An-Najah National University

Faculty of Graduate Studies

Techno-Economic Impact of Using On-Grid and Off-Grid PV Solar Systems in West Bank (Masoud village as a case study)

By

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Supervisor

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This thesis was defended successfully on 14/8/2016 and approved by:

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– Dr. Aysar yasin /Internal Examiner	……………………

Dedication

To my father ….

To my mother, brothers and sisters…….

To my husband Ali

To my son Anas

To my daughters Sara, Danya and Jana

To all friends and colleagues………

To everyone working in this field……

To all of them,

I dedicate this work

Acknowledgments

It is an honor for me to have the opportunity to thank all people who helped me to complete this study.

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This work would not have been possible without the endless support from my family, especially my mother and father for their encouragement and the patience of my husband and children, My sister Hiba for taking care of my children during the study, My thanks go also to friends and colleagues for their help.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان

Techno-Economic Impact of Using On-Grid and Off-Grid PV Solar Systems in West Bank (Masoud village as a case study)

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Declaration

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

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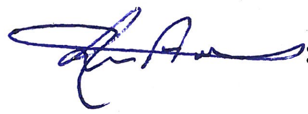

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Techno-Economic Impact of Using On-Grid and Off-Grid PV Solar Systems in West Bank
(Masoud village as a case study)

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Abstract

There are some Palestinian villages and communities still have no access to electricity as they are far from the electric grid as well as there are economic and political obstacles .This thesis presents three energy supply alternatives for such villages and communities represented in centralized PV system, decentralized PV system and the option of expanding the electrical network. The detail design of these systems and the corresponding economical and financial assessment are illustrated in details as well.

A software is designed to estimate the economic and financial indicators in order to compare between the proposed alternatives which is mainly based on the annuity cost of energy. A small community in Palestinian territories in Jenin governorate is taken as case study.

The results show that the cost annuity for centralized PV system, decentralized PV system and expanding the electrical network are 1.335NIS/kWh, 1.344NIS/kWh and 7.289NIS/kWh respectively.

The implementation of the proposed centralized PV system reduces the amount of CO_2, SO_2 and NO to about 4 tons, 30 tons and 18 tons, respectively.

The cost of electrical energy produced by a grid connected PV power system is 0.509 NIS/kWh in case the electrical network is expanding for Masoud village. The impact of applying feed in tariff (FIT) policy is studied and analyzed.

Chapter One

1.1 Introduction

There are some Palestinian villages that are having no access to electricity in Palestine territories because these villages are far from the electric grid and the cost of connection is very high in addition to political reasons in some cases. These rural villages obtain their needs of electrical energy from noisy and polluting diesel generators with high running costs . As a result, it is necessary to investigate the option of using off-grid PV system in remote villages; this system means that these villages are not connected to the grid and get all the power from the PV system. PV solar energy is feasible in Palestine for electrification of remote villages since Palestine has a high solar energy potential, where the daily average is 5.46 kWh/$m^2$and the total annual sunshine hours is about 3000 [1].

On the other side ,the cost of electricity is relatively high in Palestine in comparison with most countries in the region because most of the electric power is purchased from Israel companies through agreements include the upper limit for Peak demand of electricity for the city or village. According to these agreements, Israel shuts down power supply to any Palestinian city or village that exceeds the specified peak limit; ; Mostly all Palestinian cities and villages suffer from blackouts for many hours at peak days, especially in summers [2-3].

One of the possible solutions for these problem is take advantage of PV solar energy which can fill the gap of energy reduction and manage the energy consumptions.

It is necessary to investigate the impact of using on-grid PV system in west bank to reduce energy costs and the bad environmental impacts . That means that the solar system is connected to the utility company, which enable the customers to sell any excess power produced back to the electric company through a net metering plan.

The feasibility of using PV systems in on-grid and off-grid in Palestinian territories is studied and Masoud villages is taken as a case study.

The objectives of the study:

- Selection PV parameters of off-grid and on-grid PV systems.
- Perfuming feasibility analysis of using on-grid and off PV systems in West bank (Masoud village as case study)
- Provide Economic evaluation of supplying Masoud village by on-grid and off -grid PV system.
- Investigate the policy of PV systems in West Bank for consumers who own renewable energy facilities.

Methodology:

To achieve the objectives of this study, the following matrix is adopted:

- Illustrates the energy situation in West Bank and the main barriers for the promotion of renewable energy .
- Analysis of the resource potential in WB.

  - Definition of several scenarios of possible applications in electrification remote area in WB.
  - Description of the typical applications associated to each scenario.
  - Calculation the cost of energy of each typical application.
  - Designing of PV power system for electrification of Masoud village.
  - Evaluation the economic and environmental impacts of On grid and off-grid PV System.
- Analysis for the policy of on-grid tariffs such as net metering or feed in tariff systems.
- Analysis for the impact of subsides on the feasibility of RE system in Palestine.

1.2 Literature Review

Many works have been carried out pertaining to techno-economic feasibility analysis of solar photovoltaic power generation. A complete techno-economic feasibility of energy supply of remote villages in Palestine by PV systems, diesel generators and electric grid has been done [1]. A computer-aided dynamic economic evaluation method with five indicators is used to compare the economic effectiveness of PV energy systems and the results showed that utilizing PV systems for rural electrification in Palestine is more feasible than using diesel generators or extension of the high voltage electric grid.

Similarly a techno-economic assessment of an autonomous hybrid PV/diesel for a tourist resort in Elounda has been done [4].The different economic and financial aspects have also been calculated for different financial scenarios and concluded that the use of solar energy supply systems imply no compromise for the tourists in terms of reliability of operation and facilities compared with conventional lodging and renewable systems provide alternative solutions to the increasing global energy-demand problem [5].

Techno-economic viability of hybrid photovoltaic diesel battery power systems for residential loads in Saudi Arabia has been presented [6]. The analysis highlights several benefits of the hybrid system such as high utilization rate of PV generation; optimal satisfaction of load; maximum diesel efficiency with minimum maintenance; reliable power supply; and a reduction in the capacities of PV, diesel and battery while matching the peak loads. Emphasis has been placed on excess electricity generation, percentage fuel savings and reduction in carbon emissions for different scenarios.

The economic feasibility of standalone PV system in comparison to the most likely conventional alternative system has been analyzed for energy demand through sensitivity analysis and the analysis shows that PV-powered systems are the lowest cost option at a daily energy demand of up to 15 kWh[7].

A complete techno-economic analysis of standalone solar photovoltaic system has presented [9]. Complete analytical methodology for optimum relationship between PV array and storage battery capacity to supply the required energy at a specified energy load fraction is carried out. The techno economic optimization of a PV system has been done by using levelized energy cost computation based on the total number of battery replacements through battery lifecycle model [10].

The techno-economic analysis of grid connected hybrid wind/PV system is carried out for three different locations in Iraq, and it was observed that total amount of energy generated from wind and solar is highest for one location and less for the rest two and it is concluded that in case of solar and wind plant location strongly affect the plant performance [11].

In [12] the electrical energy demand of the Government Technical College, Wudil Kano was estimated based on watt-hour energy demands. An off grid PV system was designed based on the estimated load. Based on the equipment selected for the design, the cost estimate of the system is relatively high when compared to that of fossil fuel generator used by the college. The payback period of the system is estimated to be 2.8 years, which is obviously much shorter than the lifespan of the selected PV modules.

A net present value comparison have been performed for north Cameroon between Photovoltaic hybrid system for mini grid application, standalone photovoltaic and standalone diesel generator options for a typical energy demand [13].

A economic comparison of PV/Diesel hybrid power system with battery storage in comparison to diesel generated electricity for a village is performed and found that the hybrid system is more economical in comparison to the diesel only system to meet the energy requirement of a small village located in the north eastern part of the Kingdom and it was observed that the existing diesel generation system is economical as the diesel prices is 0.2 US $/Litre. With increasing fuel price to 0.60 US$/Litre and above, the diesel only system became uneconomical compared to that of hybrid power system [14].

A complete techno-economic comparison of rural electrification based on solar home systems and PV micro-grids to supply electricity to rural community for domestic purpose has been performed [15]. It is concluded that a micro grid might be a financially more attractive option for the user, energy service company and the society if the village has a large number of households, is densely populated and lies in a geo-graphically flat area whereas in rough areas solar home systems might be a better option if the community is small and sparsely populated.

The economic analysis has been performed on the grid connected SPV system connected to the Spanish grid [16]. Using net present value and payback period parameters, the profitability of the system was studied. The system was evaluated for its economic as well as environmental benefits and the results showed that the system is beneficial enough to be invested in, but very long pay back periods were dissuading the investors.

The techno-economic assessment has been performed to determine the technical feasibility and economic viability of a hybrid solar/wind installation to provide residences in Greece with thermal and electrical energy [17]. The energy output of the hybrid system was estimated using a simulation model and economic analysis is performed using Life Cycle Cost method and the payback period.

A strong case of standalone PV systems has been built by conducting feasibility study in an island of West Bengal India based on socio-economic and environmental aspects. The generation costs of standalone PV systems and conventional power has been compared to show how conventional power systems suffer from diseconomy when power needs to be transmitted to extremely remote locations [18].

Chapter Two

Energy Situation and Renewable Energy Potential and Strategy in West Bank.

2.1 Introduction:

The word's energy demands are still largely depend on fossil fuels such as coal, oil and natural gas. If energy consumption continues to increase at current rates, energy supply will be a serious global challenge in the near future. The world total primary energy supply in last year's growth at a high rate. Therefore, many countries have made enormous efforts to develop and utilize alternative sources of energy, particularly renewable ones, in order to meet their growing energy demands and protect the environment from greenhouse gases emitted from conventional energy sources and also to achieve sustainability in the long term [2].

Palestine territories is one of these countries where an alternative sources of energy must be sought for because of the challenges arising mainly from the complete dependency on Israeli energy to satisfy the demand for energy and electricity. As a result, Israel controls the quantity and quality of energy that Palestine imports. Accordingly, the cost of electricity in WB is relatively higher than most countries in the region due to the fact that electric power that is consumed in the West Bank is purchased from Israel through agreements. According to these agreements, Israel has the right to shut down the power supply to any Palestinian city or village that exceeds the specified peak limit. Many cities and villages in the West Bank suffer from blackouts for many hours at peak days, especially in summer. In addition to that, there are some villages that are still not having any access to electricity in Palestine because these villages are far from electric grid and because of the cost of utility transmission lines for grid- ties [1]. These rural villages fill this gap by using noisy, polluting diesel generators.

Using renewable energy in West Bank and the possibility of connecting them to the grid can offer many benefits including the reduction of conventional energy, consumption, reducing the unwanted environmental impacts and achieving sustainable development [2].

2.2 Energy situation in West Bank

West Bank depends almost on Israeli Electrical Company (IEC) for electricity supply; nearly 97% of the electric needs in the West Bank is supplied by IEC while the remaining are imported from Jordan through 33 kV medium voltage connection to supply Jericho district. The West Bank is mainly supplied by three 161/33 kV substations; one in the south in area C close to Hebron, a second in the north in the Ariel settlement close to Nablus, and a third in Atarot industrial area near Jerusalem. Electricity is supplied to the centre of the West Bank largely through Jerusalem Distribution Electrical Company (JDECO) through 33 kV and 11 kV distribution lines at several connection points with the IEC including, Ramallah Jericho, Bethlehem and the eastern part of Jerusalem [19].

The maximum capacity of electricity supply to the West Bank is about 650 MVA, 40% directly by IEC which supplies electricity to 215 towns and villages, and 60% indirectly by IEC through JDECO which supplies electricity to East Jerusalem and to 165 towns and villages in the West Bank [2].

Concerning the interconnection with Jordan, the Palestinian National Authority (PNA) has signed an agreement with Jordan on a 132 kV interconnection, but the Israel as an occupation power rejects the crossing over borders reducing the voltage to 33 kV with a maximum capacity of 20 MW [3].

Four distribution utilities are currently responsible for more than 85% of the electricity distribution system in West Bank:

- JDECO Company services East Jerusalem and the central WB.
- HEPCO Company covers the Hebron area in the southern part of the W.B.
- SELCO Company covers the remaining southern WB.
- NEDCO is being established to serve the northern WB.

Technical performance of the electric utilities

Palestinian do not have any control of the supply over the transmission or the distribution lines that extend from the 161 kV substations and its control normally begins after the connection point with these feeders. these connection points which mixed between LV and MV are metered for billing purposes by IEC to the utilities and municipalities.

The Palestinian utilities can only extend the MV network and install transformers and LV lines. The inability to extend the MV and LV networks has contributed to high voltage drop and high technical and non-technical losses [19].

It can be concluded that the characteristics of electrical energy in Palestine are [22]:

- Electrical Energy represent one- third of total energy consumed as shown in figure (2.1)

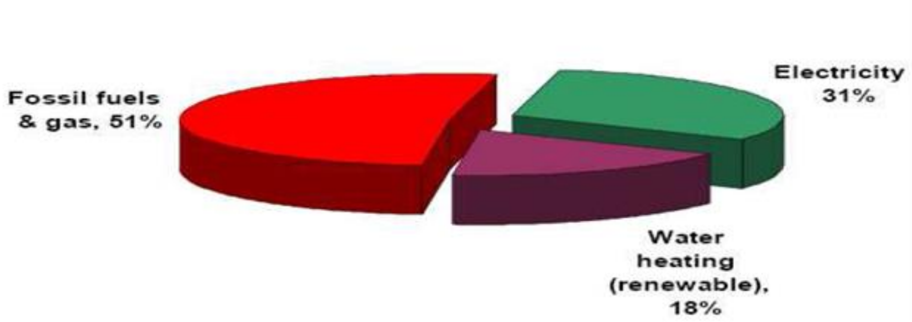

Figure (2. 1): Consumption of Energy in West Bank

- Fully dependent on the IEC.
- The percentage of housing-related public network for electricity 99.2%, and that 0.5% of homes connected to generators while 0.3% are not connected to the electricity service.
- High rate of electricity losses.
- Most of renewable energy contribution is thermal.
- Three fourth of consumption is domestic.
- High growth of electricity consumption and insufficient quantity.
- High tariff imposed from the IEC compared with neighbor countries.
- Large number of distributors (municipalities and companies).
- The absence of a unified electrical system.

Therefore there are many constraints of the electricity Sector in WB which can be summarized as follow [22] :

- Lack of local production capacity to meet the needs of the local market power

- Israeli Occupation
- Absence of an integrated electrical system.
- Large number of electricity distributors, which makes it difficult to control and reorganization
- The delay in completion of distribution companies, which must operate the system according to the specifications and appropriate standards.
- Lack of legislation and laws regulating renewable energy
- The delay in approving a national strategy to promote the use of renewable energy.
- High price of renewable energy systems, which weaken the desire of government agencies to invest in this sector.
- Government deficit and the private sector to invest in renewable energy research
- Lack of knowledge and training

Support schemes to encourage the use of renewable resources in West Bank.

A clear complete and general policy for development renewable sources is still undeveloped. The main policy barriers for the promotion of renewable energy in WB Include [20]:

- Lack of legal and institutional frameworks, including a Renewable Energy Law with the official measures for promotion RE sources.
- Lack of incentives and proper financing schemes.

- High political risk in implementing RE projects. This leads to desertion of the local and international investments and the external financial aids to participate in the development process. This barrier is the most critical; the occupation of the Israeli army along different Palestinian territories difficult the development of large renewable power plants.

2.3 R.E. potential in West Bank

Renewable energy is energy that is derived from natural processes that are renewed constantly. In its various forms, it derives directly or indirectly from the sun, wind, biomass, geothermal, hydropower, ocean energy, bio-fuels and hydrogen derived from renewable resource [21].

Renewable energy is important for Palestine Territories, both for energy security reasons as well as for improving economic conditions. The main renewable energy sources considered to have potential in Palestine are solar energy, wind energy, biogas and biomass.

2.3.1 Solar energy

West Bank has high potential of solar energy. It has around 3000 sunshine hours / year and high annual average solar energy radiation.

figure (2.2) depicts the graphical results of the correlation data analysis for jenin ground station. The figure also shows that the different series of data do not present significant differences between satellite data and ground measurements.

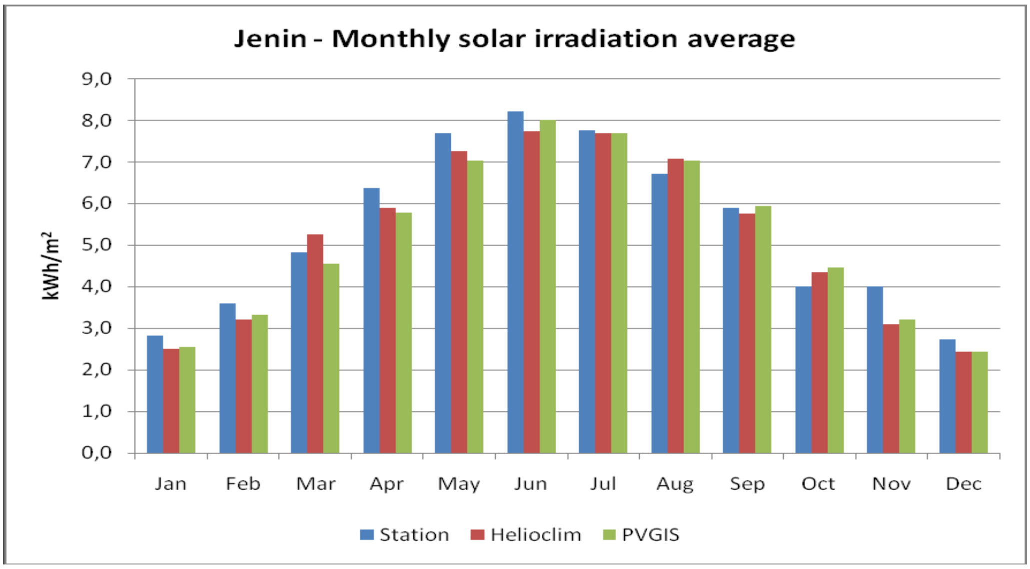

Figure (2. 2): Jenin –monthly solar irradiation average

The following table shows the solar radiation data from jenin station in tabular form.

Table (2. 1): solar radiation in jenin

Month	E kwh/m²-day	Month	E kwh/m²-day
JAN	2.82	JUL	7.75
FEB	3.58	AUG	6.7
MAR	4.82	SEP	5.83
APR	6.36	OCT	3.99
MAY	7.67	NOV	3.99
JUN	8.19	DEC	2.72

The above table shows that the average solar radiation varies by season: it reaches 2.72 kWh/m^2 in December and 8.19 kWh/m^2 in June.

In conclusion, on average Palestine has a solar global horizontal irradiation of 5,4kWh/m^2/day, which yearly stands for about 1900 kWh/m^2. The high values of solar radiation encourage the use of solar energy for different applications such as water heating, water desalination, water pumping and electrification of remote villages which is far from the grid [3].

Palestine is one of the leading countries in using solar water heaters for house applications according to the Palestine Central Bureau of Statistics, approximately 67% of Palestinian homes use solar water heaters [22].

2.3.2 Wind energy

Measured data already reveals a moderate wind potential, with some sites in the hilly region in the middle of the WB recording wind speeds above 5m/s. A wind atlas have been made for Palestine which shows more details about wind potential in Palestine for designing and planning new project activities for potential and future investments. The long-term wind velocity measurements and the longer the period of collected wind data are the more reliable to estimate wind potentials in Palestine. Therefore, there are modern meteorological stations were installed in WB by Energy Center at An-Najah university. As shown in table (2.2), Palestine has moderate wind speeds which may encourage Palestinian using wind energy in standalone systems to provide small electricity loads, such as for water pumping [3].

Table (2. 2): Average Wind Speed in Jenin

Month	Vw m/s	Month	Vw m/s
JAN	4.47	JUL	5.48
FEB	3.66	AUG	4.94
MAR	4.16	SEP	4.57
APR	3.83	OCT	3.82
MAY	4.42	NOV	2.86
JUN	5.26	DEC	3.76

2.3.3 Biomass

Palestine has a strong potential for biomass energy because it is known, historically, for its agriculture which is still a predominant economicactivity .As a result People living in rural areas may benefit from producingbiomass energy in various forms, including wood, crop residues and biogas [23].

Biomass is considered as a strategic energy resource since it may be grown almost anywhere and it contributes to environmental protection. Accordingly, if Biomass is utilized properly, it may become one of Palestine's major energy resources. Currently, biomass energy constitutes approximately 15% of Palestinian energy supply, and it is mainly used for heating purposes. At present, no crops are grown in Palestine specifically for use as fuel [24].

2.3.4 Biogas

Biogas is a clean source of energy with a high calorific value. It can be used for heating purposes, it can be converted to electricity and feed the grid, and it can be used as fuel in vehicles. Biogas can be produced from various agricultural, industrial and municipal organic waste through the natural, biological process of anaerobic digestion. The anaerobic biogas production processes have low energy requirement for operation, low initial investment cost and low sludge production.

In Palestine there is a vast number of animals according to Palestinian Central Bureau of Statistics, the number of animals in West Bank is illustrated in table (2.3)

The use of organic waste for these animals in biogas production would not only provide energy but it would also eliminate the harmful effects of this type of waste on the environment and public health when disposed of without treatment [25].

Table (2. 3): Number of animals in West Bank

2008	2007	2006	2004	Animal
32.986	34.255	36.284	33.746	Beef
688.899	744.764	793.874	803.165	Sheep
322.082	343.565	387.123	371.198	Goat

Table (2.4) shows the potential quantity of biogas production from the manure of animals. Thus, with this high potential of biogas, it could be met the cooking energy needs for the rural population. In addition, the biogas production could provide nitrogen-enriched bio-fertilizer to improve the fertility of agricultural lands [24].

Table (2. 4): Potential gas from animal

Table : Calculation of Biogas From Animal Waste , 2008					
Animal	Count	Weight, kg/one	total W in Kg	dry dung/day	biogas production m3/day
Beef	32 986	320	10 555 520	91 837.67	26 724.76
Sheep	688 899	40	27 555 960	239 749	69 766.96
Goat	322 082	35	11 272 870	98 078.94	28 540.97
Total					125 032.69

There were some small projects for producing gas for cooking at the college of Agriculture at An-Najah National University, in Jericho and in Izbt Shufa but Presently, no projects in this technology are working in WB.

2.4 R.E. Applications in West Bank

The inclusion of RE in the generation mix may provide several advantages in the development of Palestine: The security of supply and the possible deployment of national manufacturers for the different technologies are envisaged as the most interesting contributions of RE development. The main renewable source considered to have potential for expansion is mainly solar. Currently, and due to its cost-effectiveness rate, solar water heating systems presents in more than two-third of Palestinian households without government incentives [22].

the implemented renewable energy projects in Palestine are:

- Wind Potential for Power Generation in Palestine: The idea of this project was to studied the possibility of utilizing the wind energy in electric power generation in Palestine: the study includes the measurement of wind velocity and direction as well solar radiations in some promising sites in West Bank, analyzing these measurements and evaluation of the results to determine the potential of such a renewable energy in the selected areas[25].
- Electrification of small clinics located in non-electrified remote villages, clinics in eight remote villages were installed with photovoltaic power generation systems [26].
- Biogas digester in Tulkarem: Construction of a biogas digester in the Faculty of Agriculture/An Najah National University in Tulkarem for scientific and teaching purposes. The system demonstrates the possibility of producing biogas from Cow dung which could be used

for cooking and lighting purposes. The project was implemented in cooperation between ERC at An Najah University and the Agricultural Relief which also covered the costs [27].

- Rural electrification with Microgrids with Solar Hybrid Generation (MSG) in the community of Atouf, and Emnazeil villages in West Bank- Palestine. These projects were carried out within AZAHAR Program, implemented by SEBA association –Spain and ERC [28] .
- A 300 kWp of PV is implemented in Jericho, and the project is funded By JAICA [28].
- The GEF/ UNDP project also financed photovoltaic systems for electrification of a small Bedouin community and to light a bridge in Gaza [25].
- A small wind turbine with capacity of 1kW and solar PV system with capacity of 5 kWp installed as a hybrid power station, funded under the GEF small grants programme provides power to the 100 residents of Innab Al-Kabeera on the West Bank [25].

The total installed capacity of PV system in Palestine is about 5Mw peak[26]. Another project that combines the innovative capability of the private sector in Palestine with donor funding is the geothermal system that has been developed by the Ramallah based Union Construction and Investment Corp. (UCI). This project was implemented in cooperation with the Palestinian Energy Authority (PEA) and supported by the EU-financed project MED-ENEC, but the original idea came from the UCI, which was focused about the implications for energy use of the expansion of urban development around Ramallah. The private company won a competition for access to EU funds [25].

2.5 Targets and strategy of renewable energy in West Bank

Electricity is one of the major problems facing the Palestinian Authority specially as the PA imports the majority of its electricity needs .In this case renewable energy is an appropriate option for serving Palestine energy needs and enforce interdependency in Palestine .As Palestine does not have many resources such as gas or fossil fuel, it is even more difficult to achieve energy security for the country. As a result , the Palestinian National Authority in the Energy Sector Strategy 2011-2013 lays out the guidelines for the energy sector strategy detailed for its three components, Petroleum & Gas, Electricity; and Renewable Energy.

Regarding Renewable Energy sources the Palestinian National Authority (PNA) has approved the target to expand renewable energy production in 2020 to 10% of total new power generation. The expected local generation will be 50% of the demand and the RE production shall be 5% of the total electricity consumption in 2020, i.e. 5% of the indigenous generation shall be from RE sources. This is about 240 GWh in 2020 [22].

Palestinian Energy and natural resources Authority for a renewable energy strategy appeared from the fact that Palestine is abounds with Renewable energy sources for electricity generation that are not being used due several reasons like the absence of legal framework .Moreover, with the expected growth in electricity consumption in WB, renewable energy facilities are needed to help achieve security of supply .PENRA's have set three main goals of RE strategy:

1. Sustainable use of RE in Palestine.
2. Reaching rational levels of energy independence and security of supply.
3. Achieving social and economic development in Palestine.

PENRA focused on Solar energy technology and set up the Palestinian Solar Initiative (PSI) in summer 2012 as Solar energy is the RE application that is more convenient to Palestinian circumstances.

According to the Palestinian Energy Authority, the technology for solar energy generation was ready and the allocation of incentives for private sector investment in renewable energy has been approved by the Palestinian Authority. The project will include the installation of hundreds of on-grid Photovoltaic Panels, several Wind system, supply of concentrated solar readers to update the Palestinian solar ATLAS necessary for designing and planning new project activities for potential and future investments. The project will also contribute to raising awareness, and achieving clean and secure energy for Palestinians [25].

Table (1.5) illustrates the plan of the implementation of the initiative ,we can coclude that the initiative’s target is to achieve 20MW of solar renewable energy up to the year 2020 through installing PV panels at the rooftops of Palestinian households all over the West Bank.

Table (2. 5): strategy for renewable energy in West Bank.

RE Technology	2015 Capacity (MW)	2020 Capacity (MW)
On ground PV	5	25
PV small	5	20
CSP	5	20
Biogas landfill	6	18
Biogas animal	0.5	3
Small-scale wind	1	4
Wind mills	2.5	40
Total (MW)	**25**	**130**

Palestinian Solar Initiative Plan

Location	Installed Capacity (MW)
Northern West Bank	1.5
Central West Bank	2.0
Southern West Bank	1.5
Total (MW)	5

2.6 Summary

From the previous topics, the main constraints for RES expansion in Palestine are the current high costs of these systems, the absence of specific regulations to release financial and technical barriers for RES usage, the lack of qualified human resources for constructing ad maintaining RES systems and the lack of sustainable funding for the promotion of RES usage.

The high prices of petroleum products, which are imported from Israel and the abundance of solar radiation (5.4 kWh/ m2/day) are conducive to PV electrification especially in remote areas.

Chapter Three

Possible Scenarios of Small Rural Areas Electrification

3.1 Introduction

Some villages and small communities in Palestine territories are still suffering from lack of electricity as they are far away from electrical network. In general three possible scenarios may be applied to solve the problem of un-electrified villages which are:

1.Connecting the village or communities with the closest electrical network.

2. Using PV system configuration.

3.2 Connecting the village or communities with the closest electrical network.

In fact this is the best scenario but economical and political problems are encountered. Transmission lines system are designed to transport large amounts of electric power, usually expressed in watts or kilowatts, over long distances [1].

The principle elements of the electrical grid are[27]:

1. **Supports**: are generally steel tower or trusses and provide support to the conductors ;the number of the needed towers and trusses depend on the distance between the village and the nearest tower assuming that the span equals 100 m for MV.

2. **Conductors**: carry electric power from the sending end to the receiving end, the usual material is aluminum reinforced with steel. A three conductor ACSR 50mm2 for three phase lines, and a conductor ACSR 35mm2 for neutral line are usually needed, and their length depend on the distance between the village and the nearest tower,
3. **Insulators**: are attached to supports and insulate the conductors from the ground; the number of insulators for towers are at least 5 insulators and the number of insulators for trusses are at least 3 insulators.
4. **Cross arms**: provide support to the insulators, and every insulator has one cross arm.
5. **Step-up and step-down transformers:** are at the sending and receiving ends respectively; there are different capacities of transformers;150kVA ,250kVA,400kVA and 600kVA
6. **Protective devices**: these are ground wired, circuit breaker and isolator switch.

3.3 Using PV system configuration

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. There are two principle classifications of PV's system: the first is off-grid or Stand Alone Systems and the second is on-grid or grid connected .

3.3.1 Off-Grid system configuration

An off-grid solar system or standalone is designed to operate independently of the electric utility grid, to supply certain DC and/or AC electrical loads for rural areas that have no access to the grid. To ensure the access to electricity at all times, battery storage and a backup generator are used but batteries are expensive and decrease overall system efficiency. The charge controllers limit the rate of that current which is delivered to the battery bank and protect the batteries from overcharging. Figure (3.1) shows that the electrical current that flows from the PV array through the charge controller and the battery bank before it is finally converted into AC by the off-grid-inverter; Off-grid inverters do not have to match phase with the utility sine wave as opposed to grid-tie inverters [29].

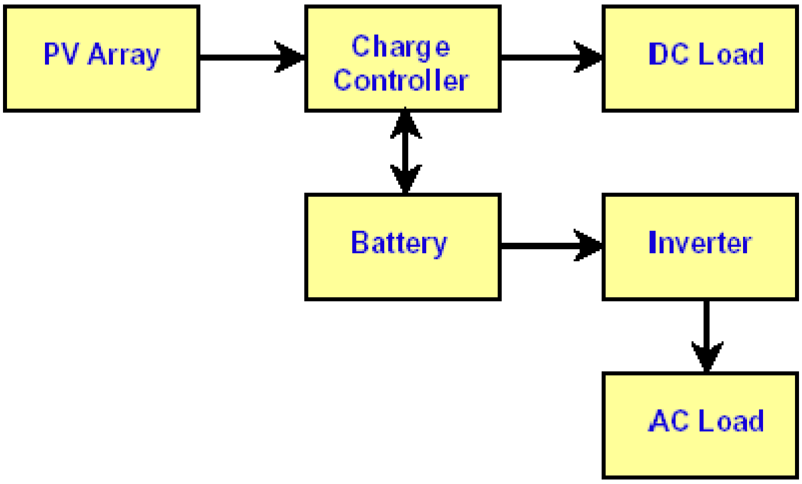

Figure (3. 1): configuration for standalone system

Standalone PV systems can be designed as:

1) DC_ decentralized PV power system:

The simplest type of standalone PV system is a direct-coupled system, where the DC output of a PV module is directly connected to a DC load as shown in figure (3.2). In direct coupled system the load only operates during sunlight hours Since there is no electrical energy storage.This type is suitable for common applications such as ventilation fans, water pumps, and small circulation pumps for solar thermal water heating systems [26].

Figure (3. 2): direct coupled system

2) AC_ decentralized PV power systems:

These kinds of systems are designed for each house alone , but such a system needs inverter to supply AC loads since most of appliances are AC .

3) AC_ centralized PV power systems:

This kind of systems is usually used to electrify small villages far away from the grid with small distances between their houses.

These systems need a mechanism of transmission components with transmission conductors, protective devices, poles and other needed components, and need a large area to be set up.

3.3.2 On grid system configuration

PV systems are designed to operate interconnected with the electric utility grid. The primary component in grid-connected PV systems is the Grid Tied Inverter (GTI). A bidirectional 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 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. As shown in figure (3.3) step-up dc–dc converter boosts the array voltage to a higher level and the GTI 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 [27].

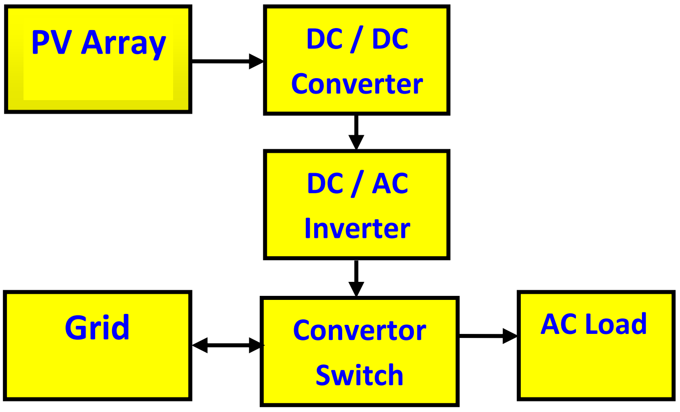

Figure (3. 3): configuration of grid tied system

3.3.3 Hybrid system configurations

Hybrid solar systems combines the best from grid-tied and standalone PV systems. These systems can either be described as off-grid solar with utility backup power, or grid-tied solar with extra battery storage as shown in figure(3.4).

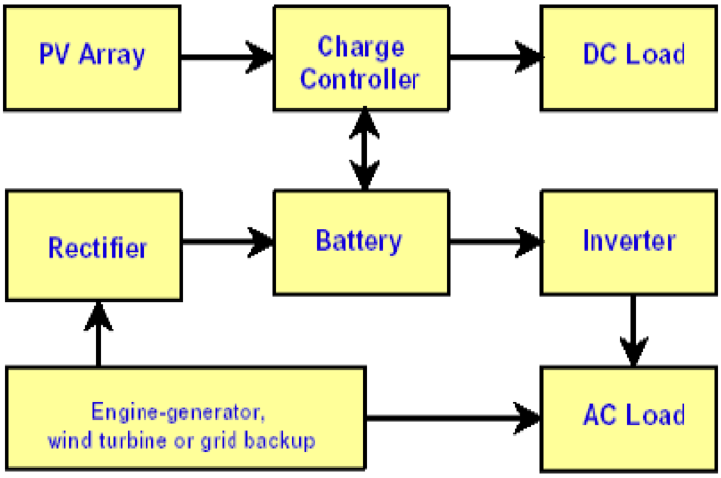

Figure (3. 4): configuration of hybrid solar system

Hybrid solar systems are less expensive than off-grid PV systems because the capacity of the battery bank can be downsized.

In this system you can temporarily store whatever excess electricity from the solar panels in batteries, and put it on the utility grid at maximum peak. Hybrid solar systems utilize battery-based grid-tie inverters. These devices combine can draw electrical power to and from battery banks, as well as synchronize with the utility grid [27].

3.4 Comparison between on-grid and off grid PV systems

Advantages and Disadvantages of On-Grid and Off-Grid Solar Systems [29]**:**

Advantages of an Off-grid System

- It is more ideal for remote areas where connecting to the utility grid is expensive.
- There will be no electrical bills.
- Electricity can be obtained in most emergency situation.

Disadvantages of an Off-grid system

- Adding batteries to a system comes with several disadvantages ; Batteries consume energy during charging and discharging which reduce the efficiency and output of the PV system and increase the complexity of the system because the cost and the installation costs are increased. Also batteries will usually need to be replaced before other parts of the system and at considerable expense.
- Electrical consumption must be carefully planned.
- The off-grid system mostly include a backup generator which is expensive and require maintenance.

Advantages of On-Grid System:

- Reducing the electricity bill because it enables the beneficent to sell excess power back to the grid at high rate and buy it back at night at a lower rate. A grid-connection will enable the beneficent to save more money with solar panels through net metering.
- No need for expensive batteries and generator and that reduces the cost of maintenance; therefore generally it is cheaper and simpler to install.
- It is flexible system; the user always connected to local grid regardless of bad weather, so electricity can be obtained from the utility grid if the solar system output is reduced or stopped.
- The electric power grid works as a battery, without the need for maintenance or replacements, and with much better efficiency rates. In other words, more electricity goes is wasted using conventional battery systems.

- The average annual electricity transmission and distribution loss is about 7% of the electricity that is transmitted. Whereas Lead-acid batteries, which are commonly used with solar panels, are only 80-90% efficient at storing energy, and their performance degrades with time.
- Additional benefit of being grid-tied include access to backup power from the utility grid in case the solar system stop generating electricity for some reasons. At the same time grid -tied system minimizing the utility company`s peak load. As a result, the efficiency of the electrical system will be increase.

Disadvantages of On-Grid System:

- The user will get a power outage when utility power goes out and your solar system also shuts down because there is no battery backup.
- The cost of utility line extension for grid- ties.
- The user are still using non-renewable resources when there is no solar.
- The bad impact of PV solar system to the electrical network (quality of the signal).

3.5 Summary

The technology of off-grid and on-grid system was introduced in this chapter. the pros and cons of each type was also mentioned. Each system has its own application and is selected based on several factors, including having access to the grid.

Chapter Four

Sizing of PV System and components

4.1 Selection of photovoltaic modules

A solar PV system is powered by many crystalline or thin film PV modules. Individual PV cells are interconnected to form a PV module. The PV modules are next connected in series into a PV string and the PV array is formed by the parallel aggregation of PV strings to achieve the desired voltage and current.

PV cells are made of light-sensitive semiconductor materials that use photons to dislodge electrons to drive an electric current. There are two broad categories of technology used for PV cells, namely, crystalline silicon which accounts for the majority of PV cell production; and thin film, which is newer and growing in popularity.

The most obvious difference amongst PV cell technologies is in its conversion efficiency, as summarized in Table (3.1).

Table (4. 1): conversion efficiencies of various PV module technologies

Technology	Module Efficiency
Mono-crystalline Silicon	12.5-15%
Poly-crystalline Silicon	11-14%
Copper Indium Gallium Selenide (CIGS)	10-13%
Cadmium Telluride (CdTe)	9-12%
Amorphous Silicon (a-Si)	5-7%

Another important differentiator in solar PV performance, especially in hot climates, is the temperature coefficient of power. PV cell performance declines as cell temperature rises as shown in figure (4.1).A PV module data sheet should specify the temperature coefficient. For crystalline silicon the temperature coefficient is -0.4 to -0.5%/C^0.

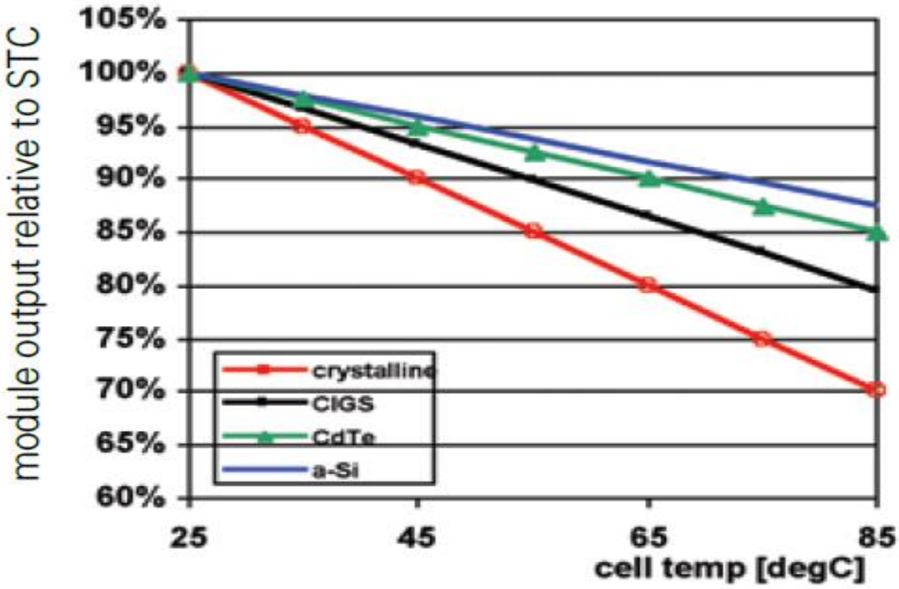

Figure (4. 1): The effect of a negative temperature coefficient of power on PV module performance

After the module type was selected, the next step is to determine the number of modules we need and how they are connected. Number of module are determined according to the size of the system in on grid since the system does not have to provide 100percent of the energy requirements. while in off-grid system number of module is depend on the requirements of the load.

The peak power (Wp) of the PV generator is obtained from the equation (4.1):

$$P_{PV} = \frac{E_L}{\eta_V \eta_R PSH} S_f \qquad \textbf{(4.1)}$$

Where

E_L : Energy consumption per day

η_v: Inverter efficiency

η_R : Charge controller efficiency(in standalone system)

PSH : the peak sun hours

S_f: the safety factor (in grid tied it not necessary to put safety factor).

The number of necessary PV modules is obtained as:

$$No._{PV} = \frac{P_{PV}}{P_{mpp}} \quad \textbf{(4.2)}$$

The number of modules in series (N_S) is determined by dividing the designed system voltage V System (usually determined by the battery bank or the inverter) and the nominal module voltage V_{Module} at standard test conditions (STC).

$$Ns = \frac{VSystem}{VModule} \quad \textbf{(4.3)}$$

And the number of string can be calculated by dividing number of module on the number of modules in series.

4.2 Selection of Charge Controller

A charge controller is only necessary in standalone systems (with battery back-up). The main function of a charge controller is to prevent overcharging of the batteries and over-discharging. In addition, charge controllers prevent charge from draining back to the PV modules at night. Some modern charge controllers include maximum power point tracking, which optimizes the PV array's output to increase the energy it produces[30].

Charge controllers are selected based on the following factors:

- PV array voltage : The input voltage of the charge controller must match the nominal voltage of the PV array.
- PV array current : The charge controller must be sized to handle the maximum current produced by the PV array multiplied by 1.25.

4.3 Selection of Battery Bank

Batteries store direct current electrical energy to use it when there is no solar radiation in standalone PV system. Since batteries reduce the efficiency and output of the PV system, Batteries also increase the complexity and cost of the system.

Types of batteries commonly used in PV systems are:

- Lead-acid batteries
- Alkaline batteries

Lead-Acid Batteries: Lead-acid batteries are most common in PV systems in general sealed lead acid batteries are most commonly used in grid-connected systems. Sealed batteries are spill-proof and do not require periodic maintenance. Flooded lead acid batteries are usually the least expensive but require adding distilled water at least monthly to replenish water lost during the normal charging process.

Alkaline Batteries: alkaline batteries are only suggested where particularly cold temperatures are predictable. The advantages of alkaline batteries include tolerance of freezing or high temperatures, low maintenance requirements, and the ability to be fully discharged or over-charged without been damaged.

The PV array must have a higher voltage than the battery bank in order to fully charge the batteries. Higher voltages may be required for long wiring distances between the modules and the charge controller and battery bank.

Sizing Battery Banks: battery banks for off-grid systems are usually sized for one to three cloudy days. The storage battery can be calculated using the following equation (4.4):

$$C_{Ah} = \frac{1.5 \times E_L}{V_B \times DOD \times \eta_B \times \eta_V} \quad (4.4)$$

$$C_{wh} = C_{Ah} V_B \quad (4.5)$$

Where:

V_B: voltage of battery block.

DOD: the permissible depth of discharge rate of a cell.

η_B: efficiency of battery block.

η_V: efficiency of inverter.

4.4 Selection of inverter

Inverters used in PV systems to convert the DC power coming from the PV modules or battery bank to AC power, to ensure that the frequency of the AC cycles is 50Hz, THD<3% and to reduce voltage fluctuations and ensuring that the shape of the AC wave is a pure sine wave for grid-connected systems.

The following factors should be considered for a grid connected inverter:

- The voltage of the incoming DC current from the PV array or battery bank.
- The DC power of the PV array
- The quality of the inverter, such as high efficiency and good frequency and voltage regulation.
- Maximum Power Point Tracking (MPPT) capability.

The inverter's DC voltage input must match the nominal voltage of the PV array for systems without batteries and for standalone system, the input of inverter have to be matched with the battery block voltage.

Grid-connected inverter are sized according to the power output of the PV array, rather than the load requirements of the village. While the nominal power for off-grid inverter is selected according to the maximum load (P_n=1.2*$P_{max,load}$).

Output of the inverter should fulfill the specifications of the electric grid of the village specified as: 220 V; 50 Hz sinusoidal voltage. Modern inverters have peak efficiencies of 92 percent to 94 percent while Inverters for stand-alone systems have slightly lower efficiencies.

Grid tied inverters include maximum power point tracking; MPPT automatically adjusts system voltage such that the PV array operates at its maximum power point. For stand-alone systems, this feature has recently been incorporated into charge controllers.

4.5 Selection of Cables

A solar cable interconnects solar panels and other electrical components of a photovoltaic system. Solar cables are designed to be UV resistant and weather resistant. It can be used within a large temperature range.

The PV generator consist of individual modules connected by solar cables. The module cables are connected into a string which leads into the generator junction box, and a main DC cable connects the generator junction box to the inverter. The positive and negative cables are laid separately in order to eliminate the risk of ground faults and short circuits.

Proper wire sizing depends on the current that will be carried by the wire, 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 circuits must thus be capable of carrying 156% of the short circuit current [31].

4.6 Disconnects

Automatic and manual safety disconnects protect the wiring and components from power Surges and other equipment malfunctions. They also ensure that the system can be safely shut down and system components can be removed for maintenance. For grid connected systems, safety disconnects ensure that the generating equipment is isolated from the grid, which is important for safety.

4.7 Evaluating a Site for Solar PV Potential

The main step in the design of a photovoltaic system is determining if the site are considered has good solar potential. So We must check if the PV system can be oriented for good performance (in Palestine PV module are oriented toward true south) and if the installation site free from shading by nearby trees, buildings or other obstructions. This is because group of cells are wired in series with each other so shading one cell will effectively turn off all the cells in its group. Equation (4.6) below shows the minimum distance of PV arrays should be separated from each other's [28]:

$$x = a\,[\sin\beta \times \tan(23.5+L) + \cos\beta] \quad (4.6)$$

Where: a=length of the PV array (m)

x= the distance between arrays

β=tilt angle

L: latitude

-Tilt Angle: The value of tilt angle depends on latitude of the location and seasonal change. Generally the optimum tilt of a PV array equals the geographic latitude in spring and autumn , In summer the tilt angle should be the latitude minus 10 degrees finally, in winter season the tilt angle should be equal to the latitude plus 20 degrees to achieve yearly maximum output of power. The following table shows the value for tilt angle in West Bank.

Table (4. 2): Tilt Angle in West Bank

Seasonal	**Tilt Angle**
Spring, Autumn	32^o
Summer	22^o
Winter	52^o

PV arrays can include tracking devices that allow the array to automatically follow the sun. Tracked PV arrays can increase the system's daily energy output (E_{dave}) to 5.6 percent. Despite tracking systems increase output power, they increase cost and complexity of the system [28].

- **Required Area** : As a general rule for the, every 1,000 watts of PV modules requires approximately 7-9m^2 of collector area for modules using crystalline silicon. When using less efficient modules, such as amorphous silicon, the area will need to be approximately doubled [30].

Chapter Five

The Economical Analysis of Different Scenarios for Electrification Remote Areas

5.1 Introduction

In this chapter the economic impact of three scenarios to electrify remote areas is analyzed and find which scenario is more suitable economically and what are the criteria for selecting one of these systems. The main objective is to find the best system to electrify remote villages with lower cost and less environment impact by calculate the cost of generated energy for each scenario and make economical comparison between them by using special software.

The prepared software program also analyze the feasibility of using on Grid system in areas where the network is already exist.

The software program is made on visual studio using C# language to analyze PV system using life cycle cost methodology and cost annuity. The algorithm used in this software is shown in figure (5.1),(5.2)and (5.3).

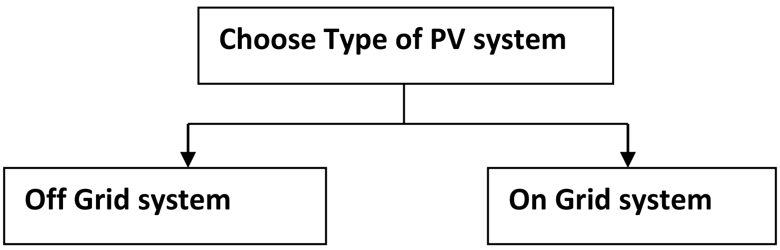

Figure (5.1) : Analysis of PV system

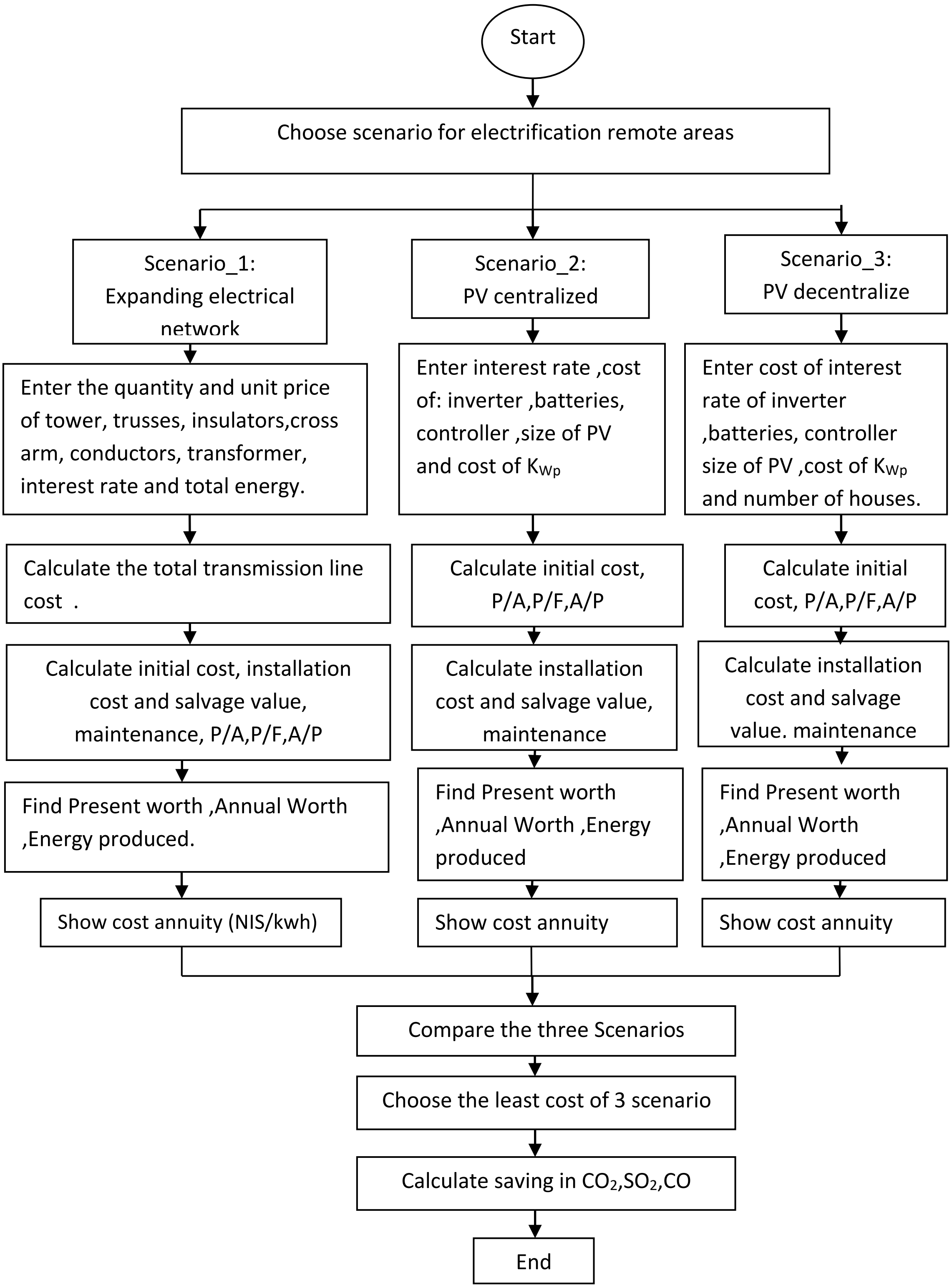

Figure (5.2): Analysis of Off-grid PV system

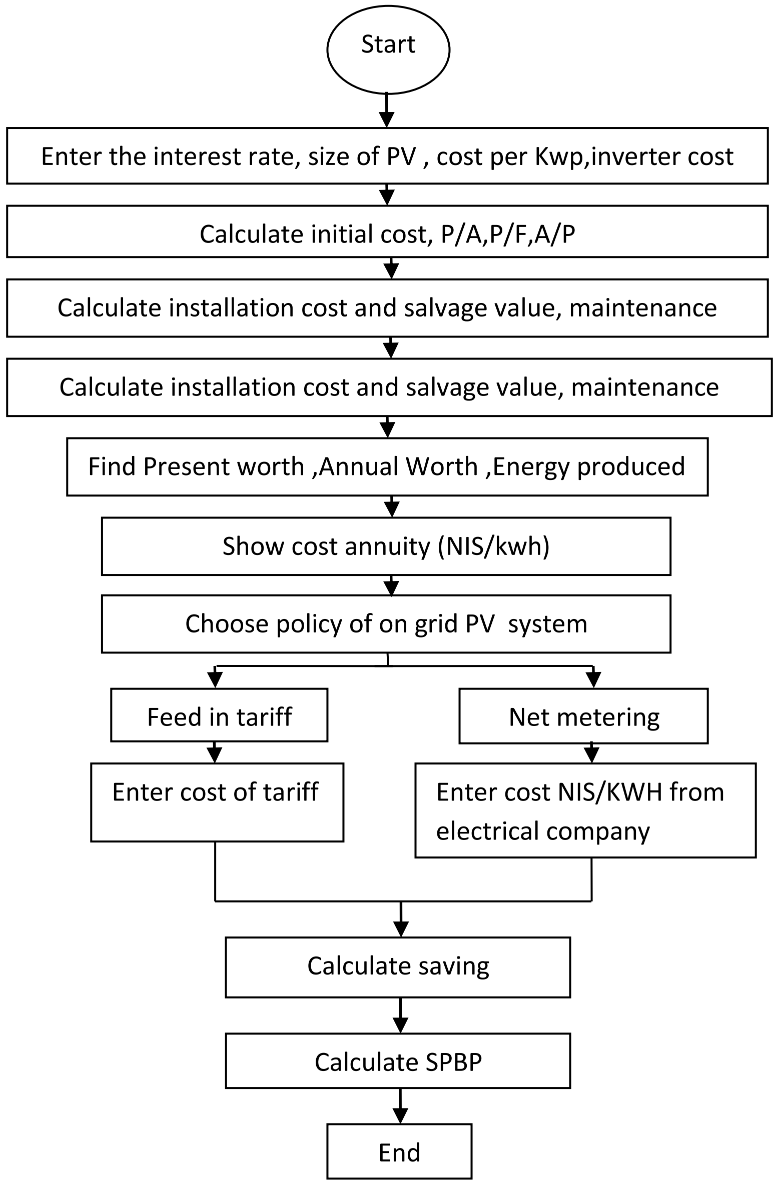

Figure (5.3): Analysis of On-grid PV system

The first window in the program is shown in figure (5.4), when the button of this window is actived, the window in figure(5.5) will be appeared

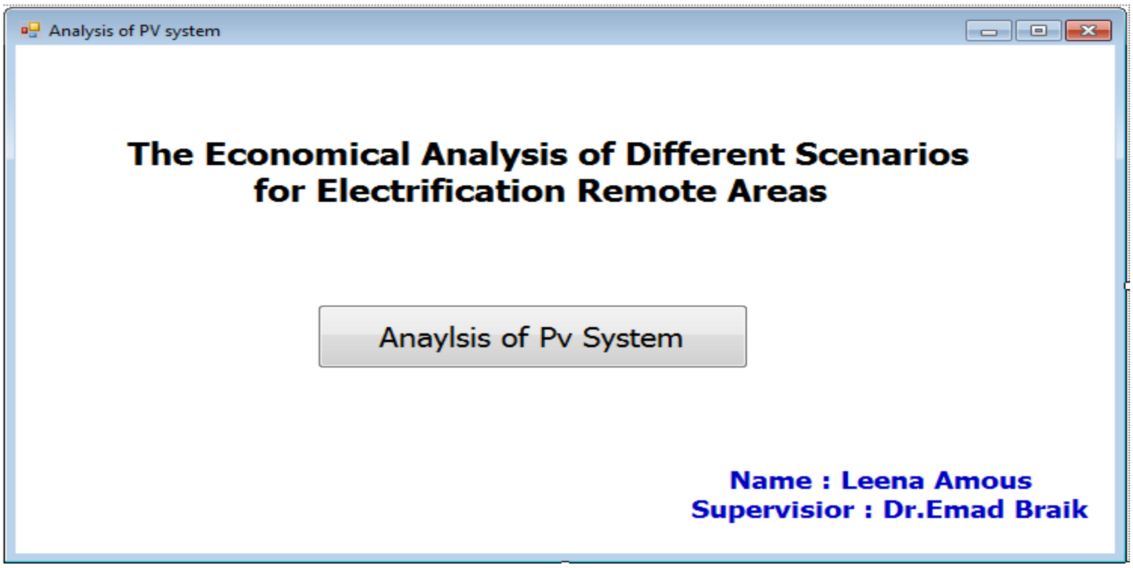

Figure (5. 4): Main form

The second window let us choose type of PV system according to the case we have (if it is off-grid or on-grid).

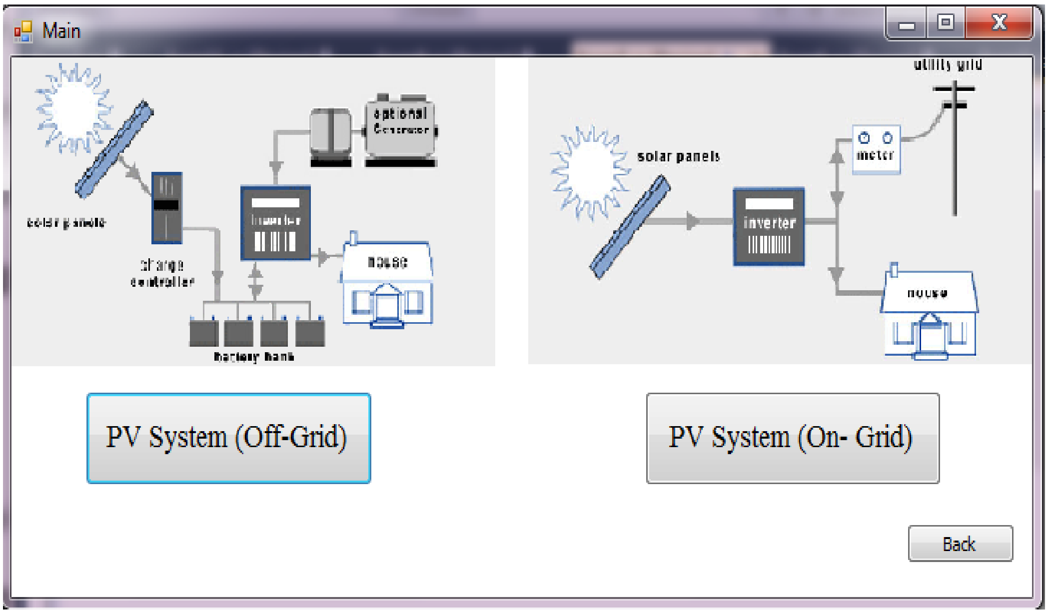

Figure (5. 5): Types of PV system

5.2 Methods of Evaluation

The economic analysis used in this program is based on the use of life cycle cost and cost annuity (NIS/kWh).

The life cycle cost (LCC) is defined as the sum of the present worth of all system components include initial cost, maintenance costs, operation costs, and salvage values.

For all proposed scenarios, the life cycle cost will be estimated as follows:

1- The lifecycle of the system components will be considered as 20 years for PV, Inverter, charge controller and 10 years for batteries.

2- The interest rate is about 10%.

5.2.1 Life cycle cost analysis

In order to calculate the equivalent uniform annual series (Aw) of any cash flow, first we must convert everything to a present worth.

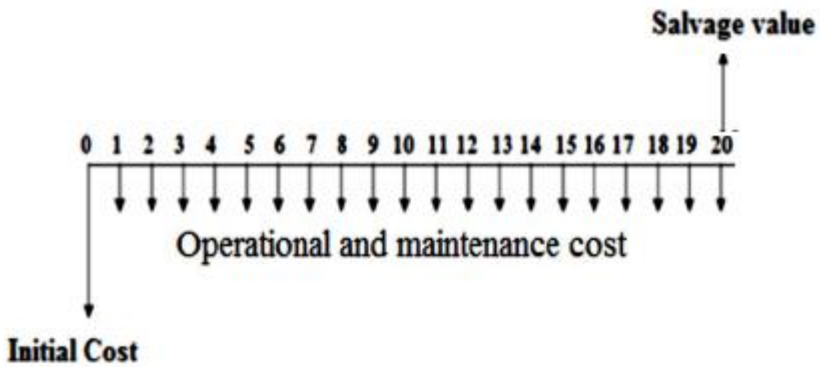

Figure (5. 6): The cash flow which represent initial, operational cost and salvage revenue

The life cycle cost = initial cost + present worth of maintenance and operation – present worth of salvage value.

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

The life cycle cost = initial cost of the system+ maintenance and operation * (P/A, i, n) – salvage value * (P/F, i,n).

Where:

-The term A (P/A, i, n) is called the uniform-series present worth which 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 this term can be found by equation(5.1)

$$(P/A,\ i\ ,n\ )=\left[\frac{(1+i)^{n}-1}{i(1+i)^{n}}\right] \tag{5.1}$$

-The term F (P/ F , i , n) is known as the single-payment present worth factor which determines the present worth P of a given future amount F after n years at interest rate i, and (P/F) can be found by equation (5.2):

$$(P/F,\ i,\ n)=\left[\frac{1}{(1+i)^{n}}\right] \tag{5.2}$$

Tables of factors values have been prepared for interest rates from 0.25 to 50% and time period from 1 to large n values to simplify the routine engineering economy calculations involving the factors.

The equivalent annual worth AW is obtained by using the factor A/P, as follow:

$$AW = PW\ (A\ /\ P,\ i\ ,\ n) \tag{5.3}$$

• The term P (A / P i ,n), called the capital-recovery factor which 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 equation (5.4)

$$(A/P, i, n)=\left[\frac{i(1+i)^n}{(1+i)^n-1}\right] \quad (5.4)$$

Then the unit cost of energy can be calculated using equation (5.5).

$$\text{Unit cost} = \frac{Aw}{E/_{year}} \quad (5.5)$$

Where E is the total yearly kWh produced**.**

5.3 Economical evaluation of electrification remote areas

There are three scenarios to electrify rural areas, the first scenario is to expand the electrical network .The other scenarios are proposed to promote renewable energy in rural areas in West Bank by using stand alone PV system (centralized or decentralized). A software computer is used to find out the best scenario in terms of economic through introduced the required data and compare between these scenarios based on calculating the cost of energy from each scenario as shown in figure (5.7).

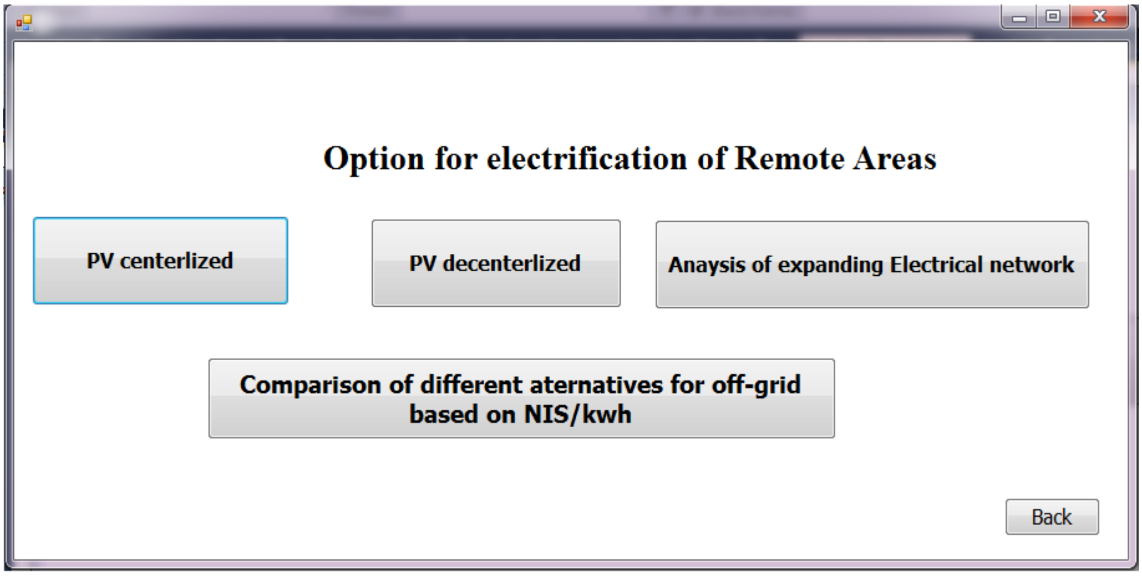

Figure (5. 7): option for electrification of remote areas

5.3.1Economical Analysis of Centralized PV system

The first scenario to electrify remote area is by using centralized PV system .The window shown in figure (5.8) illustrate the cost of component of the system that should be entered and the cost annuity will be appeared in last box using life cycle cost methodology .

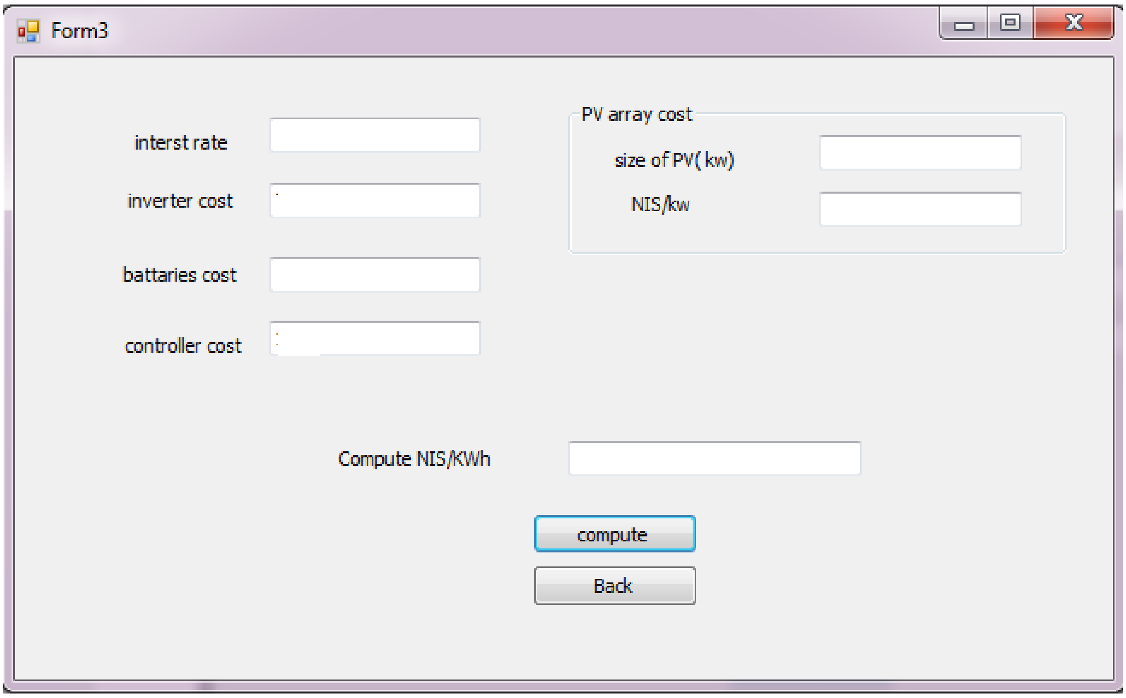

Figure (5. 8): Analysis of Centralized PV system

The mathematical modelling used to calculate the cost of producing one kWh from centralized PV system is as follows:

Fixd cost=PV array cost + first group of batteries cost + inverter cost + controller cost

The initial cost of centralized PV system =fixed cost+installation cost

While:

The installation cost is approximately 0.15 of the Fixed cost for stand alone PV systems.

The life cycle cost of centralized 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.

$(PW)_{Centralized} = P_{PV(kw)}$*NIS/kw + 0.02 *initial cost * (P/A, i,n)- 0.15 * initial cost * (P / F, i ,n)+ second group of batteries cost(P / F, i ,10).

Then the equivalent annual worth AW is obtained with equation (5.3) and the energy unit price calculated from equation (5.5)

Where E is the total yearly kWh produced from the standalone PV system which equal to:

E/year = output power of PV system×PSH×η_{INV}×$\eta_{C.R}$×η_{BAT}× 365(day) (5.6)

Where:

η_{INV}: inverter efficiency

$\eta_{C.R}$: charge controller efficiency

η_{BAT}: battery efficiency

5.3.2 Economical analysis of Decentralized PV system

The second scenario to electrify remote area is by using decentralized PV system. The window shown in figure (5.8) illustrate the cost of component of the system that should be entered and the cost annuity will be appeared in last box using life cycle cost methodology.

The mathematical modeling used to calculate the cost of producing one kWh from Decentralized PV system is the same used in Centralized PV system but here we multiply by the number of houses (n) in the village as follows:

Fixed cost= (PV array cost + first group of batteries cost + inverter cost + controller cost)*n

The initial cost of decentralized PV system =fixed cost +installation cost

The installation cost is approximately 0.15 of the Fixed cost

The life cycle cost of decentralized 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)*n.

$(PW)_{Deceentralized}$=($P_{PV(kw)}$*NIS/kw + 0.02 *initial cost * (P/A, i,n)- 0.15 * initial cost * (P / F, i ,n)+ second group of batteries cost(P / F, i ,10))*n.

Then the equivalent annual worth AW is obtained with equation (5.3) and the energy unit price calculated from equation (5.5)

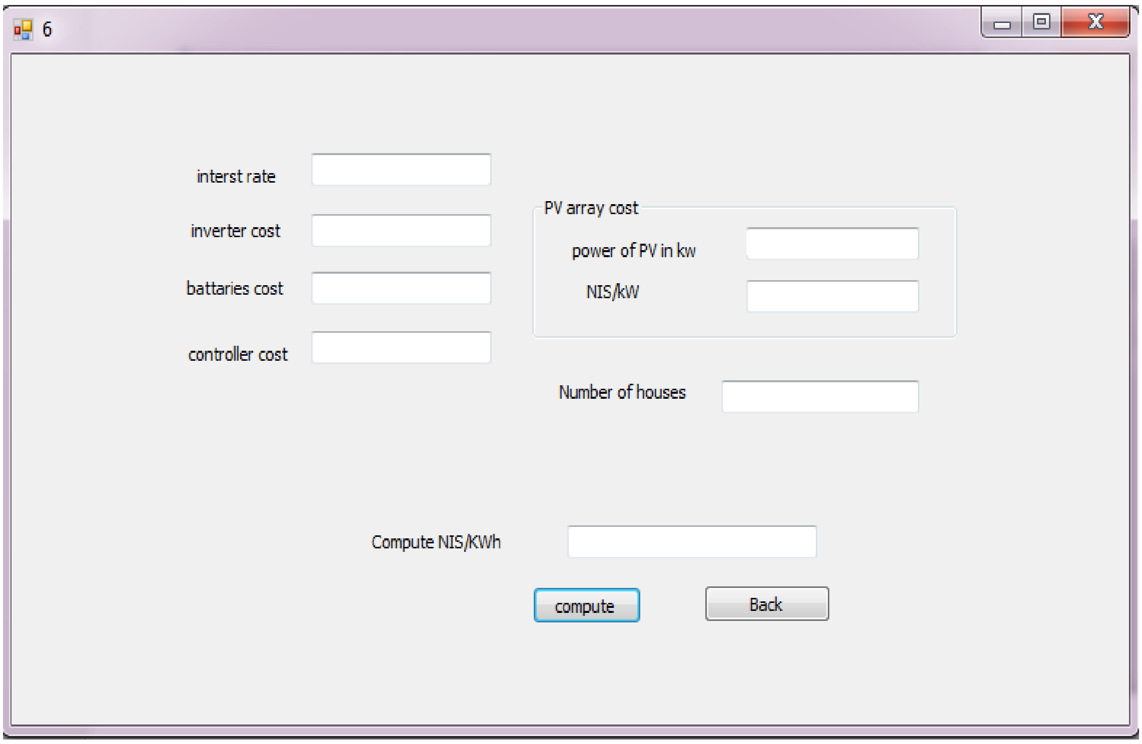

Figure (5.9): Analysis of Decentralized PV system

5.3.3 Economical analysis of expanding electrical network

Figure (5.5) shows the local costs of Transition line system components in detail with the total cost of accessories and works needed to calculate the cost of one KWh.

The life cycle cost of transmission line system = initial cost of TLS +present worth of maintenance– present worth of salvage value after 20 years.

The life cycle cost of transmission line system = initial cost of TLS + maintenance cost*(P / A, i ,n) –Salvage value*(P / F i ,n).

The maintenance cost for TLS during the life time of the system is about 2% of the total TLS cost and Salvage value is taken about 15% from the transmission line system cost

Then the equivalent annual worth AW is obtained with equation (5.3)

The cost of unit kWh from the TLS = (Aw / Total energy consumption) + cost of energy from IEC.

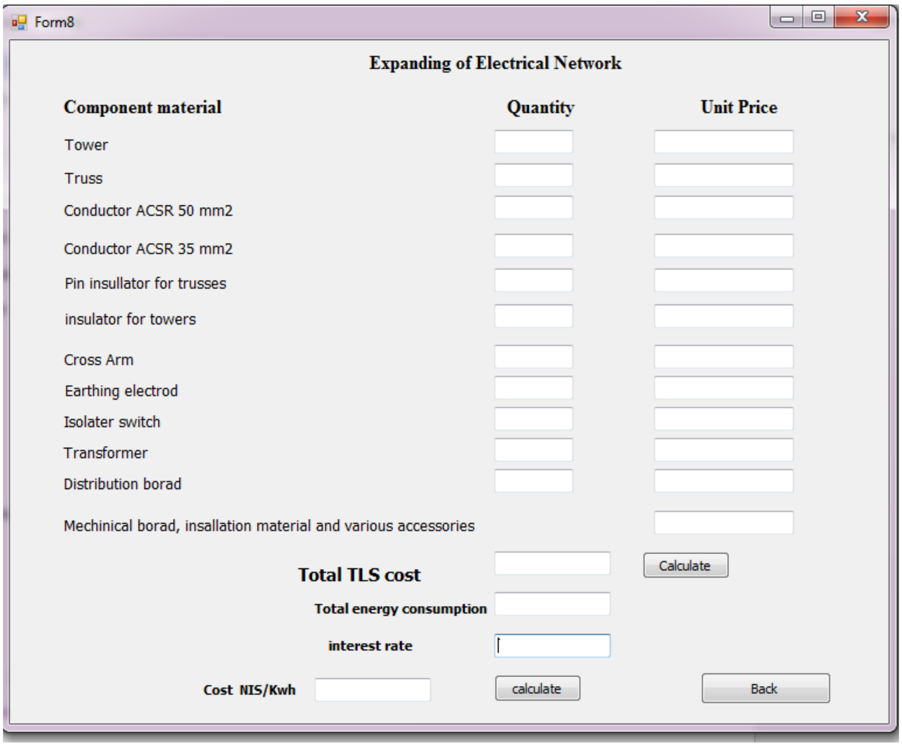

Figure (5.10): Analysis of expanding electrical network

5.4 The Economical Analysis of using on Grid PV system

In the previous section the visibility of electrify off-grid system is studied and in this section the visibility of using On Grid (Grid Tie) system will be studied.

The economic analysis that is used is based on the use of the life cycle cost and the cost annuity (NIS/kWh) as in off-grid system except in grid tie system there is no need for batteries and charge controller in the initial cost. The life cycle cost of grid tie system equal to the initial cost of PV system plus present worth of maintenance and operation minus present worth of salvage value.

Fixed Cost=PV array cost + inverter cost

The initial cost of Grid tie PV system =fixed cost + installation cost

While the installation cost is approximately 0.1 of the Fixed cost for on-grid PV systems.

Where, PV array cost= $P_{PV(kw)}$*NIS/kw

By converting every cost to present worth, the LCC will be as follows:

The life cycle cost of grid tie system= fixed cost + installation cost + Operation and maintenance * (P / A, i,n) – salvage value *(P / F, i ,n).

The equivalent annual worth AW is obtained as in equation (5.3) and the energy unit price calculated from equation (5.5)

Where E is the total yearly kWh produced from the grid tie PV system which equal to:

E = output power of PV system × PSH × η_{INV} x365(day). (5.7)

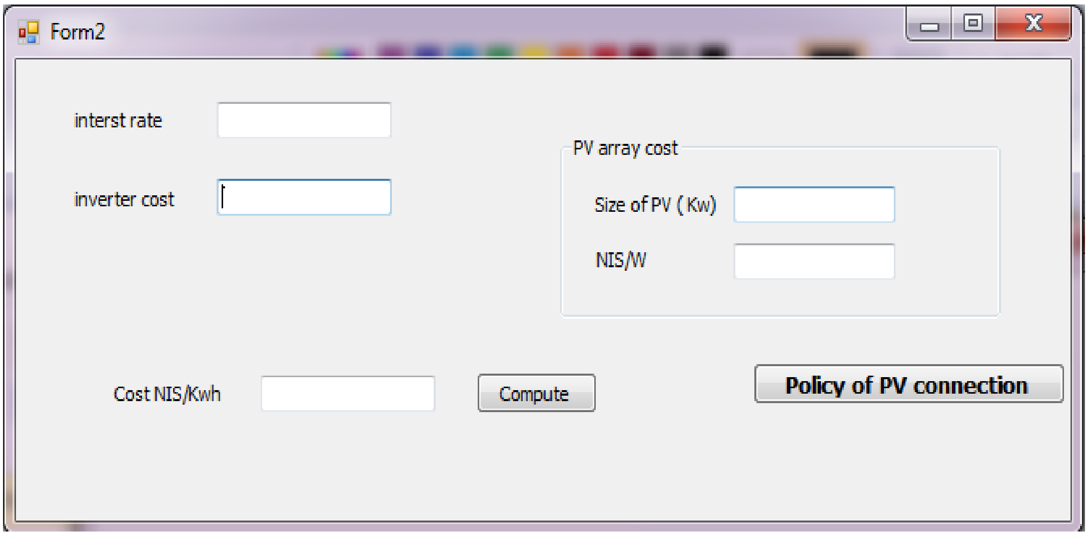

Figure (5.11): Analysis of Grid Tie PV System

5.5 Policy of on grid PV systems

Figure (5.12) shows ways for compensating the electricity delivered to the grid such as net metering or feed-in tariff

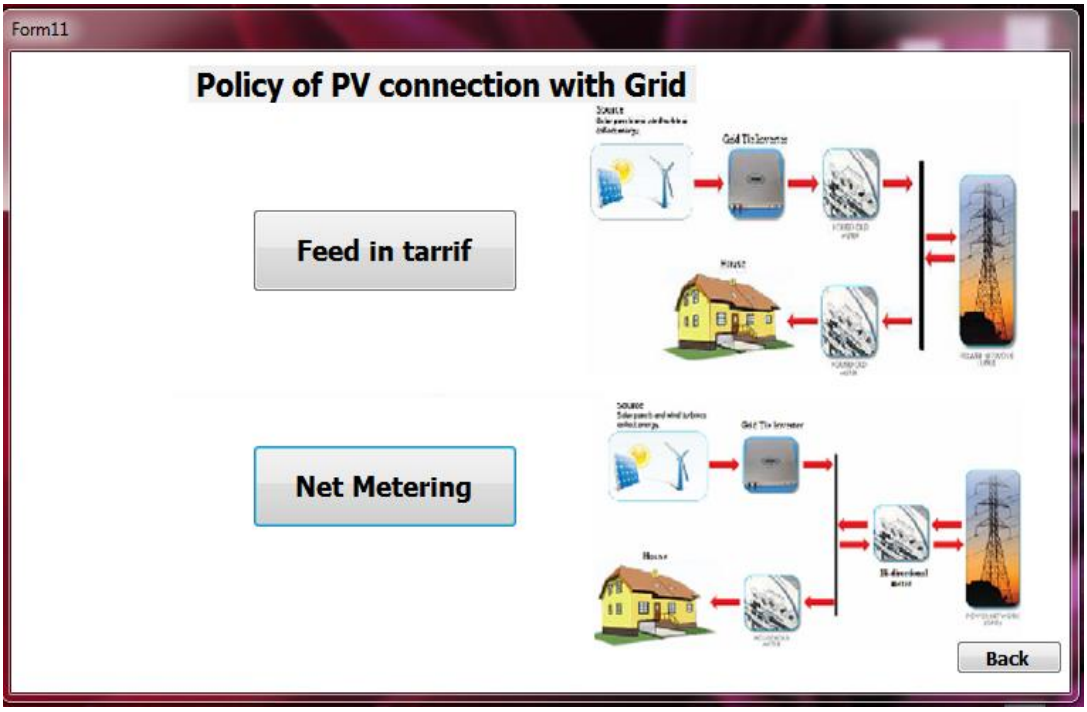

Figure (5.12): Policy of PV connection with Grid

5.5.1 Net metering tariff

Net metering uses a single, bi-directional meter which can measure current flowing in two directions and give the net electricity consumption (the difference of the energy produced from PV system and energy purchased from the grid).If the meter read is negative that means that electricity produced from PV system is more than the consumption of the home, a billing credit is applied to next bill [32].

- Evaluation the Economic Impact of on grid PV system using net metering tariff

In order to evaluate the economic impact for on grid PV system the simple payback period when using net metering and FIT systems should be calculated as shown in equation (5.7).

S.P.B.P = investment / saving (5.7)

to find the annual saving money using Net metering system, the following equation is used:

Annual saving money = Energy generated from PV system*Cost of energy (5.8).

By substituting equation (5.8) in equation (5.7) ,the simple payback period will be shown in the windows in figure(5.11).

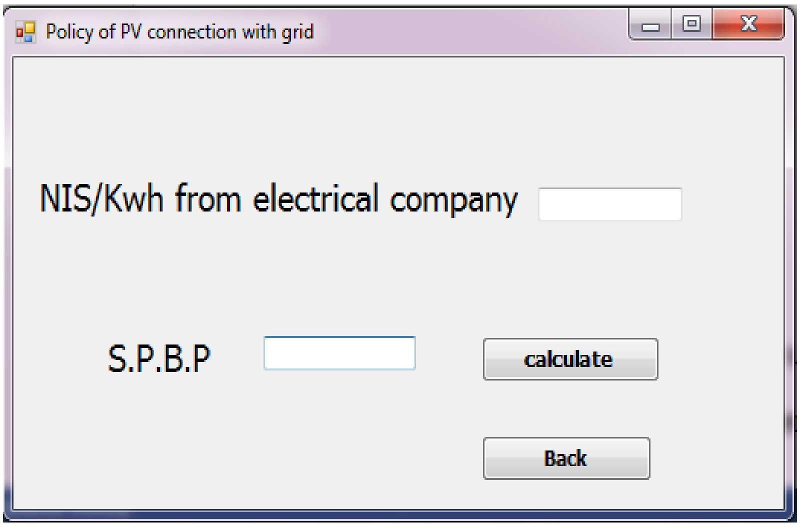

Figure (5.1): the Economic Impact of Grid Tie PV system using Net metering tariff

5.5.2. Feed in tariff

In feed in tariffs two power meters are needed ;one to measure the electricity consumption of home and the other to measure the electricity generated by the PV system .In this way the electricity consumption and the electricity generated can be priced separately.The utility pay for electricity generated by renewable energy at fixed rate through a contract and that give financial incentive to users who generate electricity from renewable energy in order to create a market for renewable energy[32].

- Evaluation the Economic Impact of on grid PV system using feed in tariff

For FIT system the following equation is used to calculate the annual saving money.

Annual saving money = Energy generated from PV system*FIT/KWH (5.9)

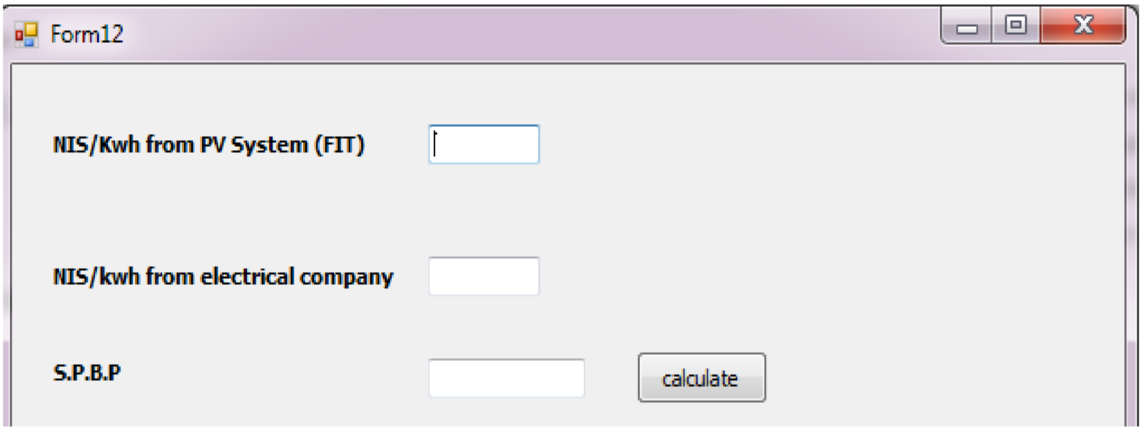

Figure (5.14): the Economic Impact of Grid Tie PV system using FIT

Then the simple payback period can be calculated using equation(5.7) and appear in the last box.

Chapter Six

Assessment of electrification alternatives of small community - Masoud villageas a case study

6.1 Introduction about Masoud Village

The software program introduced in chapter five available for any villages and communities have no access to electricity and Masoud village was found to be our case study to be subjected to a techno-economic analyses study using the software.

Figure (6. 1): Picture of Masoud village

Khirbat Masoud is in west of Jenin district, the nearest city is Yabad and is located about 300 m from the road paved. Location coordinates for Masoud village are as follows: 32º 27’ 0’’N and 35º 6’ 31’’E.

The community of Masoud is composed of 7 households. There is no productive activity other than agriculture. The daily energy needs in such villages are very low. The households use mainly biomass for cooking and baking bread. Most houses of the village have solar water heaters, which is enough to cover the total daily hot water needs.

In order to improve water supply in Khirbet Masoud; with the electrification of the community, users will be able to use individual water pump using electricity generated by solar energy. This water pump will be used to fill up existing water tanks located on the roof of each user's houses.

The main electrical loads in the village are: house hold appliances (lighting, TV, refrigerator, radio, washing machine and fan), street lighting (sodium lamps) and solar water pump[26].

6.2 Potential of Solar Energy of Masoud Village

The solar radiation data has a great effect on the performance of photovoltaic systems. Figure (6.2) shows the monthly values of solar energy.

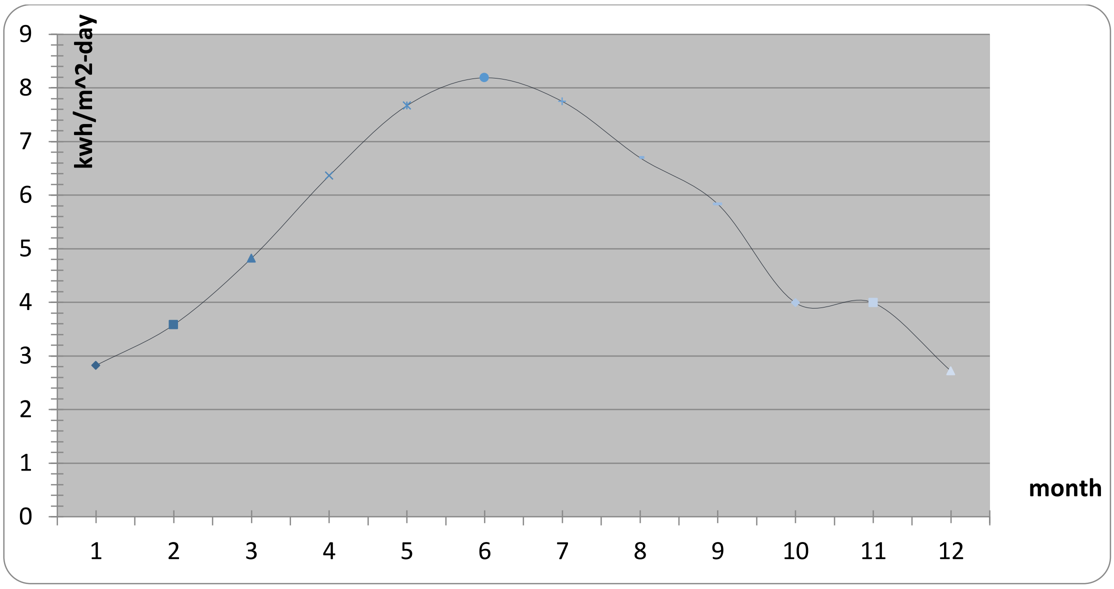

Figure (6. 2): The monthly average value of solar energy in Masoud village .

It is clear from the figure that solar energy in this region is very high during summer months, it exceeds $8kWh/m^2/day$, while the lowest average intensity is during January with a value of $2.72kWh/m^2/day$.

6.3 Option of electrification of Masoud village

6.3.1 Design of centralized PV system components for Masoud village

- **PV generator sizing**

The peak power (Wp) of the PV generator (P_{pv}) is obtained from equation (4.1)

where :E_L(energy consumption per day) = 8.48kWh ; PSH (the peak sun hours) = 5.587 ; η_R(efficiency of charge regulator) = 0.92 ; η_v (efficiency of inverter) = 0.9 ; S_f(the safety factor) = 1.15, substituting these values in equation (3.1) to get the peak power (Wp) of the PV generator one obtains:

Ppv ≈2.9 kwp

To obtain this peak value, we select to install polycrystalline -36 cells module kyocera KD140GH-2PU, which provides 140W nominal maximum power, rated at 12 VDC. The number of necessary PV modules is obtained from equation (4.2)

No PV modules=2900/140≈22

For the design PV system voltage, we will select the PV generator to be 48 V, so number of modules in series is obtained from equation(4.3)

Ns=48/17.7≈3 modules.

And number of strings =$No._{PV}$/Ns=22/3≈8 strings

The actual number of PV generator modules is 3 * 8 = 24modules.

The configuration will be as shown in Figure (6.3). The area of the array is (3*1.5) (8*0.668) = 24.048 m^2

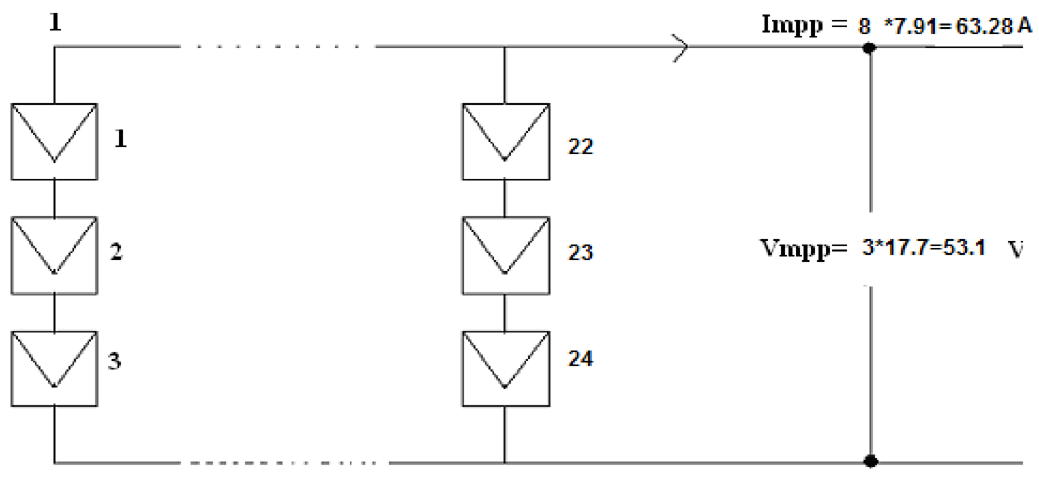

Figure (6. 3): The configuration of the centralized PV generator for Masoud village

The actual maximum open circuit voltage is $V_{o.c}$= 3*22.1 = 66.3 V DC

The actual maximum current short circuit current is $I_{s.c}$= 8*8.68 =86.8A

Accordingly, the voltage and current at maximum power point will be V_{mpp} of 53.1 V DC and I_{mpp} of 55.5 A .

The actual maximum power obtained from PV = 53.1*55.5 = 3 kWp, which is more than the required power needed.

Figure (6.4): PV array for Masoud village

- **Battery block sizing**

A lead-acid battery cell (block type) are selected for centralized PV system for Masoud village. The Ampere hour capacity (C_{Ah}) of the block battery, necessary to cover the load demands for a period of 2 days autonomy is obtained from equation (3.4).

C_{Ah}=2*8475/(48*0.75*0.85*0.9)=615.47

And the Watt hour capacity (C_{Wh}) is obtained as in equation (3.5):

C_{wh}= 615.47 * 48 = 29.542 kwh

We need 24 block batteries in series (each battery rated at 2 V / 1000 Ah) or two strings in parallel, each string of 24 batteries in series (each battery rated at 2 V / 500 Ah) as shown in Figure (6.5) (A) and (B), to build a battery block of an output rated at 48 V DC /1000 Ah .

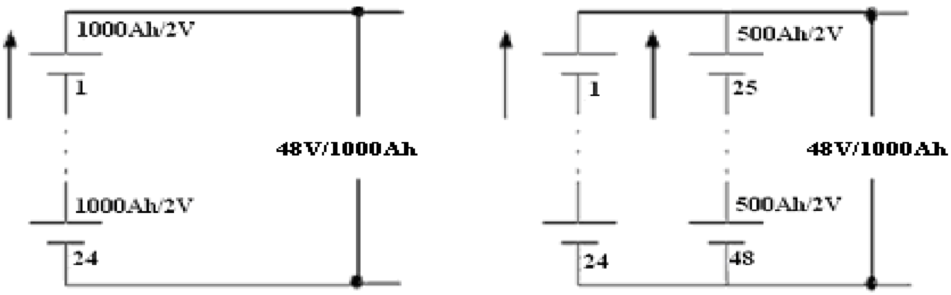

Figure (6. 5): The configuration of battery blocks of the PV system for Masoud village

A 24 Lead acid battery vented tubular 2V /686Ah is used for Masoud village as shown in figure(6.6).

Figure (6.6): Battery blocks for Masoud village.

- **Charge regulator sizing**

⁕ The appropriate rated power of CR, must be equal to P_{PV}= 3 kw.

⁕ The efficiency must be not less of 92 %.

The charge controller can be chosen to handle 1.25xIs.c =69.2Aof the array and to maintain the system voltage in the range of 48V, the appropriate rated power is 3kW.

- **Inverter sizing**

  * Input voltage has to be matched with battery block voltage (V_{input}=48v)
  * Output should fulfill the specification of the electric grid of the village specified as: 230VAC ± 5%, single phase 50 HZ, (sinusoidal wave voltage) [24].
  * Power of inverter: *P nominal* ≈3kW
  * The efficiency must be not less than 90 %
  * Inverter with nominal power 4000VA and voltage 48V DC /230V AC is used for Masoud village as shown in figure (6.7).

Figure (6.7): PV component for Masoud village.

The cost of each element is introduced in figure (6.8) according to their designed size as shown above.

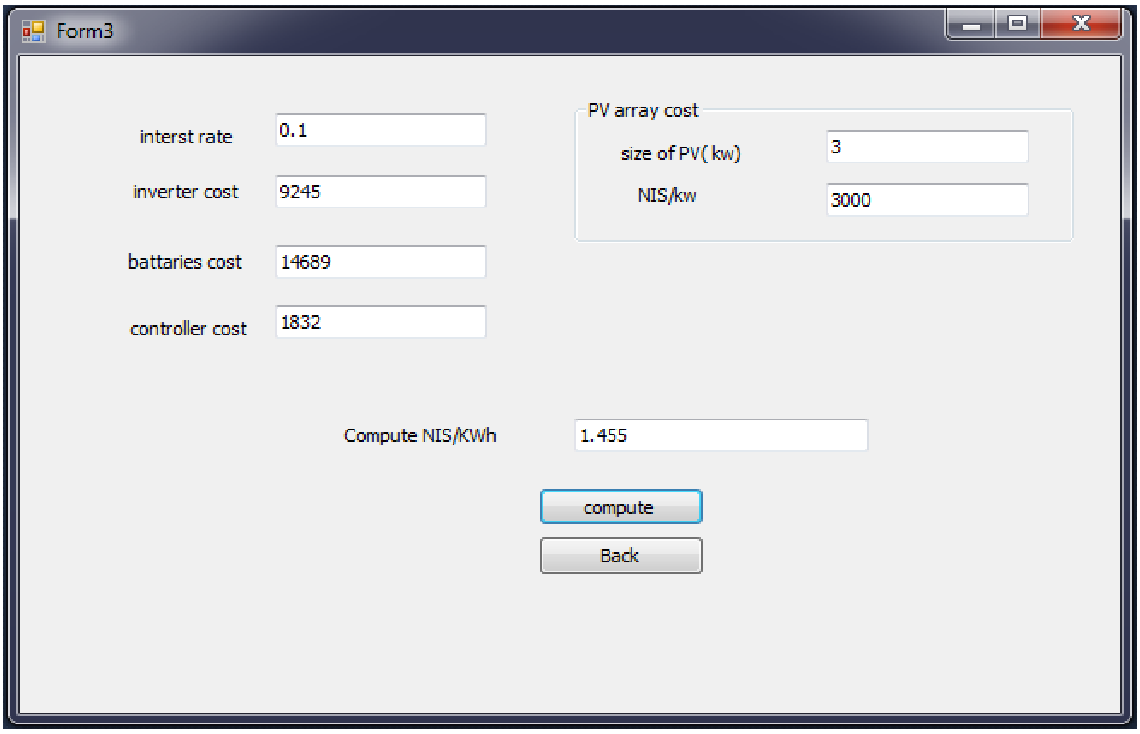

Figure (6. 8): Analysis of centralized PV system for Masoud Village

After running the window shown in figure (7.5) the cost of producing one kWh from centralized PV system is 1.455 NIS.

6.3.2 Design of Decentralized PV System Components for Masoud Villages

Since the houses of Masoud village are almost similar to each other's, we take one of these houses and according to its electrical load, we can calculate of the peak power (W_P) of the PV generator (P_{PV}) for one house to be the same for other houses. From equation (3.1) we obtain:

$P_{PV} = 1210.7*1.15/0.9 * 0.92 * 5.587 = 300.98Wp$

To obtain this peak power, we select the same module as in centralized PV system.The number of necessary PV modules is obtained from equation (3.2) to be:

No. $_{PV}$= 300.98Wp /140W≈2 PV modules

We select the voltage of the PV generator to be $V_{nominal}$ =24V, so number of modules in series is obtained from equation (3.3) to be:

Ns= 24/17.7 ≈2 modules

And number of strings =1

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

The configuration will be as shown in Figure (6.9). Area of the array is 2*1.5*0.668= 1.002 m²

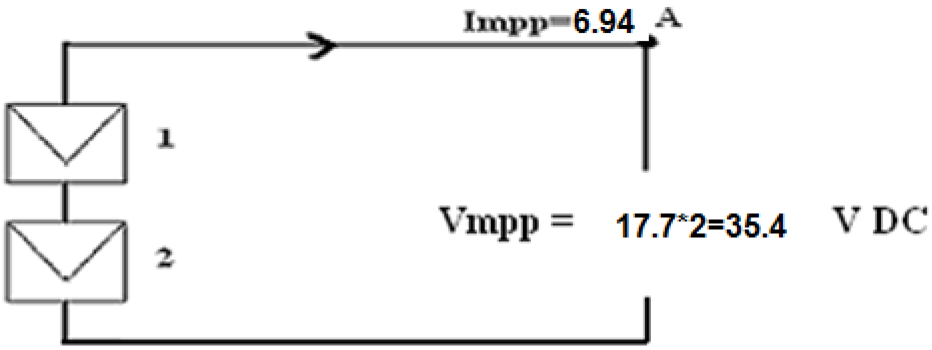

Figure (6. 9): The configuration of the PV generator for a typical unit of decentralized PV system

The actual open circuit voltage *V o.c* = 2*22.1 = 44.2 V DC

The actual short circuit current I_{sc}= 1*8.68 = 8.68 A

Accordingly, the voltage and current at maximum power point will be V_{mpp} of 35.396 V DC and I_{mpp} of 6.94 A.

The actual maximum power obtained from PV = 35.396*6.94 = 245.79Wp.

Which is less than the peak power P_{PV},so the number of string wil be increased to 2,so we need 4 modules(P=491.6wp).

- **Battery block sizing**

According to equation (3.4), and 2 days autonomy. The ampere hour capacity:

C_{Ah}= 2*1210.7/24*0.75*0.85*0.9=175.85 Ah

And the watt hour capacity is obtained from equation (3.5) to be:

C_{Wh}= 175.85 *24=4.22 kWh

We need 1 regular (lead acid) battery rated at 24 V / 180 Ah or 2 batteries in series (each battery rated at 12 V / 180 Ah) as shown in Figure (6.10) (A), (B), to build a battery block of an output rated at 24 V DC / 160 Ah (12 V / 160 Ah block battery has been selected).

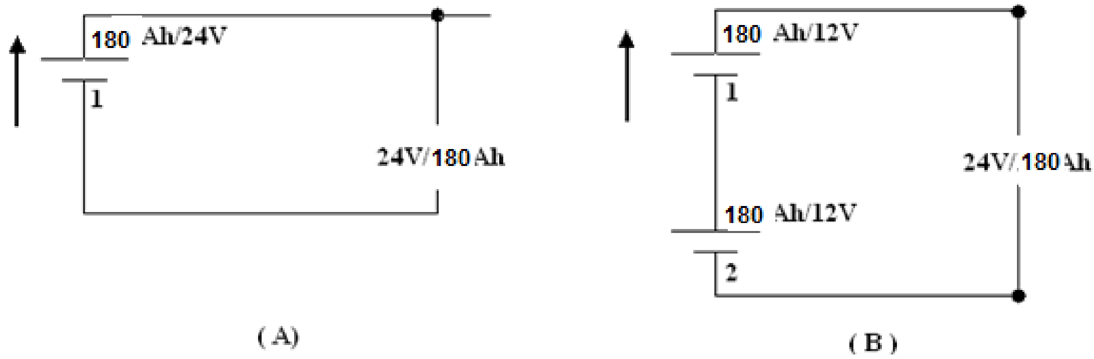

Figure (6. 10): The configuration of battery blocks of the PV system for a typical unit of decentralized PV system.

- **Charge regulator sizing**

-The appropriate rated power of CR, must be equal to P_{PV}= 491W ≈ 500 W.

-The charge controller can be chosen to handle 1.25xIs.c =17.4 A of the array and to maintain the system voltage in the range of 24V, the appropriate rated power is 500W.

- **Inverter sizing:**

  • The output voltage(210-230)V AC, single phase, 50 Hz, sinusoidal wave voltage .

  • The nominal power : *P nominal* =491W ≈ 500 W have been selected for each separated house for Masoud village .

So, we need 7units of 500w inverters for Masoud village**.**

The cost of each element is introduced in figure (6.8) according to their designed size as shown above.

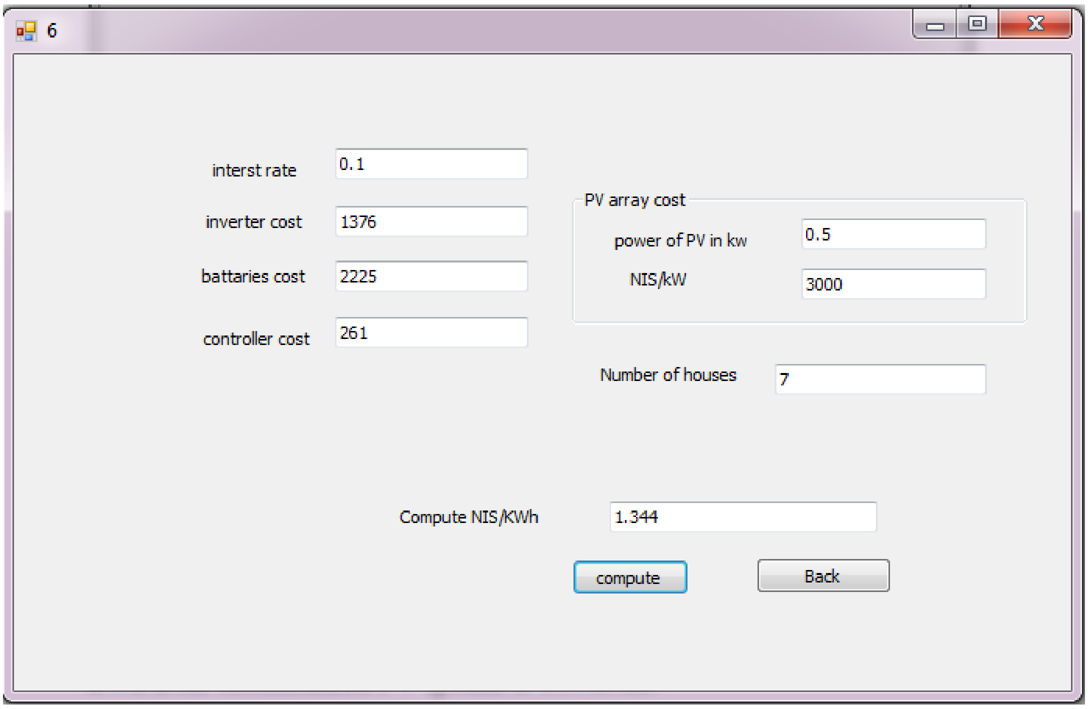

Figure (6. 11): Analysis of Decentralized PV system for Masoud Village

After running the window shown in figure (6.8) the cost of producing one kWh from decentralized PV system is 1.344NIS.

6.3.3 Expanding of electrical network for Masoud village

The last scenario to electrify rural areas is expanding the electrical network.

The principle elements for this option for Masoud village are:

1- **Supports**:

To calculate the number of towers and trusses, assume that the span equals 100m, and the distance between Masoud village and the nearest tower of 33kV is 2km, then:

Number of towers and trusses =2000m/100m =20

The number of trusses = 20 x 3 /4 = 15 trusses with 12m length and the number of towers are 5 with 12m length.

2- Conductors:

The conductor length is 2km from ACSR 50mm2 for phase lines, and 2km from ACSR 35mm2 for neutral line.

3- Insulators:

Number of Insulators for towers (6 insulators) = 5 x 6 = 30 insulators.

Number of Insulators for trusses (3 insulators) = 15 x 3 = 45 insulators.

4- **Cross arms**: Arms for towers = 15, Arms for trusses = 5.

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

6-Earthing electrode =15

After entering the quantity of each elements and its unit price in the window in figure (6.12), the cost of energy can be calculated using life cycle cost methodology.

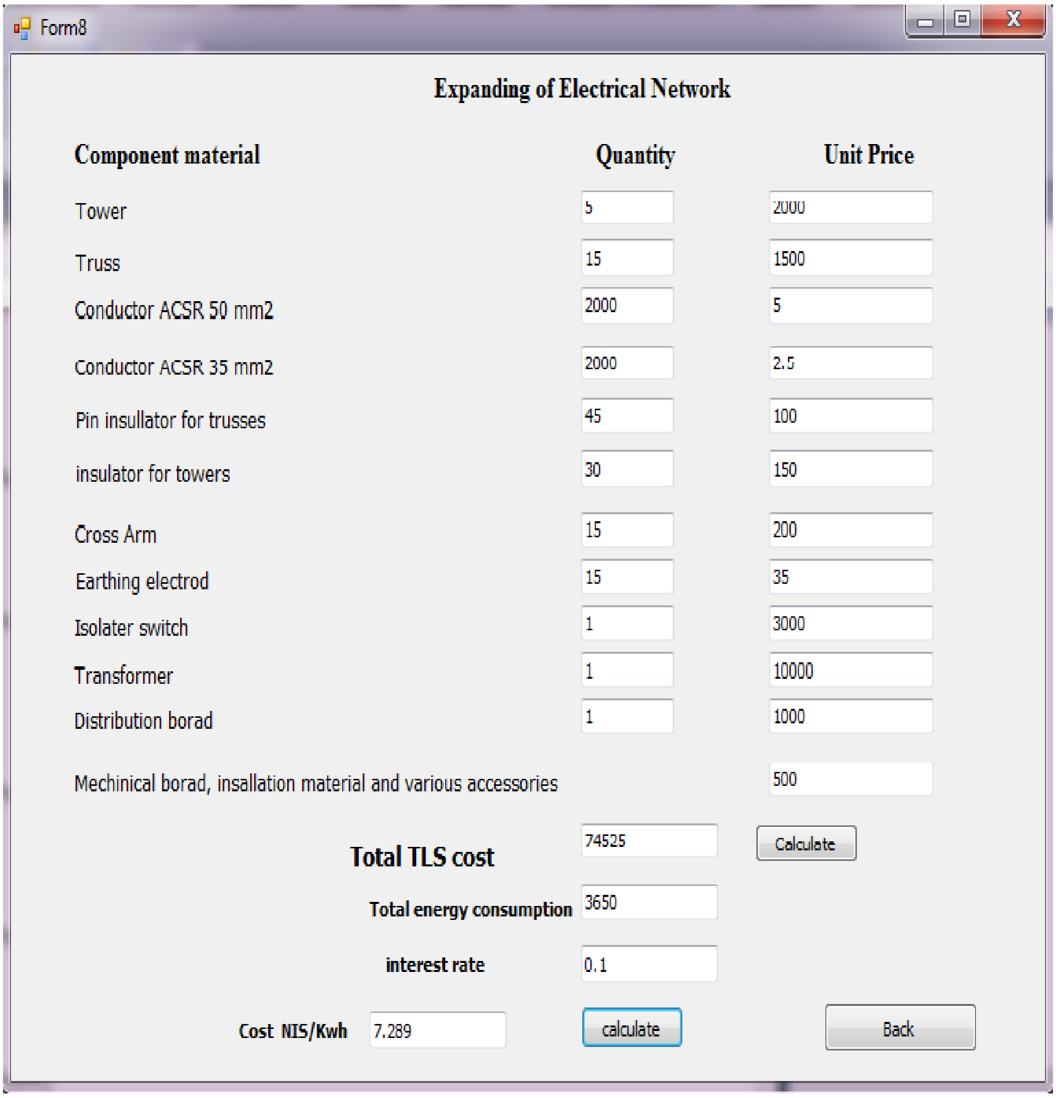

Figure (6. 12): Results of expanding electrical network for Masoud Village

As we see from the result the cost of energy for expanding the electrical network is very high (7.289= NIS/kwh) **.**

6.3.4 Comparison of different alternative for electrification Masoud village based on unit cost.

After the software program compute the cost of one kwh produced from the three scenarios proposed to electrify Masoud village (the case study of this research), a comparison will be made between these scenarios to choose the best alternative based on the lowest cost of energy (NIS/kwh).

The window shown in figure (6.13) shows that the best scenario to electrify Masoud village is by using Centralized PV system which gives the lowest cost of energy produced. The highest cost of energy produced is from expanding the electrical network and that is because of small loads of the village; Expanding the electrical network for remote areas is expensive operation especially when considering the number of habitants in these areas, electrical consumption, and the political situation of the site.

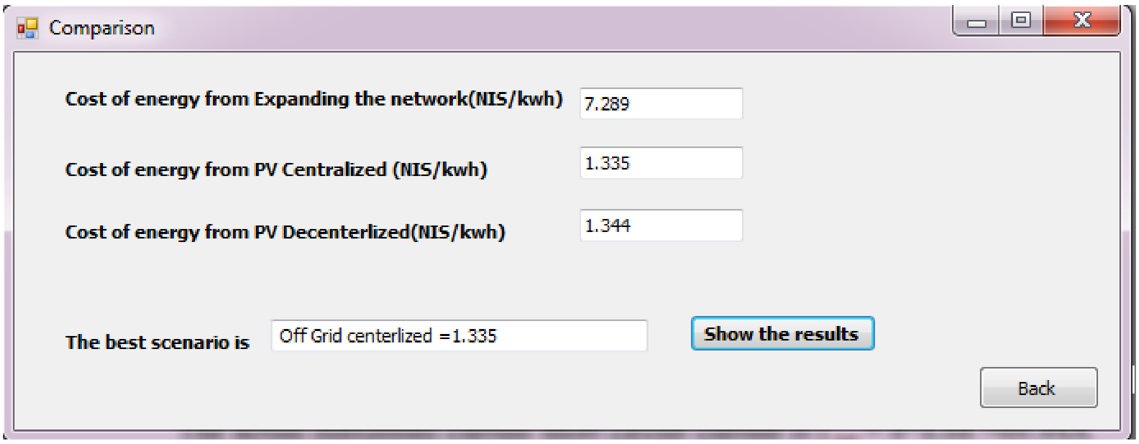

Figure (6. 43): Comparison of different alternative for Off-Grid based on NIS/kwh for Masoud Village

There is a small difference in cost of energy produced between using Centralized and Decentralized PV system ,but that depend on the distance between houses. As a result each case is considered separately because there are several factors that influence the choice of the best scenario to electrify remote villages, such as the nature of the loads and distance from the nearest electrical grid and distribution of houses in the village.

Table (6.1) summarizes the cost annuity for three options, centralized AC load, decentralized AC load PV system and expanding the electrical network for Masoud village.

Table (6. 1): Summary of cost of 1kWh for different type of systems

Type	Cost of 1 kWh (NIS)
Centralized PV system	1.335
Decentralized PV system	1.344
Transmition line system	7.289

6.4 Design of Grid Tie PV System for Masoud Village

In case the electrical network is expanding and we want to design a grid tied PV system to calculate the cost of energy, the configuration of PV generator will be different as in off-grid PV system. Also there is no need for the batteries and the charge controller. The design will be as follows.

A) PV Array Sizing

The peak power (Wp) of the PV generator is obtained from the equation (6.1).

$$Ppv = \frac{El}{\eta_{inv} * PSH}$$

(6.1)

Where: E_L(energy consumption per day) = 8.48kWh ; PSH (the peak sun hours) = 5.587 ; η_v (efficiency of inverter) = 0.9 ; substituting these values in equation (6.1) to get the peak power (Wp) of the PV generator:

Ppv≈1.7 kwp

To obtain this peak value, we select to install polycrystalline -36 cells module kyocera KD140GH - 2PU, which provides 140W nominal maximum power, rated at 12 VDC. The number of necessary PV modules is obtained from equation (3.2):

$No.\ PV$=1700/140≈12

We select the voltage of the PV generator to be =300V, so number of modules in series is obtained as:

Ns=300/17.7≈17

And number of strings 12/17≈1 strings

The actual number of PV modules is 17 modules .

The actual maximum power obtained from PV = 300.9*7.91 = 2.38 kWp.

The configuration will be as shown in Figure (6.11). The area of the array is (17*1.5*0.668) =17.034 m2

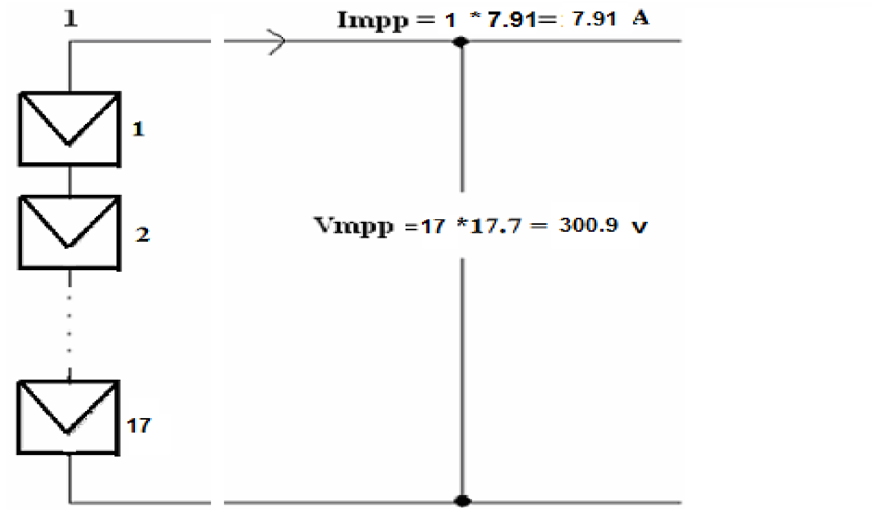

Figure (6. 5): The configuration of PV generator for Masoud village

B) Inverter Sizing

The main parameter to size the grid tied inverter suitable to PV system are:

*V_{input} should be located in the inverter MPPT voltage range (DC100~500V) and V rated = 300v.

*V_{output} should fulfill the specification of the electric grid of the village specified as: Vrated=300 v$\pm$5% AC, one phase 50 Hz, sinusoidal wave voltage.

*In grid tied system the power of inverter's size depends on PV array ,So

P_n>2.38 kW.

*The efficiency = 95% - 97%

After we inter the cost of elements for grid tie PV system ,as the window shown in figure (6.15) for Massoud village ,according to the size of PV array and size of inverter shown above , we get that the cost of energy equal 0.509 NIS/kwh.

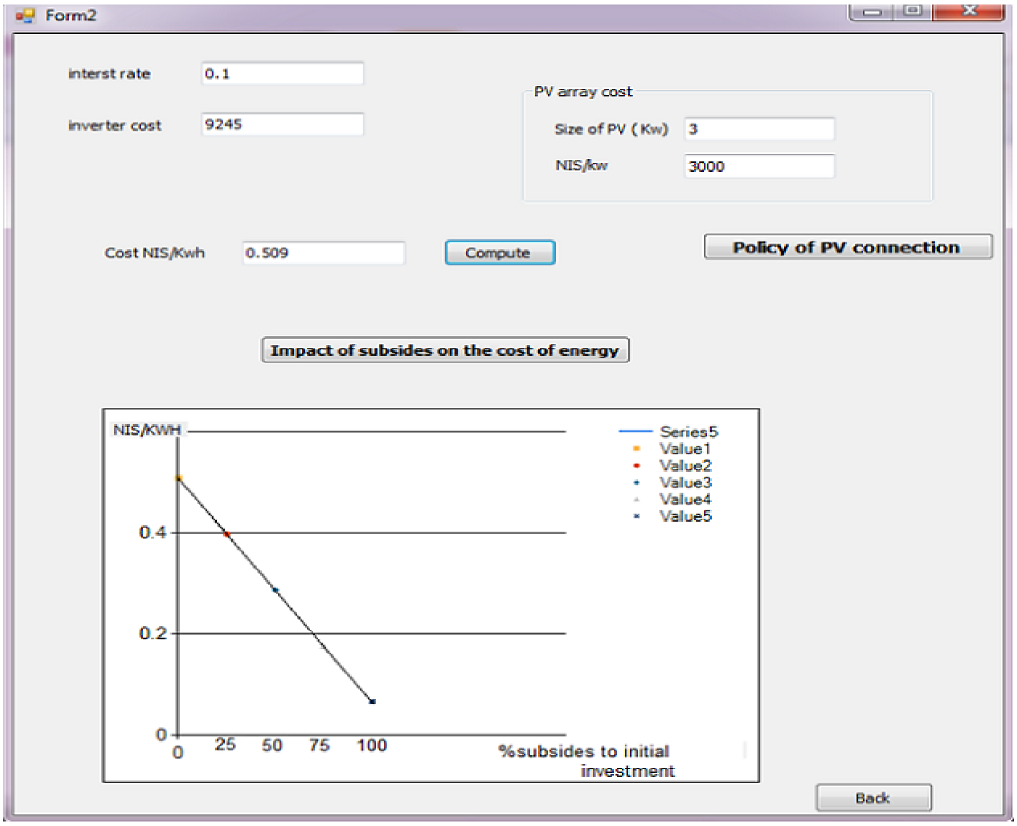

Figure (6. 6): Analysis of on-grid PV system for Masoud Village

To stimulate investment in renewable energy projects, the impact of subsides on the cost of energy is shown in figure (6.15), the analysis determined that increasing the subsides to initial investment from 25% to 50% the cost of energy lower from approximately 0.4 NIS/kwh to 0.27 NIS/kwh as shown in table (6.2).

Table (6. 2): Impact of subsides to initial investment on cost of energy

% subsidy to initial investment	0%	25%	50%	75%	100%
Cost Of Energy (NIS/kwh)	0.51	0.4	0.29	0.18	0.09

If the net metering policy is chosen ,The window in figure(6.16) shows the simple payback period of on grid PV system for Masoud village which is 6.73 years.

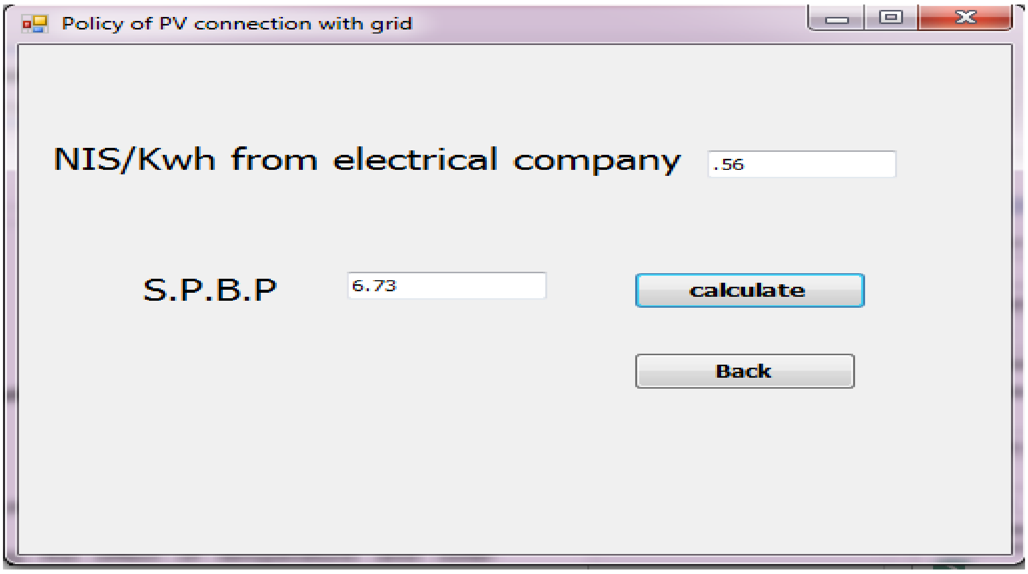

Figure (6. 7): the Economic Impact of Grid Tie PV system using Net metering system for Masoud Village

And for FIT system (FIT=0.7),The simple payback period for our case study is 5.39 years as shown in figure (6.17) which is more visible than using net metering system.

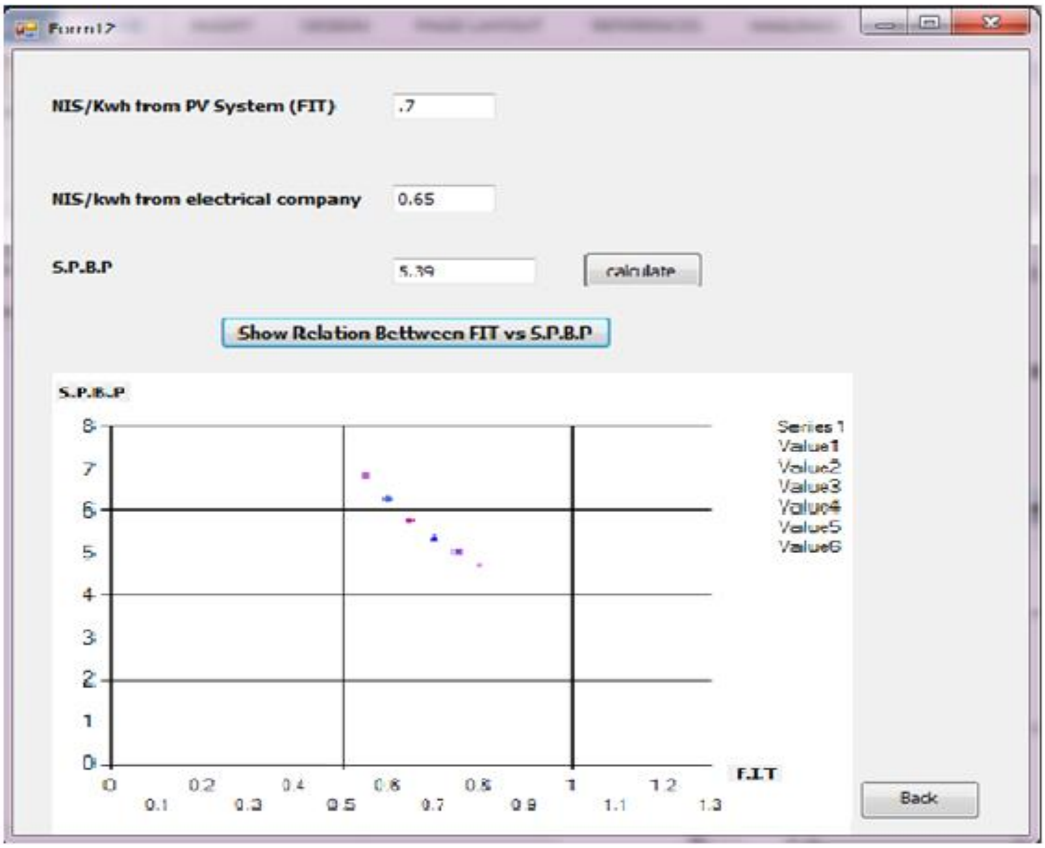

Figure (6. 8): the Economic Impact of Grid Tie PV system using FIT system for Masoud Village

The curve shown in figure (6.17) analyzes the policy of RE in Palestine regarding the impact of different FIT systems; As FIT increases from 0.7NIS/kwh to 0.8NIS/kwh the simple payback period decreases from 5.39 years to 4.71 years as shown in table(6.3).

Table (6. 3): The policy of RE in Palestine regarding the impact of different FIT systems.

FIT(NIS/KWh)	0.6	0.65	0.7	0.75	0.8	0.85	0.9
SPBP	6.29	5.8	5.39	5.03	4.71	4.44	4.19

6.5 Environmental Impact of PV system for Masoud Village

Recently, environmental benefits may be the most important reason for using PV system. The environmental impact of PV is small when compared with conventional sources. Thermal power plants produce huge quantities of CO2 ,SO_2 ,NO and other particulates which contribute to the global warming which directly affects the increase the temperature of the earth and climate change related.

To calculate saving in CO2,SO2and NO when using PV system; Every Kwh produced from conventional source using fossil fuel produce wastes according to table (6.4).

Table (6. 4): Emissions per kwh for a typical thermal power plant

Typical thermal power Plant	
Waste	**Waste/Kwh**
CO2	0.91-0.95 kg/kwh
SO2	6.94-7.2 kg/kwh
NO	4.22-4.38 kg/kwh

The annual reduction of CO2, SO2 and NO when using PV system for Masoud village is shown in figure (6.18)

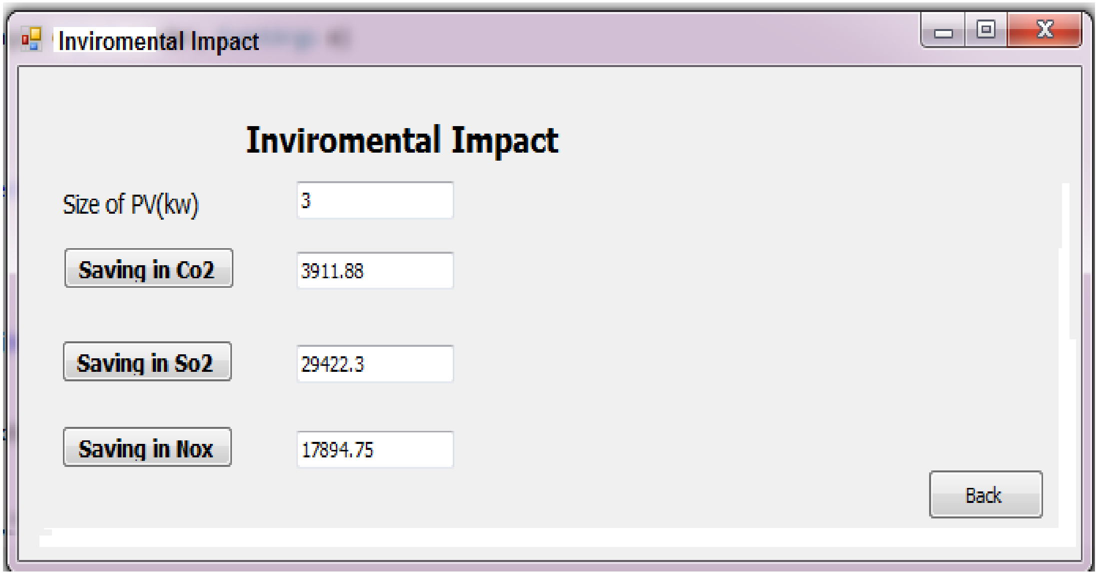

Figure (6. 9): Environmental impact of PV system for Masoud village

The implementation of the proposed centralized PV system reduces the amount of CO_2, SO_2 and NO to about 4 tons, 30 tons and 18 tons, respectively.

Chapter Seven

Conclusions

-This study analyzed the feasibility of electrification small communities in Palestine Territories by using different options "centralized, decentralized PV systems and expanding the electrical network.

- Preparing a software program using C# language for evaluation of different options for rural areas in West Bank.
- The Life Cycle Cost methodology for comparing the different alternatives is used.
- The unit Cost for Masoud village was also done for each scenario. It's found that unit cost for centralized PV system is1.335NIS/kWh, for decentralized PV system is 1.344 and for expanding the electrical network is 7.289 which is higher than using PV system and that due to the small load of the village, centralized PV system has the lower cost and it has to be adopted for our case study.
- The environmental impact when using PV system for Masoud village is also computed, it's found that the saving in CO2,SO2and NO are 3911.9kg,29422.3kg and 17894.8kg respectively.
- Design of grid tie PV system for Masoud village is also done in case the electrical network is exist in the future. it's found that the cost of energy for grid tie PV system is 0.509 NIS which is less than cost of energy from electrical company.
- The policy of RE in Palestine regarding the impact of different FIT system is analyzed in chapter six, it is shown that when FIT

increases from 0.7NIS/kwh to 0.8NIS/kwh, the simple payback period decreases from 5.94years to 5.2 years.

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جامعة النجاح الوطنية

كلية الدراسات العليا

الآثار التكنولوجية والإقتصادية لأنظمة الخلايا الشمسية المربوطة والغير مربوطة مع الشبكة الكهربائية في الضفة الغربية: قرية مسعود كحالة دراسية

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قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة الطاقة المتجدده وترشيد الإستهلاك بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

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الملخص

هناك بعض القرى والتجمعات الفلسطينية التي لم يصلها الكهرباء حتى وقتنا الحاضر بسبب بعدها عن الشبكة الكهربائية وكذلك بسبب العقبات الاقتصادية والسياسية.تقدم هذه الأطروحة ثلاثة بدائل لإمدادات الطاقة لهذه القرى و التجمعات ممثلة في نظام الخلايا الشمسية المركزية واللامركزية وخيار توسيع الشبكة الكهربائية. وتم توضيح تصميم هذه النظم والتقييم الاقتصادي والمالي لكل نظام.

وتم تصميم برنامج لتقدير المؤشرات الاقتصادية والمالية من أجل المقارنة بين البدائل المقترحة والتي تقوم أساسا على تكلفة الكيلووات الواحد للطاقة. وتم أخذ تجمع صغير في الأراضي الفلسطينية في محافظة جنين كحالة دراسية.

وأظهرت النتائج أن تكلفة وحدة الطاقة لنظام الخلايا الشمسية المركزية، نظام الخلايا الشمسية اللامركزية وتوسيع الشبكة الكهربائية هي1,335شيكل / كيلو واط في الساعة، 1,344شيكل / كيلو واط في الساعة و7,289شيكل /كيلو واط في الساعة على التوالي.

وقد تبين أن تنفيذ نظام الخلايا الشمسية المركزية المقترح يقلل من كميةCO_2 ، SO_2 و CO إلى حوالي 4 طن و 30 طن و 18 طن على التوالي.

تكلفة الطاقة الكهربائية التي تنتجها نظام الخلايا الشمسية المربوطة على الشبكة هي 0,509 شيكل / كيلو واط في الساعة في حالة تم توسعة الشبكة الكهربائية لقرية مسعود.وتم دراسة وتحليل أثر نظام التعرفة العائد.