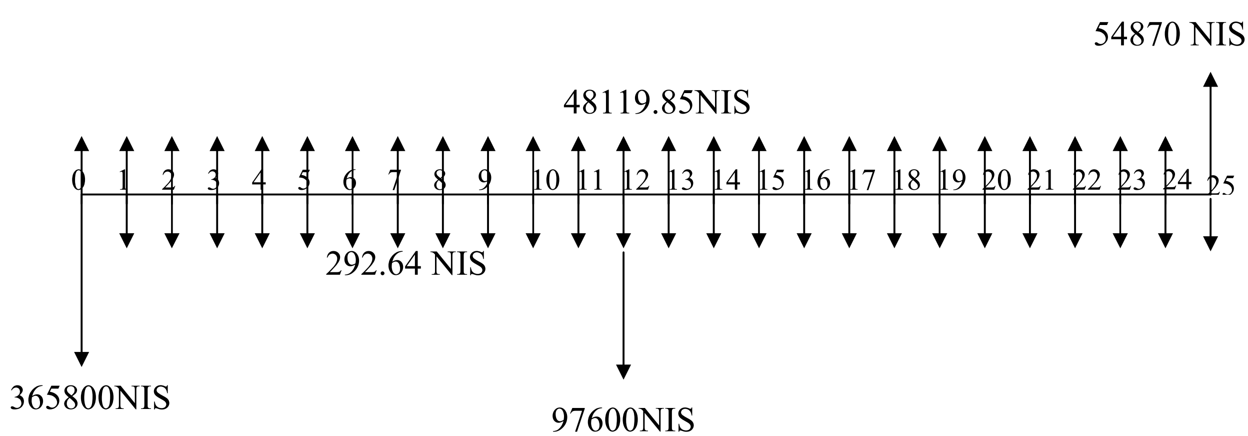
3- Cost of battery is 97600NIS.

4- Annual cost of maintenance is 292.64 NIS.

5- Salvage value is 54870NIS.

6- Annual cost of energy from diesel generator which is equal to energy consumption in the village multiply by cost of 1 kWh from diesel generator, it is equal 16147.6kWh/year x 2.98NIS/kWh = 48119.85NIS.

From cash flow in figure(8-4), and by using try and error method, ROR is obtained as follow:



Figure(8-4): Cash flow to find ROR

Annual cost of energy from diesel generator and salvage value are saving values (Income values), but initial cost of the PV system, cost of battery and annual cost of maintenance are assuming to be outcome values.

Income = $48119.85 \, (P / A_{i, 25}) + 54870 \, (P / F_{i, 25})$.

Outcome = $365800 + 292.64 \, (P / A_{i, 25}) + 97600 \, (P / F_{i, 12})$.

Income + Outcome = 0.

$48119.85 \, (P / A_{i, 25}) + 54870 \, (P / F_{i, 25}) - 365800 - 292.64 \, (P / A_{i, 25}) - 97600 \, (P / F_{i, 12}) = 0$.

$^{-}365800 - 97600 \, (P / F_{i, 12}) + 54870 \, (P / F_{i, 25}) + 47827.21 \, (P / A_{i, 25}) = 0$

By try and error the approximate i is between 11% and 12%. Therefore, use i = 11% to estimate the actual rate of return.

From appendix(3), the term $(P / A_{11\%, 25})$ is equal to 8.4217, $(P / F_{11\%, 25})$ is equal to 0.0736, and $(P / F_{11\%, 12})$ is equal to 0.2858, then:

$^{-}365800 - 97600(P / F_{11\%, 12}) + 54870(P / F_{11\%, 25}) + 47827.21(P / A_{11\%, 25}) = 0$

$^{-}365800 - 97600 \times 0.2858 + 54870 \times 0.0736 + 47827.21 \times 8.4217 = 0 < 13131$

We are too large on the positive side, indicating that the return is more than 11%. Try i = 12%.

$^{-}365800 - 97600 \, (P / F_{i, 12}) + 54870 \, (P / F_{i, 25}) + 47827.21 \, (P / A_{i, 25}) = 0$

From appendix(4), the term $(P / A_{12\%, 25})$ is equal to 7.8431, $(P / F_{12\%, 25})$ is equal to 0.0588, and $(P / F_{12\%, 12})$ is equal to 0.2567, then:

$^{-}365800 - 97600 \, (P / F_{12\%, 12}) + 54870 \, (P / F_{12\%, 25}) + 47827.21 \, (P / A_{12\%, 25}) = 0$

¯365800 – 97600 x 0.2567+ 54870 x 0.0588+ 47827.21 x 7.8431= 0 > –12514

Since the interest rate of 12% is too high, interpolate between 11% and 12% to obtain:

$$i = 0.11 + \frac{13131 - 0}{13131 - (-12514)}(0.01)$$

$$= 0.11 + 0.0051 = 0.1151 = 11.51\% = \text{ROR}$$

8.3. Tariff Structure for the PV-System in Atouf Village

The electricity tariff in the village depends primarily on the upper limit for daily consumption of the village, and this in turn determines the amount of money to be paid to the Village Council, Table(8-2).

Table(8-2): Upper limit for daily consumption

	Name	Upper limit for daily consumption (Wh/day)	Monthly price(NIS)
1	Abed Al-Aziz Absharat	1650	78
2	Rabah Ali Busharat	550	45
3	Jamal Hasan Audeh	1650	78
4	Omar Khaled Bani Audeh	1650	78
5	Mohammad Mostafa Busharat	550	45
6	Khader Mostafa Busharat	1100	61
7	Abed Al-ghani Bani Audeh	1650	78
8	Naji Yousef Bani Audeh	550	45
9	Tamam Abdullah Busharat	550	45
10	Mohammad Mostafa Bani Audeh	825	53
11	Rasheed Mohammad Busharat	1650	78
12	Naji Hesein Busharat	1650	78
13	Jamal Khader Bani Audeh	825	53
14	Naeem Mostafa Bani Audeh	1650	78
15	Khair Allah Bani Audeh	550	45
16	Fayad Bani Audeh	550	45
17	Maher Aeid Bani Audeh	550	45
18	Aaref Abed Al-Wali Bani Audeh	1650	78
19	Waleed Mostafa Busharat	1650	78
20	Khalid Yousef Ahmed	1650	78
21	Khadir Ahmad Bani Audeh	1100	61
22	School	1100	61
23	Mosque	1100	61

The tariff contracted and the consumption limited by the device called energy Dispenser/Meter, figure(8-5). The energy Dispenser/Meter is an electronic energy meter which is installed in each user's home. It contains an algorithm that limits consumption and guarantees each user a minimum amount of energy according to the tariff contracted. The energy dispenser/meter [36]:

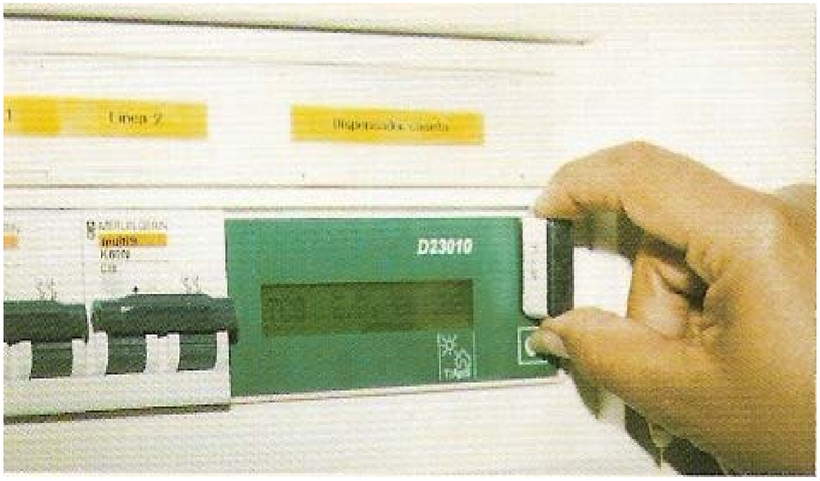
1- Avoids the risk of individual over-consumption.

2- Enables new, sustainable tariff systems, better adapted to generation using renewable energy.

3- Reduces the investment required and encourages maximum use of a available energy.

Figure(8-5): Energy Dispenser/Meter

The tariff contracted is recorded on an individual user token which contains full information about energy available and total consumption, figure (8-6). This token can be removed and used in another dispenser/meter, giving individual users great flexibility in using this energy in different consumption points equipped with energy dispenser/meter [36].



Figure(8-6): A user inserting the individual token in the energy dispenser/meter

Conclusion

1. There are 63 localities in the PT which are not connected to the public electricity network, and the probability of connecting them with high voltage grid in the near future is very poor due to financial and political situation, small diesel generators of power range from 3 to 7 kVA are widely used in these villages to cover the power demands of their houses and sell the excess generated power at very high price.

2. Renewable energy has not reached a satisfactory level of utilization in Palestine but solar energy is very familiar to the Palestinian population and is used essentially for water heating. Palestine has a high solar energy potential, where average of solar radiation is 5.46 kWh/m^2 per day, and the total annual sunshine hours amounts to about 3000, these figures are very encouraging to use solar energy for electrification of remote villages as Atouf village.

3. Atouf village use Diesel Generator in their Electricity production, the operating hours of the Generator is about 5 hours, the electrical load in the village is mainly concentrated on the night period, the total electricity consumption is about 16146 kWh/year. The price of diesel in Palestine is very high, and the generator requires approximately 14 liters of diesel in a day even works, and in most cases the village could not pay for fuel.

4. Cost of energy from transmission line system is very high about 13.7 NIS/kWh compared with diesel generator which is 2.98 NIS/kWh, this high is due to the small loads in Atouf village. The TLS is very

important in the future, it will be used to supply other villages or factories located near Atouf village.

5. After the first 2 months of operation of PV system, based on the data measured and data analyzed, it was concluded that the 11.7 kWp photovoltaic power system had worked effectively. All types of PV technology had generated power that varied linearly with the solar irradiation, the average of electricity production per day is 36.55kWh. It ranged from 35.015kWh (January 2008) to 38.09kWh (December 2007).

6. In part of energy storage, it was found that the energy from battery was only a little utilized in relation to the daily energy analyzed, resulting in surplus energy being wasted on sunny days and insufficient energy on cloudy days. This result is an indication of the limitation of this PV stand-alone system. The surplus energy generated can be supplied to other loads while any energy shortage can be compensated by other energy supply sources like diesel generator.

7. The life cycle cost of the PV system is 2.35 NIS/kWh which is less than that of the diesel generator and transmission line systems in Atouf village.

8. The tariff contracted and the consumption limited by the device called energy Dispenser/Meter in Atouf village, this device avoids the risk of individual over-consumption and enables new, sustainable tariff systems, better adapted to generation using renewable energy.

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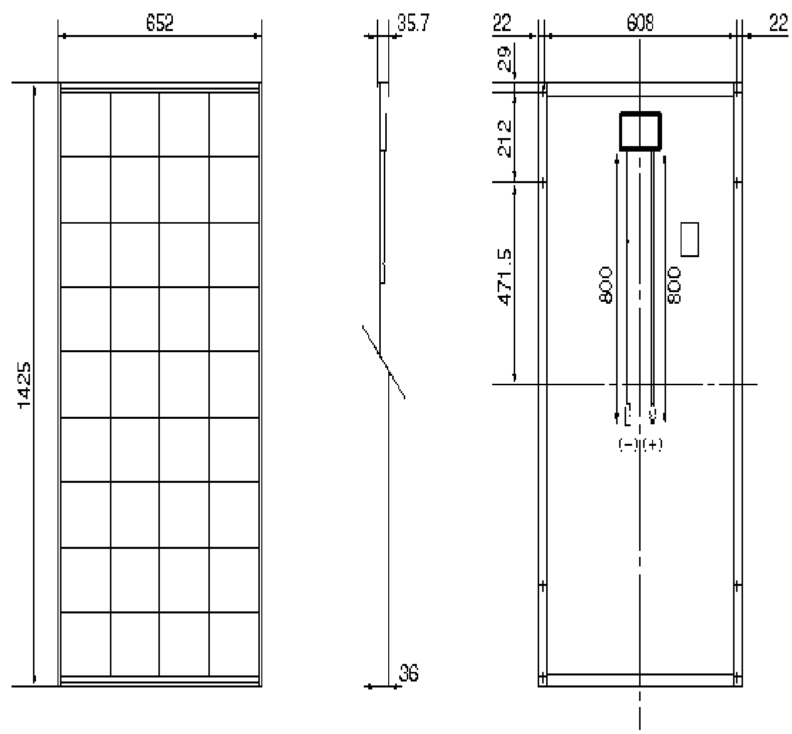
Appendix

Appendix (1): Specifications of Kyocera KC130GHT-2

SPECIFICATIONS KC130GHT-2

■ 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.

Appendix(2): Table of interest at i = 10%

10%								10%
	Single Payments		Uniform-Series Payments				Uniform Gradient	
n	Compound Amount *F/P*	Present Worth *P/F*	Sinking Fund *A/F*	Compound Amount *F/A*	Capital Recovery *A/P*	Present Worth *P/A*	Gradient Present Worth *P/G*	Gradient Annual Series *A/G*
1	1.1000	0.9091	1.00000	1.0000	1.10000	0.9091		
2	1.2100	0.8264	0.47619	2.1000	0.57619	1.7355	0.8264	0.4762
3	1.3310	0.7513	0.30211	3.3100	0.40211	2.4869	2.3291	0.9366
4	1.4641	0.6830	0.21547	4.6410	0.31547	3.1699	4.3781	1.3812
5	1.6105	0.6209	0.16380	6.1051	0.26380	3.7908	6.8618	1.8101
6	1.7716	0.5645	0.12961	7.7156	0.22961	4.3553	9.6842	2.2236
7	1.9487	0.5132	0.10541	9.4872	0.20541	4.8684	12.7631	2.6216
8	2.1436	0.4665	0.08744	11.4359	0.18744	5.3349	16.0287	3.0045
9	2.3579	0.4241	0.07364	13.5795	0.17364	5.7590	19.4215	3.3724
10	2.5937	0.3855	0.06275	15.9374	0.16275	6.1446	22.8913	3.7255
11	2.8531	0.3505	0.05396	18.5312	0.15396	6.4951	26.3963	4.0641
12	3.1384	0.3186	0.04676	21.3843	0.14676	6.8137	29.9012	4.3884
13	3.4523	0.2897	0.04078	24.5227	0.14078	7.1034	33.3772	4.6988
14	3.7975	0.2633	0.03575	27.9750	0.13575	7.3667	36.8005	4.9955
15	4.1772	0.2394	0.03147	31.7725	0.13147	7.6061	40.1520	5.2789
16	4.5950	0.2176	0.02782	35.9497	0.12782	7.8237	43.4164	5.5493
17	5.0545	0.1978	0.02466	40.5447	0.12466	8.0216	46.5819	5.8071
18	5.5599	0.1799	0.02193	45.5992	0.12193	8.2014	49.6395	6.0526
19	6.1159	0.1635	0.01955	51.1591	0.11955	8.3649	52.5827	6.2861
20	6.7275	0.1486	0.01746	57.2750	0.11746	8.5136	55.4069	6.5081
21	7.4002	0.1351	0.01562	64.0025	0.11562	8.6487	58.1095	6.7189
22	8.1403	0.1228	0.01401	71.4027	0.11401	8.7715	60.6893	6.9189
23	8.9543	0.1117	0.01257	79.5430	0.11257	8.8832	63.1462	7.1085
24	9.8497	0.1015	0.01130	88.4973	0.11130	8.9847	65.4813	7.2881
25	10.8347	0.0923	0.01017	98.3471	0.11017	9.0770	67.6964	7.4580
26	11.9182	0.0839	0.00916	109.1818	0.10916	9.1609	69.7940	7.6186
27	13.1100	0.0763	0.00826	121.0999	0.10826	9.2372	71.7773	7.7704
28	14.4210	0.0693	0.00745	134.2099	0.10745	9.3066	73.6495	7.9137
29	15.8631	0.0630	0.00673	148.6309	0.10673	9.3696	75.4146	8.0489
30	17.4494	0.0573	0.00608	164.4940	0.10608	9.4269	77.0766	8.1762
31	19.1943	0.0521	0.00550	181.9434	0.10550	9.4790	78.6395	8.2962
32	21.1138	0.0474	0.00497	201.1378	0.10497	9.5264	80.1078	8.4091
33	23.2252	0.0431	0.00450	222.2515	0.10450	9.5694	81.4856	8.5152
34	25.5477	0.0391	0.00407	245.4767	0.10407	9.6086	82.7773	8.6149
35	28.1024	0.0356	0.00369	271.0244	0.10369	9.6442	83.9872	8.7086
40	45.2593	0.0221	0.00226	442.5926	0.10226	9.7791	88.9525	9.0962
45	72.8905	0.0137	0.00139	718.9048	0.10139	9.8628	92.4544	9.3740
50	117.3909	0.0085	0.00086	1163.91	0.10086	9.9148	94.8889	9.5704
55	189.0591	0.0053	0.00053	1880.59	0.10053	9.9471	96.5619	9.7075
60	304.4816	0.0033	0.00033	3034.82	0.10033	9.9672	97.7010	9.8023
65	490.3707	0.0020	0.00020	4893.71	0.10020	9.9796	98.4705	9.8672
70	789.7470	0.0013	0.00013	7887.47	0.10013	9.9873	98.9870	9.9113
75	1271.90	0.0008	0.00008	12709	0.10008	9.9921	99.3317	9.9410
80	2048.40	0.0005	0.00005	20474	0.10005	9.9951	99.5606	9.9609
85	3298.97	0.0003	0.00003	32980	0.10003	9.9970	99.7120	9.9742
90	5313.02	0.0002	0.00002	53120	0.10002	9.9981	99.8118	9.9831
95	8556.68	0.0001	0.00001	85557	0.10001	9.9988	99.8773	9.9889
96	9412.34	0.0001	0.00001	94113	0.10001	9.9989	99.8874	9.9898
98	11389	0.0001	0.00001		0.10001	9.9991	99.9052	9.9914
100	13781	0.0001	0.00001		0.10001	9.9993	99.9202	9.9927

Appendix(3): Table of interest at i = 11%

11% | **11%**

	Single Payments		Uniform-Series Payments				Uniform Gradient	
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Annual Series A/G
1	1.1100	0.9009	1.00000	1.0000	1.11000	0.9009		
2	1.2321	0.8116	0.47393	2.1100	0.58393	1.7125	0.8116	0.4739
3	1.3676	0.7312	0.29921	3.3421	0.40921	2.4437	2.2740	0.9306
4	1.5181	0.6587	0.21233	4.7097	0.32233	3.1024	4.2502	1.3700
5	1.6851	0.5935	0.16057	6.2278	0.27057	3.6959	6.6240	1.7923
6	1.8704	0.5346	0.12638	7.9129	0.23638	4.2305	9.2972	2.1976
7	2.0762	0.4817	0.10222	9.7833	0.21222	4.7122	12.1872	2.5863
8	2.3045	0.4339	0.08432	11.8594	0.19432	5.1461	15.2246	2.9585
9	2.5580	0.3909	0.07060	14.1640	0.18060	5.5370	18.3520	3.3144
10	2.8394	0.3522	0.05980	16.7220	0.16980	5.8892	21.5217	3.6544
11	3.1518	0.3173	0.05112	19.5614	0.16112	6.2065	24.6945	3.9788
12	3.4985	0.2858	0.04403	22.7132	0.15403	6.4924	27.8388	4.2879
13	3.8833	0.2575	0.03815	26.2116	0.14815	6.7499	30.9290	4.5822
14	4.3104	0.2320	0.03323	30.0949	0.14323	6.9819	33.9449	4.8619
15	4.7846	0.2090	0.02907	34.4054	0.13907	7.1909	36.8709	5.1275
16	5.3109	0.1883	0.02552	39.1899	0.13552	7.3792	39.6953	5.3794
17	5.8951	0.1696	0.02247	44.5008	0.13247	7.5488	42.4095	5.6180
18	6.5436	0.1528	0.01984	50.3959	0.12984	7.7016	45.0074	5.8439
19	7.2633	0.1377	0.01756	56.9395	0.12756	7.8393	47.4856	6.0574
20	8.0623	0.1240	0.01558	64.2028	0.12558	7.9633	49.8423	6.2590
21	8.9492	0.1117	0.01384	72.2651	0.12384	8.0751	52.0771	6.4491
22	9.9336	0.1007	0.01231	81.2143	0.12231	8.1757	54.1912	6.6283
23	11.0263	0.0907	0.01097	91.1479	0.12097	8.2664	56.1864	6.7969
24	12.2392	0.0817	0.00979	102.1742	0.11979	8.3481	58.0656	6.9555
25	13.5855	0.0736	0.00874	114.4133	0.11874	8.4217	59.8322	7.1045
26	15.0799	0.0663	0.00781	127.9988	0.11781	8.4881	61.4900	7.2443
27	16.7386	0.0597	0.00699	143.0786	0.11699	8.5478	63.0433	7.3754
28	18.5799	0.0538	0.00626	159.8173	0.11626	8.6016	64.4965	7.4982
29	20.6237	0.0485	0.00561	178.3972	0.11561	8.6501	65.8542	7.6131
30	22.8923	0.0437	0.00502	199.0209	0.11502	8.6938	67.1210	7.7206
31	25.4104	0.0394	0.00451	221.9132	0.11451	8.7331	68.3016	7.8210
32	28.2056	0.0355	0.00404	247.3236	0.11404	8.7686	69.4007	7.9147
33	31.3082	0.0319	0.00363	275.5292	0.11363	8.8005	70.4228	8.0021
34	34.7521	0.0288	0.00326	306.8374	0.11326	8.8293	71.3724	8.0836
35	38.5749	0.0259	0.00293	341.5896	0.11293	8.8552	72.2538	8.1594
40	65.0009	0.0154	0.00172	581.8261	0.11172	8.9511	75.7789	8.4659
45	109.5302	0.0091	0.00101	986.6386	0.11101	9.0079	78.1551	8.6763
50	184.5648	0.0054	0.00060	1668.77	0.11060	9.0417	79.7341	8.8185
55	311.0025	0.0032	0.00035	2818.20	0.11035	9.0617	80.7712	8.9135
60	524.0572	0.0019	0.00021	4755.07	0.11021	9.0736	81.4461	8.9762
65	883.0669	0.0011	0.00012	8018.79	0.11012	9.0806	81.8819	9.0172
70	1488.02	0.0007	0.00007	13518	0.11007	9.0848	82.1614	9.0438
75	2507.40	0.0004	0.00004	22785	0.11004	9.0873	82.3397	9.0610
80	4225.11	0.0002	0.00003	38401	0.11003	9.0888	82.4529	9.0720
85	7119.56	0.0001	0.00002	64714	0.11002	9.0896	82.5245	9.0790

Appendix(4): Table of interest at i = 12%

12%									12%
	Single Payments		Uniform-Series Payments				Uniform Gradient		
n	Compound Amount F/P	Present Worth P/F	Sinking Fund A/F	Compound Amount F/A	Capital Recovery A/P	Present Worth P/A	Gradient Present Worth P/G	Gradient Annual Series A/G	
1	1.1200	0.8929	1.00000	1.0000	1.12000	0.8929			
2	1.2544	0.7972	0.47170	2.1200	0.59170	1.6901	0.7972	0.4717	
3	1.4049	0.7118	0.29635	3.3744	0.41635	2.4018	2.2208	0.9246	
4	1.5735	0.6355	0.20923	4.7793	0.32923	3.0373	4.1273	1.3589	
5	1.7623	0.5674	0.15741	6.3528	0.27741	3.6048	6.3970	1.7746	
6	1.9738	0.5066	0.12323	8.1152	0.24323	4.1114	8.9302	2.1720	
7	2.2107	0.4523	0.09912	10.0890	0.21912	4.5638	11.6443	2.5512	
8	2.4760	0.4039	0.08130	12.2997	0.20130	4.9676	14.4714	2.9131	
9	2.7731	0.3606	0.06768	14.7757	0.18768	5.3282	17.3563	3.2574	
10	3.1058	0.3220	0.05698	17.5487	0.17698	5.6502	20.2541	3.5847	
11	3.4785	0.2875	0.04842	20.6546	0.16842	5.9377	23.1288	3.8953	
12	3.8960	0.2567	0.04144	24.1331	0.16144	6.1944	25.9523	4.1897	
13	4.3635	0.2292	0.03568	28.0291	0.15568	6.4235	28.7024	4.4683	
14	4.8871	0.2046	0.03087	32.3926	0.15087	6.6282	31.3624	4.7317	
15	5.4736	0.1827	0.02682	37.2797	0.14682	6.8109	33.9202	4.9803	
16	6.1304	0.1631	0.02339	42.7533	0.14339	6.9740	36.3670	5.2147	
17	6.8660	0.1456	0.02046	48.8837	0.14046	7.1196	38.6973	5.4353	
18	7.6900	0.1300	0.01794	55.7497	0.13794	7.2497	40.9080	5.6427	
19	8.6128	0.1161	0.01576	63.4397	0.13576	7.3658	42.9979	5.8375	
20	9.6463	0.1037	0.01388	72.0524	0.13388	7.4694	44.9676	6.0202	
21	10.8038	0.0926	0.01224	81.6987	0.13224	7.5620	46.8188	6.1913	
22	12.1003	0.0826	0.01081	92.5026	0.13081	7.6446	48.5543	6.3514	
23	13.5523	0.0738	0.00956	104.6029	0.12956	7.7184	50.1776	6.5010	
24	15.1786	0.0659	0.00846	118.1552	0.12846	7.7843	51.6929	6.6406	
25	17.0001	0.0588	0.00750	133.3339	0.12750	7.8431	53.1046	6.7708	
26	19.0401	0.0525	0.00665	150.3339	0.12665	7.8957	54.4177	6.8921	
27	21.3249	0.0469	0.00590	169.3740	0.12590	7.9426	55.6369	7.0049	
28	23.8839	0.0419	0.00524	190.6989	0.12524	7.9844	56.7674	7.1098	
29	26.7499	0.0374	0.00466	214.5828	0.12466	8.0218	57.8141	7.2071	
30	29.9599	0.0334	0.00414	241.3327	0.12414	8.0552	58.7821	7.2974	
31	33.5551	0.0298	0.00369	271.2926	0.12369	8.0850	59.6761	7.3811	
32	37.5817	0.0266	0.00328	304.8477	0.12328	8.1116	60.5010	7.4586	
33	42.0915	0.0238	0.00292	342.4294	0.12292	8.1354	61.2612	7.5302	
34	47.1425	0.0212	0.00260	384.5210	0.12260	8.1566	61.9612	7.5965	
35	52.7996	0.0189	0.00232	431.6635	0.12232	8.1755	62.6052	7.6577	
40	93.0510	0.0107	0.00130	767.0914	0.12130	8.2438	65.1159	7.8988	
45	163.9876	0.0061	0.0074	1358.23	0.12074	8.2825	66.7342	8.0572	
50	289.0022	0.0035	0.00042	2400.02	0.12042	8.3045	67.7624	8.1597	
55	509.3206	0.0020	0.00024	4236.01	0.12024	8.3170	68.4082	8.2251	
60	897.5969	0.0011	0.00013	7471.64	0.12013	8.3240	68.8100	8.2664	
65	1581.87	0.0006	0.00008	13174	0.12008	8.3281	69.0581	8.2922	
70	2787.80	0.0004	0.00004	23223	0.12004	8.3303	69.2103	8.3082	
75	4913.06	0.0002	0.00002	40934	0.12002	8.3316	69.3031	8.3181	
80	8658.48	0.0001	0.00001	72146	0.12001	8.3324	69.3594	8.3241	
85	15259	0.0001	0.00001		0.12001	8.3328	69.3935	8.3278	

جامعة النجاح الوطنية
كلية الدراسات العليا

استراتيجية التشغيل الأمثل و التحليل الاقتصادي لانارة المناطق الريفية – قرية عطوف ، باستخدام أنظمة الخلايا الشمسية ،أنظمة الديزل ،وشبكات الكهرباء

إعداد
أسماء مفيد ياسين

إشراف
د. عماد بريك

قدمت هذه الأطروحة استكمالا لمتطلبات نيل درجة الماجستير في هندسة الطاقة النظيفة وإستراتيجية الترشيد بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.
2008

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إعداد

أسماء مفيد ياسين

إشراف

د. عماد بريك

الملخص

تصف هذه الأطروحة إستراتيجية التشغيل الأمثل والتحليل الاقتصادي لإنارة قرية عطوف باستخدام شبكات الكهرباء، مولّد ديزل والخلايا الشمسية، وأيضا تصف تصميم واختبار النظام المقترح للقرية من خلال استخدام الخلايا الشمسية بقدرة مقدارها ١١,٧كيلوواط وكذلك تلخص نتائج أداء النظام بعد ستة شهور من التشغيل. هذا النظام يعمل كنظام كهربائي مستقل يستعمل لتزويد قرية عطوف بالكهرباء، حيث أنّ هذا النظام يشمل المكوّنات التالية: مصفوفة مكونة من عدة وحدات من الخلايا الشمسية من نوع خلايا شمسية سيليكونية متعددة البلورات بقدرة مقدارها ١٣٠واط لكل وحدة لتكون نظام كامل بقدرة ١١,٧كيلوواط . وأيضا يحتوي النظام على محول قدرته ٧,٢ كيلوواط ، ونظام تخزين الطاقة بسعة مقدارها ١٢٠ كيلوواط ساعة.

بعد ستة شهور من تشغيل النظام خلال الفترة من شهر كانون أول –٢٠٠٧ إلى شهر أيار– ٢٠٠٨ وجد أن النظام بجميع مكوناته يعمل بشكل فعال، حيث أن النظام قام بتوليد ٧٥٩٦ كيلوواط ساعة خلال فترة التشغيل، حيث أن متوسط الإشعاع الشمسي اليومي خلال فترة التشغيل هو حوالي ٤,٦٧ كيلوواط ساعة /م^2، ولقد كان متوسط إنتاج الكهرباء هو حوالي ٤٦,١١ كيلوواط باليوم.

من الناحية الاقتصادية وجد أن نظام الخلايا الشمسية يختلف عن الأنظمة التقليدية الأخرى بأن كلفته الأولية عالية وتكاليف تشغيله منخفضة. ومن خلال هذه الدراسة تبين لنا أن سعر الكيلوواط ساعة من الخلايا الشمسية يصل إلى ٢,٦٩ شيكل وهذا أقل من تكلفة إنتاج الطاقة الكهربائية بواسطة استخدام مولد الديزل في قرية عطوف.