An-Najah National University

Faculty of Graduate Studies

Excess Energy Management of Hybrid Standalone Renewable Energy Power System

By

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Dedication

To my father ….

To my mother ….

To my husband….

To my brothers and sisters ….

To all friends and colleagues ….

To everyone who works in the field ….

I dedicate this work.

Acknowledgement

I would sincerely thank all those who helped me during performing the Master degree.

My deep gratitude to my beloved family, especially my husband who believed in what I have and my ability to succeed, and my mother's support for most of my life.

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I would like to thank my friends for their permanent support to me.

Finally, many thanks to my colleagues in the master program and work.

الاقرار

أنا الموقع أدناه، مقدّم الرسالة التي تحمل العنوان:

Excess Energy Management of Hybrid Standalone Renewable Energy Power Systems

أقر بأن ما اشتملت عليه هذه الأطروحة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الاشارة إليه حيثما ورد. وأن هذه الرسالة كاملة، أو اي جزء منها لم يقدم من قبل لنيل اي درجة او لقب علمي او بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

Declaration

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

Student's Name: **اسم الطالب:**

Signature: **التوقيع:**

Date: **التاريخ:**

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List of Abbreviations

Abbreviations	Meaning
BSS	Battery Storage System
COE	Cost Of Energy
CO_2	Carbon Dioxide
DG	Distributed Generation
BSS	Battery Storage System
EMS	Energy Management System
FC	Fuel Cell
FESS	Flywheel Energy Storage System
HRES	Hybrid Renewable Energy Systems
HOMER	Hybrid Optimization Model of Electric Renewable energy
LOCE	Levelized Cost of Energy
MGT	Micro Grid Turbine
NPV	Net Present Value
OEM	Original Equipment manufacture of battery
PAFC	Phosphoric Acid
PENRA	Palestinian Energy Natural Resources Authority
PEM	Proton Exchange Membrane
PT	Palestinian Territories
PV	Solar Photovoltaic
PVG	Photovoltaic Generator
RE	Renewable Energy
RES	Renewable Energy Sources
SHS	Solar Home System
SOC	State Of Charge
SOFC	Solid Oxide Fuel Cell
WEG	Wind Energy Generator

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Abstract

Palestinian Territories suffer from high shortage of conventional energy and it imports all its needs of petroleum and about 90% of electrical energy needs from Israeli energy companies. The exploitation of the RES in PT for electricity generation is growing up and spread widely. There are a lot of rural areas on PT still suffer from continual interruption of power supply. This makes the implementation of stand-alone systems a feasible option. Better sizing of stand-alone systems increases the feasibility and reduce the simple back period .The excess energy causes technical problems to the systems as well as reduces its feasibility. The base proposed case is a stand-alone (off-grid) hybrid system includes PV, generator(diesel), and battery. The load is for small residential community in Jericho comprises of 10 households. The average load demand is 111 kWh/day. By using HOMER Pro software the optimum design was modeled and achieved. With actual solar radiation, load profile (electrical demand) for the residential proposed load and cost of all equipment.

The base system consists of PV modules, batteries, generator(diesel), load and converter. The net present cost of base proposed system is USD

101,361. The Cost of energy is USD 0.194 /kWh. The contribution of RE is 92.2%. The surplus electricity is 7469 kWh/year about 13.8%.

Different strategies and configurations are proposed to reduce and using the excess electrical energy produced from the base case: with water pumping system, with fuel cell system, with boiler water heating system, and with hybrid boiler water heating and water pumping system. The results showed the best hybrid is(PV/Diesel Generator/BSS with hybrid boiler water heating and Water Pumping System). With Analysis the surplus power and studying the residential load and the water pump and storage tank, a deferrable load is assumed. The results show feasible improvement in the amount of excess power, that the main purpose of this research regardless of NPC & COE, while the NPC & COE that have been studied to economical study just.

The PV/Diesel Generator/BSS with hybrid boiler water heating and Water Pumping System is feasible strategy to electrify the residential load and the most economical system. The COE is USD 0.214/kWh. The NPC of the system is USD $140,220. The capacity of the PV system is 30 kW, 40 batteries of 1150 Ah each and 3 kW diesel generator. The proposed system provides the residential and pumping load and heating load with about no interruption to the power supply. Sensitivity analysis is used to study the impact and affections of variations in other parameters (PV cost, costs of extra equipment, diesel fuel price). Energy management procedure by this configuration to reduce the surplus electricity from 13.8 % to 5.3%.

Chapter One

Introduction

1.1 Overview

Energy resources are essential for every society, whether it is an industrialized country or a poor country. There are many different energy sources, some of which are conventional and well-known, such as coal or petroleum, while others are renewable, such as solar energy, wind, tides, or heat within the earth and other different energy sources.

Conventional non-renewable energy is the energy comes from materials that are not naturally renewed but rather limited. The depletion of traditional energy sources sooner or later, and the era of oil is approaching, which makes the future dangerous. During the generating and consuming electrical energy using traditional techniques, the environment was severely affected. This is a challenge for the entire world to reduce this negative impact on planet and learn how can generate the energy from clean energy sources. The primary fuel mix for electricity generation has changed over the past four decades, as shown in Figure (1.1).

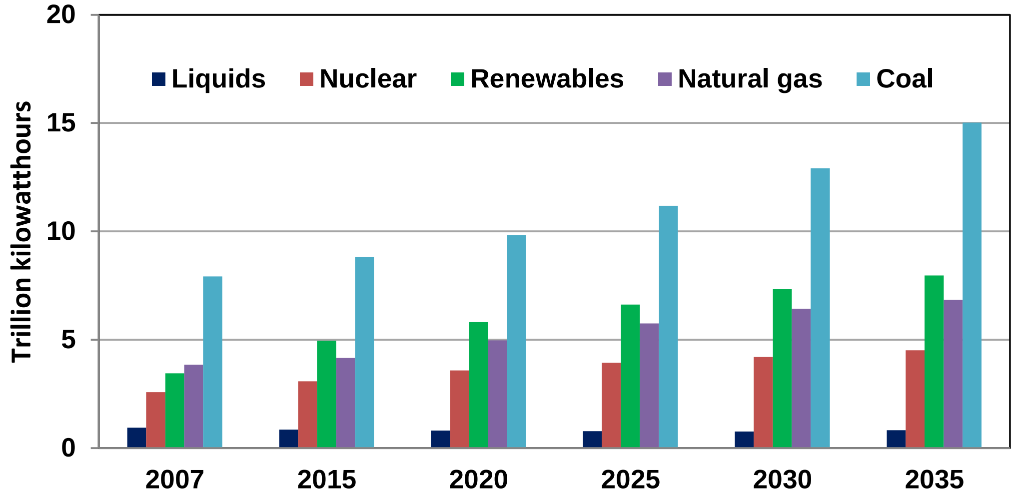

Figure 1.1: Eectricity generation by fuel,2007-2035[1]

Renewable energy is the energy comes from resources naturally replenished on a human timescale life, like solar, wind, geothermal, hydropower, tidal energy, and biofuels.RE is the fastest growing source of electricity generation as depicted from Figure (1.1).

1.2 Energy Situation in Palestine

PT is a very complicated area it consists of two separate administrative regions, cause limits to the development of infrastructures and to the development policies of energy sector. The energy situation is weak in Gaza Strip and is improving in West Bank. This hard energy situation is due to the high dependence on Israel, the physical separation of Gaza and West Bank, high political instability and insufficient infrastructure.

The energy balance in Palestine as shown in in Figure (1.2) by a Sankey diagram. Energy conservation in uses has played an important role in improving energy efficiency in the industrial, commercial and residential sectors. The aims of the Palestinian energy sector have been to ensure the security of supply and minimizing the dependence upon foreign source.

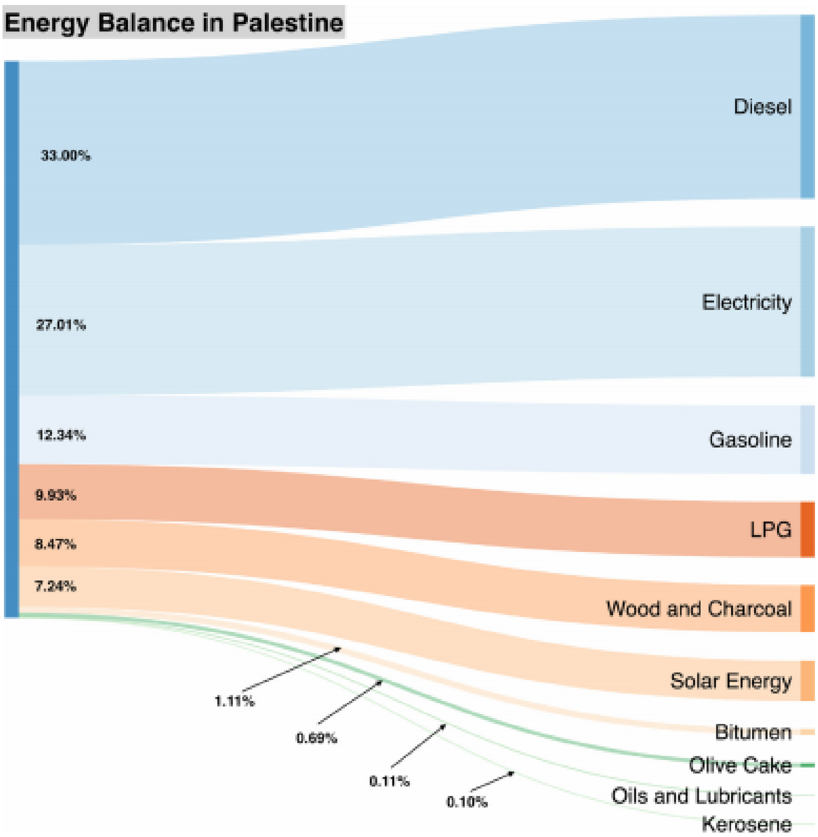

Figure 1.2: Sankey diagram of energy balance in Palestine[2]

The utilization of RES is one of the most important strategies towards independency in the field of energy for Palestinians. PT suffer from strict shortage of energy demand and the fluctuations of energy prices. All electrical energy products are bought from Israeli companies cause the Palestinian authority has no control on borders. Small amount of electrical energy demand is generated in Gaza power plant and about 37 MW is imported from Jordan and Egypt [3].

The major aim behind making Palestinian renewable energy strategy by PENRA is using renewable energy for electricity generation. The purpose is to generate 240 GWh electricity from RES about 10% of electrical energy required by 2020[4].

PT have a high solar radiation potential and high sunshine hours all of the year, The horizontal yearly average daily solar radiation is 5.45 kWh/m^2[5]. The wind energy potential in Palestinian Territories is low, but is an acceptable potential in specific locations can be used in small scale wind turbines.

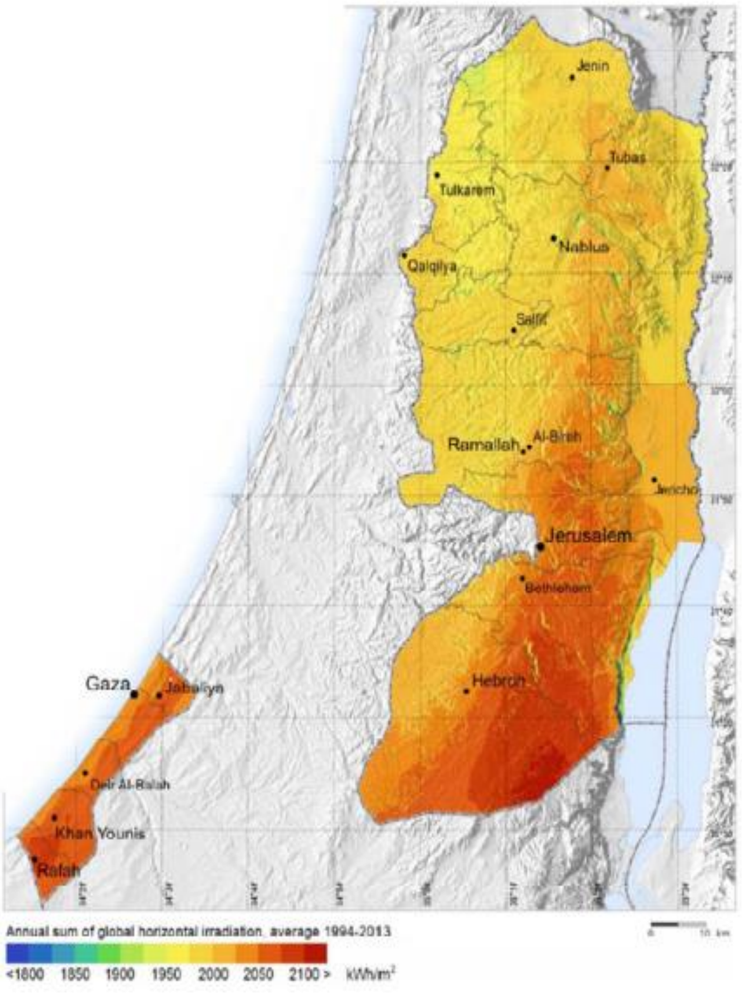

Figure 1.3: Annual sum of irradiance for surface inclined to the south with 270[6]

Figure (1.3) shows annual sum of global horizontal irradiance average. The temperature and wind speed are very important variables, the Table (1.1) shows monthly averages of maximum temperatures in three different places, Figure (1.4) shows wind speed in three differen Palestinian areas.

Table 1.1: Monthly averages of maximum temperatures [6]

Area	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Hilly area	14	15.3	18.7	23.8	28.1	30.7	32.5	32.5	30.6	27.1	21.3	16
Jordan valley	18.2	19.2	23.5	28.3	32.7	35	36.3	36.3	35	31.8	24.7	20.3
WB North	14.8	15.7	18.7	23.3	27.8	30.6	32.5	32.9	31.2	28	22.2	16.8

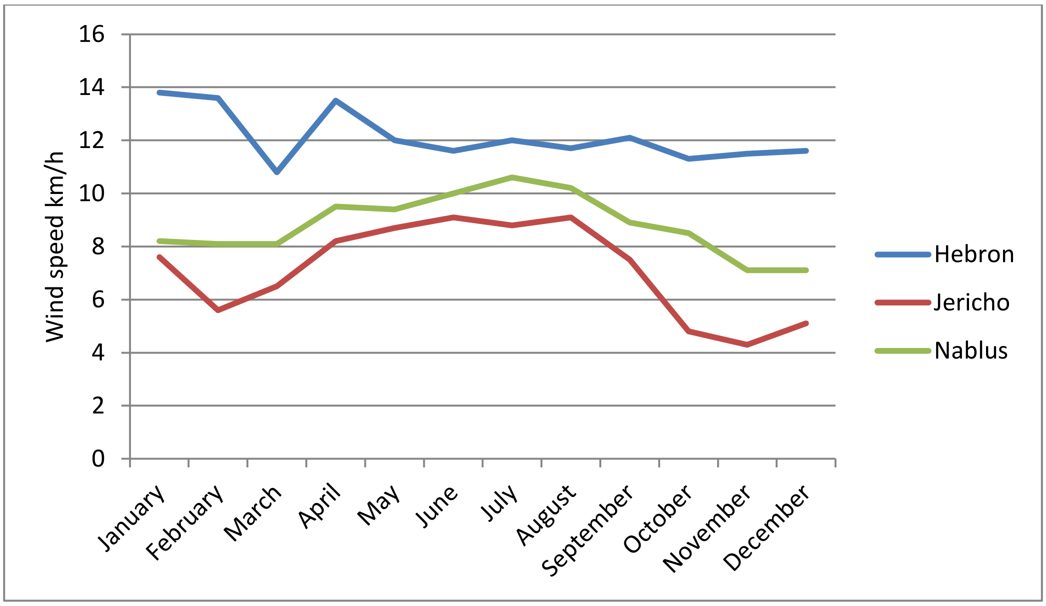

Figure 1.4: Wind speed of selective sites in the three areas in Palestine[6].

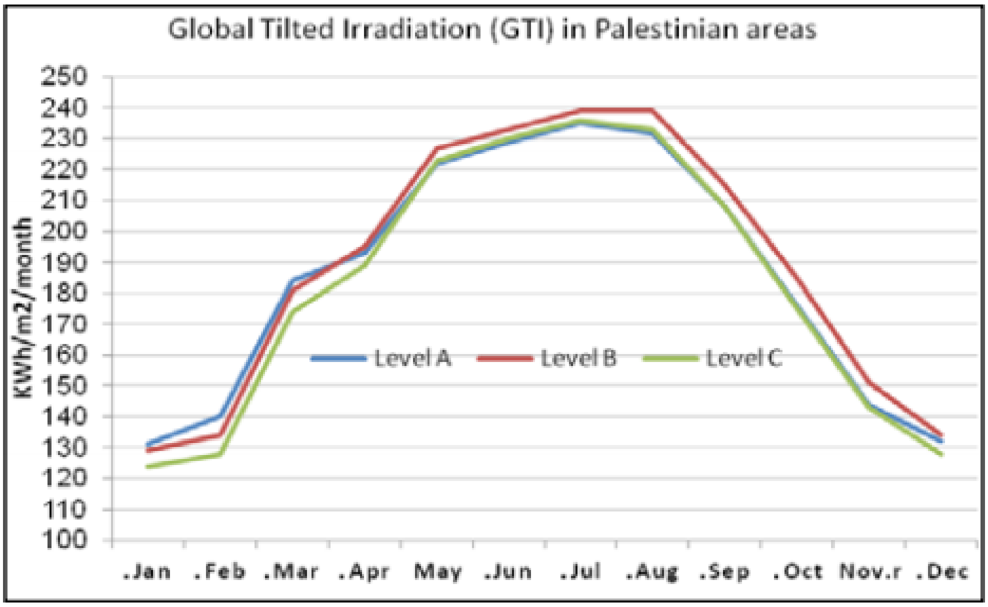

Figure 1.5: Average monthly values of potential energy production during the year[6].

Figure(1.5) shows average monthly values of potential energy production during the year[6], it shows a maximum and a minimum solar radiation for those areas as follows:

- Area with irradiation level A: max. of 680W/m^2 and a min. of 350W/ m^2.
- Area with irradiation level B: max. of 1000W/m^2 and a min. of 550W/ m^2.
- Area with irradiation level C: max. of 1250W/m^2 and a min. of 450W/ m^2.
- In Table (1.2) shows the imported energy in PT from outside [6].

Table 1.2: Imported Energy in Palestine, 2019[6].

Month	Electricity (MWh)	Gasoline (Thousand Liter)	Diesel (Thousand Liter)	Fuel Oil (Thousand Liter)	Kerosene (Thousand Liter)	LPG (Ton)	Bitumen (Ton)	Wood and Charcoal (Tons)
Jan	597608	25618	67601	544	467	20493	3200	320
Feb	517696	23174	61488	253	302	17113	2847	277
Mar	553711	23031	56913	244	184	14542	2608	307
Apr	466427	24731	64209	313	86	14115	3508	483
May	481043	26587	61787	315	16	14774	3783	350
June	514426	25764	56215	372	5	9932	2741	382
July	549272	29219	69872	408	47	11281	2889	347
Aug	555955	26979	62065	237	16	14316	1582	267
Sept	515335	26490	65799	502	70	11493	2791	341
Oct	485208	25604	62933	278	51	16204	2301	389
Nov	454272	23361	58563	233	102	14688	2264	286
Dec	558151	25054	65442	398	344	18723	2432	254
Total	6249104	305612	752887	4097	1690	177674	32946	4003

The renewable energy sources have to assure both the suitable electricity generation and being economically visible. These two requirements always play a critical role in the rapid penetration of any new energy technology.

1.3 Solar Power System types

Solar energy systems differ according to their connection to the network and its components, as they are divided into three types according to the location and the available components, so each type must be understood and how it works and is used.

1.3.1 On-Grid solar power systems

A grid-connected(on-grid) system is called when connected to the grid, and called an off-grid (standalone) system will not connected to grid. On-grid systems are the most common type. It will save money by metering, net efficiency rates, metering, lower installation cost and equipment. By net metering the users can give the excess electricity to the grid instead of storing it with batteries. The local grid like a stand-by battery, without the need for replacements or maintenance and with better efficiency rates. On-grid systems do not provide protection from power cuts(no electricity from grid). When the electrical grid off, on grid systems will not continue to operate. As shown in Figure (1.6).

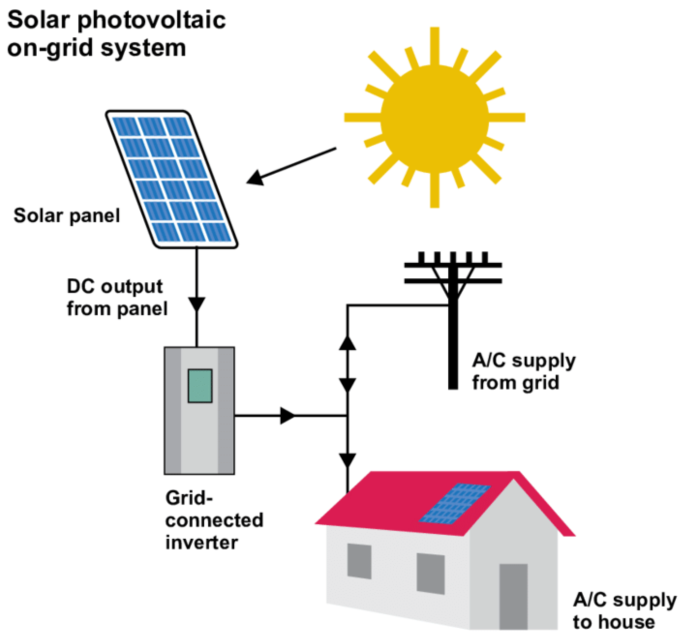

Figure 1.6: On-grid system

1.3.2 Off-Grid solar power systems

Off-grid solar system give electricity at all times and far away from grid. An off-grid solar system needs battery for energy storage and an inverter for convert DC to AC. The battery must be replaced after 10 years. To enables a longer life, better efficiency and less space. The PV system ensures the customer never faces power fails and can be installed in any location have good solar irradiance. Shown in Figure (1.7).

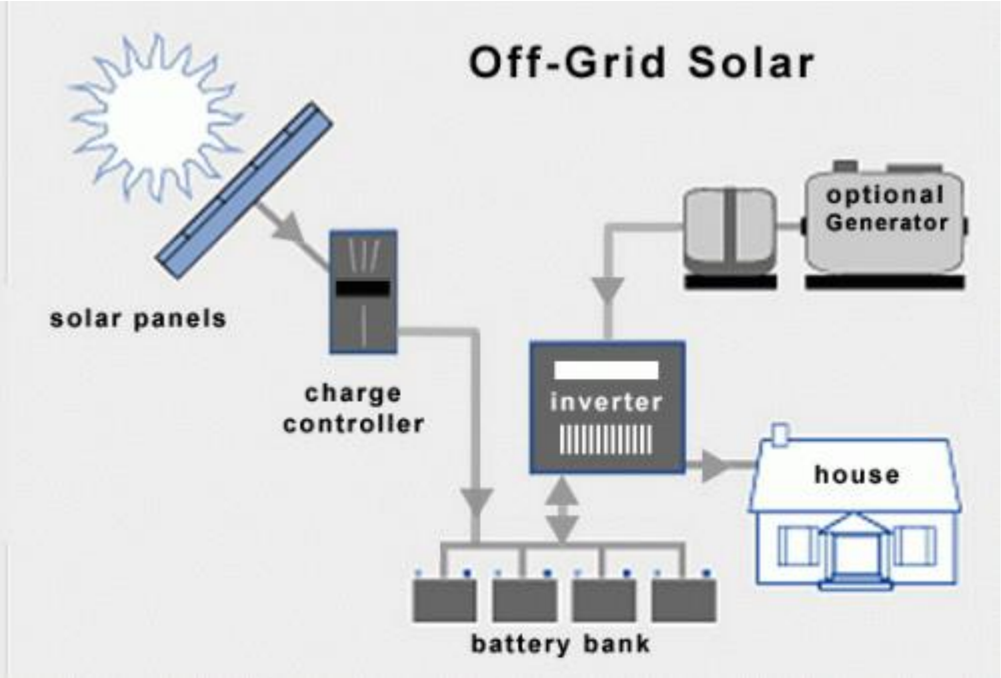

Figure 1.7: Off-grid solar system

The stand-alone system needs to have energy storage system to handle the power variations in solar energy. If the system can supply the grid and local loads, called grid-connected hybrid system.

The components of stand-alone systems:

- PV arrays: A lot of PV modules generate direct current from solar energy.
- Inverter: The inverter converts the DC to AC and feeds into the alternating current grid.
- DC/DC charge controller: It can be used to charge a battery.
- Batteries: For energy storing and support the grid when not producing sufficient electricity. The batteries will be charged again, when excessed energy than is consumed.

- Battery inverter: The battery inverter forms the stand-alone grid. It regulates the balance between the energy that is generated and the energy that is used and a battery, PV array and load management system.

- Battery fuse: Protection the battery connection lines of the battery inverter. And ensure DC side disconnection of the battery inverter.

- Generators: Used to supply the energy supply when no energy being supplied by the PV and batteries drops. It is supply AC directly.

- Wind turbine systems: Convert wind energy to electrical energy and supply AC directly.

- Hydroelectric power plants: Convert the kinetic energy of water into electrical energy.

1.3.3 Hybrid solar power systems

A hybrid solar system include the benefits of both types: the suitability of a grid connected system with a battery, means that still have electricity, even during a power blackout. Wth a grid connection to devices, hybrid systems can provide the flexibility of being able to store the energy generate during the day instead of feeding it back into the grid at a low feed-in tariff. This energy can be used in the night instead of buying power back at a high price. They are fully programmable and the system will provide a smart combination of all the energy sources available, giving a strategic advantage in the cost, reliability and environmental impact of electricity usage with the best batteries. The hybrid system shown in Figure (1.8).

Figure 1.8: Hybrid solar system

Hybrid power systems conclude different types of renewable power conversion systems can be classified as DC or AC coupled topologies.

A DC coupled hybrid power system is a system which different power sources are connected to a main DC bus, the AC power sources, if available, will be converted to DC voltage using DC/DC power converter. The DC bus is normally connected to DC/AC inverter to convert the DC power to the AC power at specific voltage and frequency to satisfy the AC load or AC grid. The capacity of inverter should be selected in order to cover the peak load demands. The nominal limited capacity of the DC/AC inverter is the main obstacle for expanding the system by increasing a component capacity or adding further generators. An AC coupled hybrid power system is a system whose different power sources are directly connected to the AC grid or AC user load.

In a DC coupled system, all energy sources are coupled via direct current, special DC/ DC charge controllers used to integrate the PV array, the battery stores energy generated by the PV array during the day, and in the evening the stored energy will be available for operating the lighting.

DC coupling is suitable for simple systems and is beneficial in cases where the electricity supply is primarily used to operate lighting. Alternating current loads in a DC coupled off-grid system can only be operated by an additional small inverter.

Among the above scenarios, this study investigates a stand-alone distributed generation system mainly based on RES with AC coupled topology. Each inverter in AC coupled system topology synchronized to its generator, that it can provide power to load separately and with other inverters unlike DC coupled configuration6. This feature offers flexibility to load demand management, the advantage is that the off-grid system can be built and expanded flexibly with modular standardized components. In the peak demand times, the required power sources and storage systems are operated in parallel to cover the load demand while one inverter operates and other inverters work in a stand-by mode in the case of low load demand.

In hybrid systems the battery can be charged by a generator at the same time. The design of hybrid systems is more complicated than the design of purely AC coupled systems.

In hybrid power systems, a number of power generators and energy storage systems are combined to meet the energy demand of a load. In this research only renewable energy sources are considered.

The solar irradiation is the most important renewable energy resource, Wind energy, on the other hand, is a clean energy source that contributes to reduce the dependency from fossil fuels, with full advantage from a cost reduction of the wind generator technology in times in which the cost of traditional fuels instead increases.

Different stand-alone hybrid system plants are proposed to be analyzed and discussed in details in the next chapters. All the considered plantsthree basic components: PV, DG and a battery storage system (BSS). This chapter includes a general comparison study between on-grid system with off-grid.

Among the solutions adopted by PENRA is the distributed generation (DG) systems mainly based RES. DG as electric power generation facilities that are not directly connected to a bulk power transmission system[7]. DG devices placed in power systems for grid reinforcement, reducing power losses and on-peak operating costs, improving voltage profiles and load factors, eliminating for system upgrades, and improving system integrity, reliability, and efficiency. Figure (1.9) shows the conventional central power plants versus the distributed generation system.

Many combinations of renewable DG technologies and storage devices can be built to form a standalone or grid-connected hybrid system. The common combinations are shown in Figure(1.10).

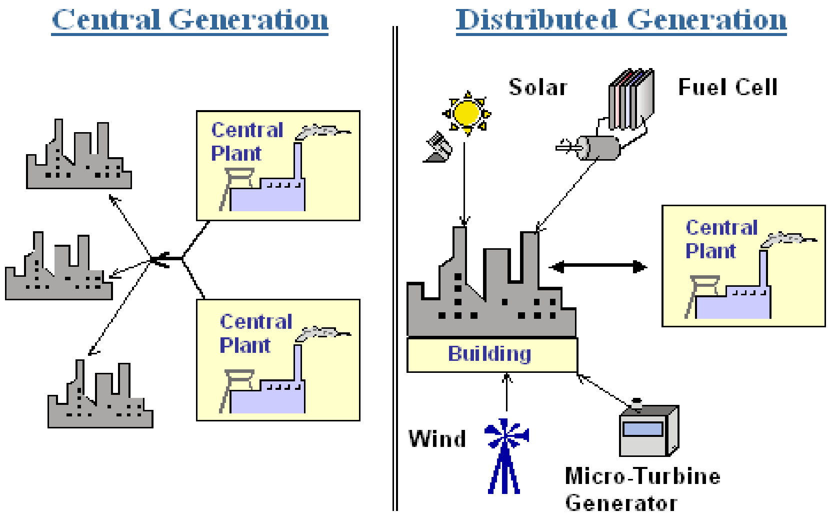

Figure 1.9: Central power generation plant versus the distributed generation plant

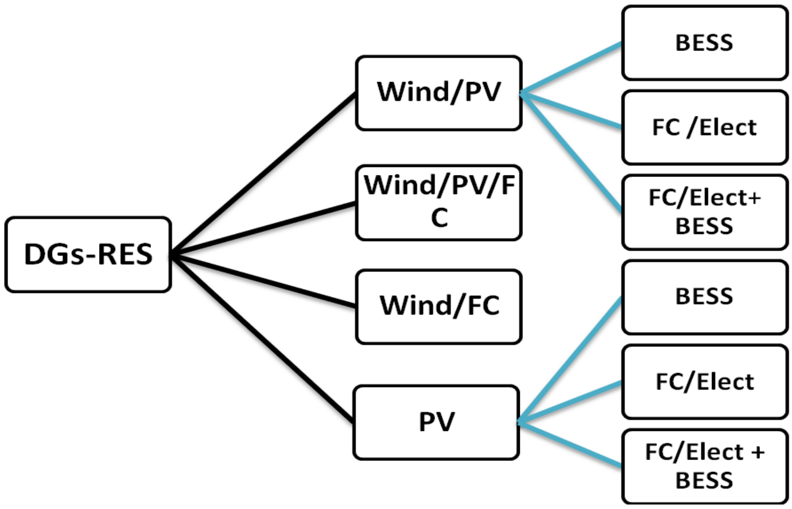

Figure 1.10: Common DGs combinations based on RES

1.4 Software Programs

The software programs for economic analysis allow the researcher to calculate the whole cost of RE systems, because they contain a database of economic elements and their market prices. Different economic indicators are estimated as cost of energy (COE), the payback period and life cycle cost. Detailed data must be entered to the software so as to possess accurate results. Every type of losses are considered within the evaluation. during this group we will find HOMER PRO software.

HOMER PRO software for hybrid optimization model for electric renewable and the most purpose of finding the optimum design of both stand-alone and grid-connected power systems for a various applications by performing three tasks: simulation, optimization, and sensitivity.

1.5 Problem Statement

The RE hybrid standalone systems suffer from several problems. The most important of which is feasibility, mainly due to poor excess energy management. Most systems eliminate excess energy without use, and this reduces the value of the energy used and produced by the systems. The wasting energy can be used in several areas under good and thoughtful management. Poor management of the excess energy distorts the system voltage and frequency, and the efficient use of additional energy will increase the applicability of these systems.

Proposed Solution

Manage excess energy in different configurations of hybrid standalone power systems based on RES through. The configurations include different modes of energy storage systems. Thermal/electrical storage application for an off-grid (stand-alone) system is one of the options. Cooling and heating water, water pumping, space heating, and cooling are other options.

1.6 Objectives of the research

The main objective of this work:

- Improve the feasibility of standalone hybrid PV systems by managing the excess energy instead of dumping it.
- Performing techno-economic analysis for each studied option.
- Design several options of independent systems and analyze them on special programs.

This study investigates different approaches to manage the excess energy produced from stand-alone hybrid energy systems based on RES. Different stand-alone power plants will be considered. The waste power can reach up to 50%. Surplus energy management or thermal management is imperative with high necessity.

Different stand-alone RES with different energy storage will be studied. Different scenarios will studied, the percentage ratio of the thermal/electrical energy from waste energy to total power output will be evaluated.

1.7. Thesis Structure

This thesis is orderly as following: Chapter one introduces the thesis, chapter two talk about literature view while chapter three discusses the methodology of the research. In chapter four structure of proposed system is discussed and analyzed. Chapter Five shows the results of simulation software. Chapter six shows the results and discussions while chapter seven concludes the thesis and propose some recommendations.

Chapter Two

Literature Review

In fact, very little papers and studies discuss the excess energy management of a stand-alone systems, among the studies that directly and indirectly discuss the subject is illustrated in this section.

Alnejaili and et al[8]have performed a study on the energy management scenario for a stand-alone system to control the energy flow, and used simulation models applied in Matlab/Simulink software to test the hybrid power system and evaluate the performance and effectiveness of dynamic controllers from the management strategy. The results shows the efficiency of the proposed strategy, as it increases system reliability and improves its power balance. It enables to reduces the ON-OFF switching cycle of the fuel cell and increase the life of the battery and fuel cell, and prevents deep battery discharge under heavy loads and adverse weather conditions. Their study was limited to examining strategy and did not take into account the redundant capacity of the battery and the system.

K. Kusakana and et al[9] has study an overview of the research improvements in the area of optimal operation control applied to hybrid RES and discussed different challenges encountered the hybrid systems, and future improvements help in improving it. The results shows that there is a number of research papers dealing with optimal sizing of hybrid systems; But few research works have dedicated to optimal operation control of hybrid renewable energy systems.

Baileraa M. and et al[10]presented a methodology decision-making to size and manage a cogeneration system. About 35 potential proposed scenarios have been studied, depending on the excess electricity, holding of the intermediate storages of hydrogen and methane, and thermal demand. This study has been developed to design and resize energy storage and operation facilities based on energy conversion to gas. The proposed strategy is the first approach to developing a complete algorithm of control and scheduling. In this research, possible limitations and operating conditions are improved to save as a technical basis for future control algorithms. Economic parameters taking into account fixed and variable costs, the prices of buying and selling gases and income for the avoided CO2 emissions. Also, it will serve the basis of advanced control algorithms to reach a positive economic balance.

Mayur P and et al[11]presented management power control strategy is proposed for stand-alone PV, Battery Energy Storage (BES) hybrid system. The proposed strategy control algorithm tracks the Maximum Power Point of the solar-cells with avoiding overcharging of LiBs under different solar radiation and load conditions. The research detected the proposed power control strategy is strong and meets multiple objectives of standalone PV-BES hybrid systems such as no overcharging, 0% excess output power generation, and not transferred any energy to the dump load. Solar insolation data from a small village in India for a year has been used in the simulation. The results show the proposed strategy meets performance objectives such as zero dumped energy, avoiding of overcharging of the

BES system and maintaining a safe SOC for the operation of the BES system. The important objective of this work is to show the use of a physics-based model like SPM for accurate performance prediction and robust control scenarios.

M.S. Ismail and et al[12]a study provided an overview of the literature dealing with using surplus energy methods, and analysis of effective using of excess energy. A lot of researches suggest dumping the surplus energy by dumped loads, injected to the grid, or to generate hydrogen using electrolyzers and storing hydrogen in hydrogen tanks to be used in the fuel cells. Excess energy can be used in water heating, water pumping, and space heating and cooling and water desalination. Studies found the using of excess energy for hot water for residential applications and space heating or cooling by air conditioning can be achieved with little to minimal cost.

Akhtaria.R.M and et al[13] have a study which attempted for optimization and examination the techno-economic feasibility of stand-alone (HRES) to satisfy simultaneously electric, heat and hydrogen load of a large energy consumer. The strategy suggest to recover excess electricity to generate heat and low emissions. The system consists of solar panels, wind turbine, diesel generator, electrolyzer and boiler in different cities in Iran. Using HOMER Pro software and thermal load controller (TLC) (including electric boiler) was added to generate thermal energy by converting excess electricity of renewable energy production. a decrease in conventional fuel consumption, emissions and cost of energy (COE), and increasing the renewable fraction of HRES.

Kumar, A and et al[14]presented an energy management system for a stand-alone system in a rural location. The proposed system with RE resources solar, wind, with diesel generator and battery. Using MATLAB for proposed control system, and using HOMER PRO for sizing the micro grid. HOMER PRO is used for cost-effective power management between production and demand. Results show the proposed system controllers is using to manage the power flow from source to load.

Maghami and et al[15] proposed an energy strategy based on designing a Program Logic Controller unit. by different strategies comparing such as a hydrogen energy system and demand response the hybrid system is evaluated. The purpose is to extract excess power for reducing the cost of the system and reducing peak demand. By eliminating degradation and improving the system performances. Local companies must ensure the systems are working exactly and their investments will pay off. The hybrid system designed of three RES including PV, Hydro, and wind turbine and with battery storage and fuel cells and a converter.

Pradhan.S.R and et al[16]proposed a design for a stand-alone network for remote areas. The average solar radiation and the amount of data required for the biomass are to predict the overall performance of the generation system. Batteries can also be used in this system to store additional power that can also be used for backup. The additional power is used to supply the grid. the simulation is done using the HOMER program. Results and analysis can be used to improve the development of the proposed model. The analysis was given to a systematic procedure for planning a PV-

Biomass system and economic analysis with calculating the percentage of savings, and the recovery period analysis. It will give the complete solution to remote areas that are not accessible through the network. The schemes initially be expensive, but frequent use of such schemes and the wide spread acceptance of the technology can reduce the cost of these schemes.

Bhayo and et al [17] developed PV-Battery power system with using of the excess power for water pumping. The first aim is to meet the demand of residential unit. The design of system size by varying the number of PV's and Battery capacity, and to be used for water pumping. If the water is pumped to elevated storage, it may be used for extra hydro power generation by hybrid PV-Battery-Hydro power. And it will be used for the irrigation and portable use, or for operation of water pump for side power generation.

Salameh, T. and et al.[18]designed and developed control strategies of the standalone RES to meet the residential load. The effects of temperature and dust on the solar PV panels are studied. Modeling, simulation optimization and control strategies were used to determine the performance and the cost of the proposed system. The excess power is used for electrolyzer and the fuel cell will operate to meet the load. The results show the distributed power production using solar PV and Fuel with an electrolyzer for hydrogen production, and cycle charging dispatch control strategy shows the best performance.

Tao Ma and et al[19]proposed a storage system for hybrid energy system, combines super capacitor for dynamic power regulation, and battery for long-term energy management for remote area RE power supply systems. The main aim of the research is to evaluate the benefit and possibility to combine super capacitors and batteries for achieving a performance between two devices. The results explain the passive hybrid leads to developed energy storage performance. The battery performs as the base energy source for longer periods and the super capacitor as the auxiliary power source for peak power smoothing. The combination makes energy storage possessing both high energy density and power, and extending battery life.

Arani, A. K., Karami and et al[20]presented an overview of the structures and applications of flywheel energy storage system in power system and problems, challenges, and future works discussed. Search of various studies shows that FESS is as instrumental in operating the current and future energy system. It includes of an electrical machine, DC link capacitor, converter and a massive disk. Benefits of FESS that is an environmentally-friendly, short- or medium-term energy storage system, has the capability of huge charge and discharge cycles. The FESS a suitable choice for different applications in the power system such as power quality improvement, stability improvement, power smoothing, and renewable energies integration support.

Aziz, A. S. and et al[21]analyze the economic, technical and environmental feasibility of stand-alone systems for a rural area in Iraq. HOMER Pro is used with the multi-year unit to check the hybrid power optimization system. Five design scenarios are proposed and evaluated based on combinations of PV, hydro, diesel and battery power storage generators, and choosing the proposed system that is environmentally friendly as it contains low emissions of gases. The multi-year unit has been found to produce more reliable results than the one-year unit.

Mandal, S and et al[22]examined the ability to meet the simultaneous electrical demand and convection of a stand-alone system with different scenarios. The model takes into account the use of excess energy, the excessed heat recovered, and different energy management strategies using (HOMER) program. the waste heat recovery options along with the heat load control unit, they are checked to fulfill the heating demand. The cost of energy and net present cost were comparable to the hybrid system meeting only electrical load and simultaneous electrical and thermal loads. Reduction in the size of the hardware components was done by satisfying the thermal demand through the use of surplus electricity and the lost heat recovery unit. The hybrid system is found with both a convection control unit (it uses surplus energy) and a heat recovery option for lower energy costs and higher renewable energy breakthrough than the system with the option to only use the excess energy via the convection controller.

Yasin A and et al [23] proposed an off-grid system to electrify a agricultural community in PT. The loads are residential load and water pumping. The best strategy was studied using HOMER Pro software, with actual solar radiation, load profile and water pumping, and cost of all equipment. The results showed the best strategy is a hybrid PV system with energy storage and a diesel generator. Sensitivity analysis used to study the effect of PV cost, diesel fuel price, and maximum annual capacity shortages. The maximum annual capacity shortages has no effects. Using energy management procedure to reduce the excess electricity.

Yimen, N., and et al[24]presented a technical economic analysis and optimize the storage of pumped hydroelectric power based on an stand-alone and renewable hybrid power system to electrify the city of Jindi. Homer used as an analysis tool. It will be applicable in parts of sub-Saharan Africa. A stand-alone hydraulically pumped hybrid power system content of a wind turbine, a PV array and a biogas generator has been proposed to cover the Djoundé's electricity demand. By designing and implementing a good proposed system, the proposed system has been modeled, simulated and improved. The important results are the cost-effectiveness and environmental benefits of the proposed system compared to previous cases in sub-Saharan Africa.

Chapter Three

Methodology

The aim of this research is to utilize the excess energy in standalone PV systems. The methodology is briefly shown in Figure (3.1).

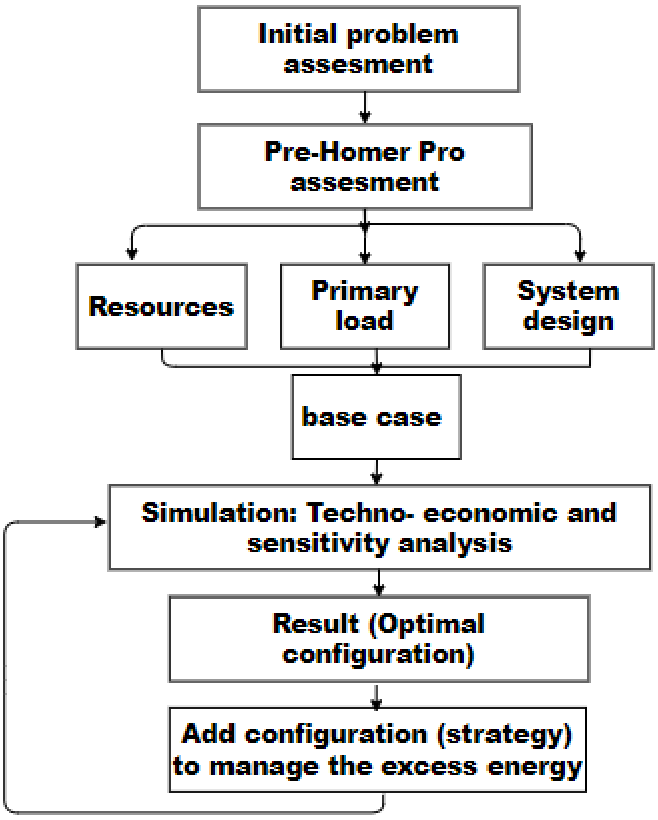

Figure 3.1: Methodology of research

Initially, a stand-alone PV system is designed in Jericho. The solar radiation of the specific place is considered in addition to weather data. The main elements are: PV modules, diesel generator, BSS, and the converter. Homer Pro software is utilized to obtain the optimum design with lowest excess energy and lowest net cost and cost of energy.

The aim of the research is to implement specific strategies to exploit the excess energy and use it in specific applications at the lowest possible prices and highest efficiency. While the least COE is not necessarily the best one, because the excess energy can be used in other applications.

The proposed strategies are:

- PV/Diesel Generator/BSS with Water Pumping System.
- PV/Diesel Generator/BSS with Fuel cell system.
- PV/Diesel Generator/BSS with boiler water heating system.
- PV/Diesel Generator/BSS with hybrid boiler water heating and Water Pumping System

The suggested strategies will be developed to reduce the excess capacity and apply each strategy to the base system, analyze it, discuss the results, and compare the strategies in terms of the final value of the excess energy, taking into account several basic factors, the most important of which are the NPC and COE for each system.

Chapter Four
Structure of base case

In this chapter, the base system will be designed and the basic elements of the system assumed, then the system will be analyzed and the best design will be obtained that enables obtaining the lowest value for the excess energy and obtaining price values for the base system and the price of the energy produced after that the excess energy will be managed through several strategies that will be detailed in this chapter.

4.1 Structure of base system

The first step in designing any system is to know the load in the area to be designed and to take into account all the electrical loads present, and determining the basic elements of the system designed to stabilize them and adding other elements to obtain the best management of the surplus energy while preserving the main system. It is important for the economic study, reliability and analysis of a standalone system that it is designed on demand.

Figure (4.1) shows the diagram of base system contains the primary load, photovoltaic cells, converter, batteries and diesel generator.

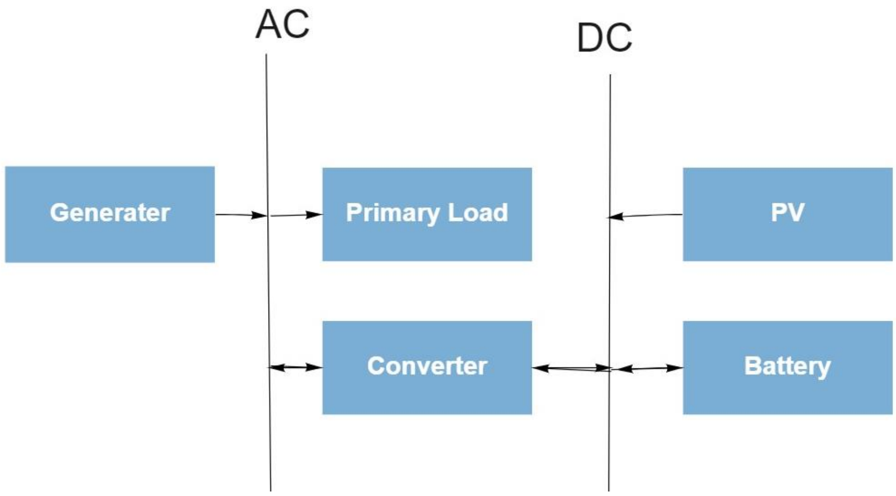

Figure 4.1: Base system

Fundamentals of standalone system design include the followings:

- The main objective of the proposed base system
- Loads and times of use the loads(load profile)
- Geographical characteristics of the proposed site
- Enabled power generators(diesel)
- Solar Fraction (SF): The PV energy as a proportion of the total power supply in stand-alone system
- Usable batteries

A preliminary design can be made using data that can give information on size and suitable power suppliers and components, and each proposed strategy is analyzed on the proposed system.

All the components of the system, their principle of operation, their importance and their classifications will be explained. To facilitate their use in this chapter in analyzing the system and determining the size of these elements and the extent of their use within the base system.

The proposed base system will give the electricity the residential load and the water energy will operate a pump as a proposed scenario. The chosen community includes about 10 homes.

The following Table (4.1) provides the assumed loads, their strengths, and typical operating times of the day.

Table 4.1: Proposed loads for one household

Electrical Appliances	Nominal power (Watt)	Operating time per day (h)	Energy consumption per day
Air Conditioner	3500	2	7 kWh
Dryer	1000	0.25	0.25 kWh
Washing machine	2000	0.5	1 kWh
Cooker (hob and oven)	2000	0.25	0.5 kWh
Dishwasher	1300	0.25	0.325 kWh
Water pump	200	1	0.2 kWh
Computer	150	1	0.15 kWh
Freezer 200 L	100	2	0.2 kWh
Kettle	1800	0.1	0.18 kWh
Refrigerator	90	5	0.45 kWh
Television (screen size 28")	100	3	0.3 kWh
Microwave oven	1200	0.1	0.12 kWh
Toaster	1200	0.1	0.12 kWh
Hair dryer	1000	0.25	0.25 kWh
Iron	1000	0.1	0.1 kWh
Energy saving lamp	15	8	0.12 kWh
Satellite receiver	18	3	0.054 kWh
Mixer	200	0.1	0.02 kWh
Shaver	15	0.1	0.0015 kWh

Table 4.1 shows an example of household loads for one day. All the values are estimated maybe should be more or less. The 10 homes are assumed to have the same loads. The average load energy demand is 111.02 kWh / day and the average power demand is 4.63kW. Average load factor is 0.39.

The residential load will be included in the Homer Pro program in the form of a residential load throughout the year, summer and winter as shown in Figure (4.2).

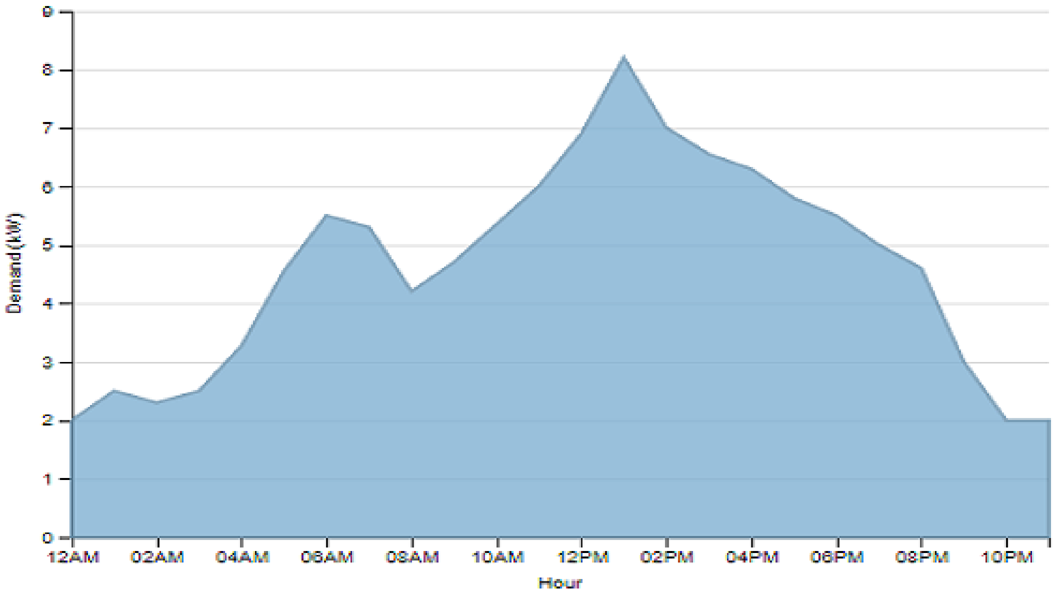

Figure 4.2: Average power demand for residential load

4.1.1 Solar Photovoltaic systems

Solar Photovoltaic (PV) systems are semiconductor devices that convert sunlight into electrical energy. Photons of light that collide with the solar panel hit the electrons, and these electrons are directed outside the panel to generate electricity with direct current. Inverter is used to convert DC into AC, which makes it more usable directly for consumers because most modern electrical appliances only run on AC power. Solar PV systems provide many advantages including simple design, long operating life, high reliability and no additional pollution while saving energy.

Its mission is to collect solar energy and convert it into useful electricity. Solar panels are made of silicon which has semiconducting properties.

Number of these solar cells are required to build a solar panel and many of them form a photovoltaic array. There are three types of photovoltaic: mono crystalline silicon, polycrystalline silicon, and thin film.

4.1.2 Diesel Generator

A diesel generator is an electric generator with diesel engine and other auxiliary devices to generate electrical energy. Used as a part of spots without connection with a power grid, or as emergency power(backup) supply if the grid drops, and for complex applications peak-lopping, grid support and fare to the power grid.

The diesel fuel density was considered as 820 kg / m^3, a lower heating value of 43.2 MJ / kg, a carbon content of 88%, and a sulfur content of 0.33%. The average price of diesel fuel in the PT for the year (2020) was about US $ 1.3 / litter.

The efficiency of a generator is represented below in Figure (4.3) as a function of load for a fixed speed. The maximum out power is limited by the operating speed. At high speeds (3600 RPM), the maximum power will be higher, the output load percent will be lower, the efficiency will decreasing. While low operating speeds (1800 RPM), the maximum power will be lower, increasing the efficiency of the load, but the output power will be limited. The efficiency of the system could be improved by allowing the speed to vary with respect to the specific load, or increasing load to correspond to the maximum output for a given speed.

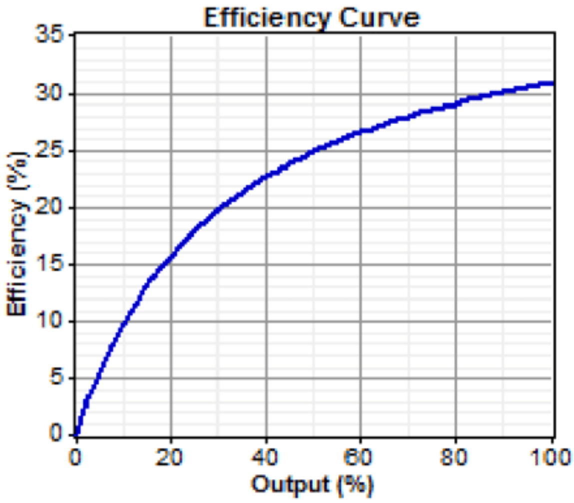

Figure 4.3: Efficiency of diesel generator[25]

4.1.3 Solar batteries

Solar energy systems generate electrical energy during the availability of solar radiation and can feed the elements associated with it in real time. But in the absence of solar radiation or in poor environmental conditions, the need for a way to store energy that generated for later use, and here lies the importance of batteries in solar systems isolated from the grid.

Solar batteries are an important solution to dispense with the electrical grid and save on electricity costs. Scientists are doing many researches to develop batteries in terms of their efficiency and capacity, in addition to increasing their safety and stability. Important discoveries have begun to appear that may change the future of solar systems and electric cars.

Batteries operate according to the oxidation and reduction process and consist of two main components: the positive electrode in which the positive charges collect and attract negative charges (electrons), and the cathode in which the electrons collect, and the electrically conductive element (electrolyte). This part separates the anode and the cathode and allows the transfer of positive charges inside the battery from positive electrode to negative electrode. The electrons are prevented from passing through it, and thus to transfer electrons. The battery must be connected to an external circuit, which pushes the electrons to pass through the external circuit to reach the positive electrode, thus forming an electric current. Batteries vary due to the difference in the type of anode and cathode in addition to the type of electrolyte, as it was a liquid rich in electrolytes, then using semi-polymers or gels to replace liquids.

Battery capacity is a measure of the charges stored in the battery that generated by electrochemical reactions in the battery, and it is measured in (Ah). Amount of energy can be extracted from the battery under certain conditions such as temperature, charging and discharging rates, and to the battery's default life. The battery capacity very important whereas charging and discharging rates effect on it, as the rapid discharge of the battery as the current drawn is large, the nominal battery capacity will decrease every time and the battery cannot be fully discharged due to the internal design of the batteries as it maintains a certain amount of charges to avoid damage to the internal components.

Battery depth (DOD) indicates the percentage of battery discharged in relation to total battery capacity and SOC is an amount of the battery charge level and is the opposite of DOD. Usually SOC is used to discuss the current state of the battery in use while DOD is used when discussing battery life.

Figure 4.4: Battery

4.1.4 Inverters

The solar panels convert the energy from solar radiation into electrical energy, the electricity is produced in the form of DC. The DC must be converted into an AC to be used in electrical devices, for this reason inverters are used.

The inverter in electrical systems is the second most important component, as it converts the DC from the PV panels into an AC compatible with the devices. Inverters monitor and control the PV system, ensure the PV panels operate at maximum power under conditions of solar radiation and real temperature. And it monitors the electricity company constantly and is responsible for involve to various safety standards.

A lot of inverters types used in PV systems and all of them operate according to the same principle. The difference lies in the power factors, the design in the continuous section of the solar system, and the topology of the electrical circuit. Inverters for solar systems are divided into the following types: Central inverters, string inverters and micro inverters.

To choose the right inverter for the project, the most important basic principles are: the size of the project, costs, the location of the project and the surrounding conditions.

Today, companies are working on developing these inverters and increasing their capacity from less than one kilowatt of micro-inverters to 4.6 megawatts for central inverters. The companies that manufacture inverters are also communicating with the panel manufacturers to produce photoelectric panels equipped with built-in micro inverters, which saves labor. It reduces installation costs, so there is no need to install panels and install inverters separately. Figure(4.5) shows the efficiency of inverter.

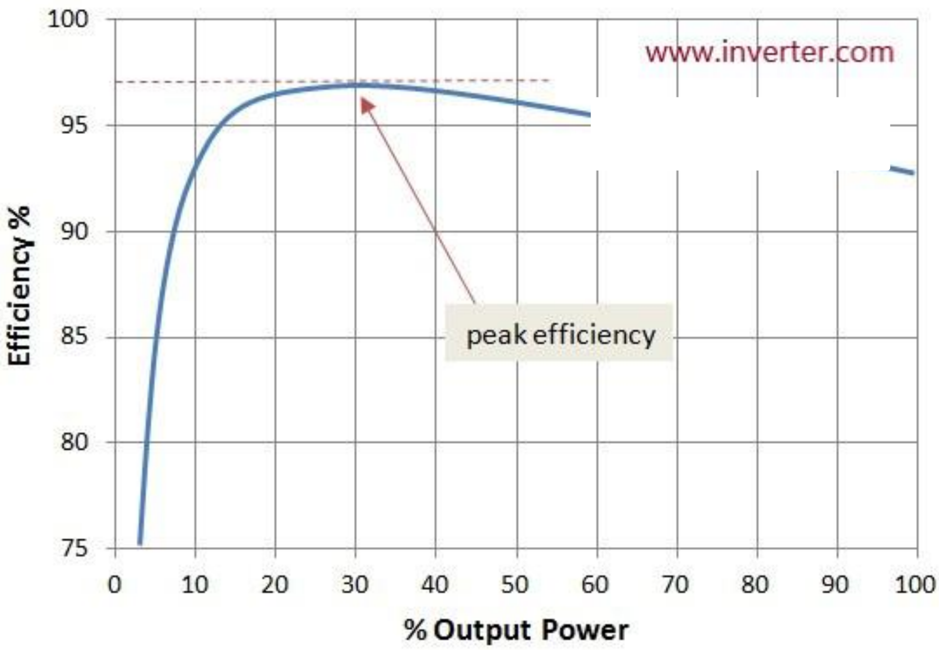

Figure 4.5: Efficiency of inverter

Designing RES for small grids is very complex and needs exact values. HOMER Pro is a tool used to efficiently solve such problems, aiming to arrive at an optimum strategy by sensitivity analysis with many variables. HOMER stands for Hybrid Renewable Energy Improvement Model.

4.2 Simulation Software

Homer Pro Software will be utilized to implement the system and analyze each proposed strategy.

HOMER is a simulation model, used to simulate a proposed system of all possible strategies of components being considered. HOMER simulates alot of systems. The simulation then optimization step. The simulated systems are sorted and filtered according to criteria and parameters that we define and considered, so we can see the best possible solution. And HOMER fundamentally is an economic optimization model, also to choose the minimum using of fuel. The sensitivity analysis was used to know the effect of variables as required, such as cost of parameters, and to see how the optimum proposed system changes with these differences.

Life cycle cost approach is very important to the economic analysis at Homer pro by calculating the net present value. And will be more realistic and convenient when it comes to comparing systems[26]. The net present value is calculated using (1).

$$NPV = InitialCost + Annualcost\ ((1 + i)\ N \text{ - } 1i\ (1 +)\ N) \quad (1)$$

HOMER Analysis provides a lot of indicators. The most important one is Stable Cost of Energy (COE) in USD / kWh which is a good value to compare with other alternatives energy resources and systems. Cost of energy can be calculated using (2).

$$COE = NPV\ (\ (1+i)N\ (1+i)N-1)\ /\ El+Edef+Egrid \quad (2)$$

Where El and E_{def} are the sum of the initial load and deferred load quantities, respectively. E_{grid} is the annual amount of electrical energy sold to the grid. HOMER simulates the different strategies of the hybrid system during the process improvement. An optimal solution is a configuration that gives a minimum net present value and minimum cost of energy [27].

4.2.1 Site description

The case study is located in Jericho. It contains large lands far from the network and lands not suitable for agriculture that can be exploited and benefited from. Jericho is located in the Jordan valley, and it is bounded on the east by the Jordan river and Jerusalem on the west.

4.2.2 Solar radiations profile

PT have good solar radiation to be used for electricity generation. The daily average of solar radiation was measured to be 5.45kWh/m^2 day[4]. Figure (4.6) shows the monthly average daily solar radiation input data of the selected proposed site (Jericho) to HOMER software which data set using special procedure from NASA meteorology and solar energy data base at specific day. The monthly solar radiation of Jericho city as shown in Figure (4.6). The hourly average temperature during the day is ranging from 20 to 27°C as shown in Figure (4.7).

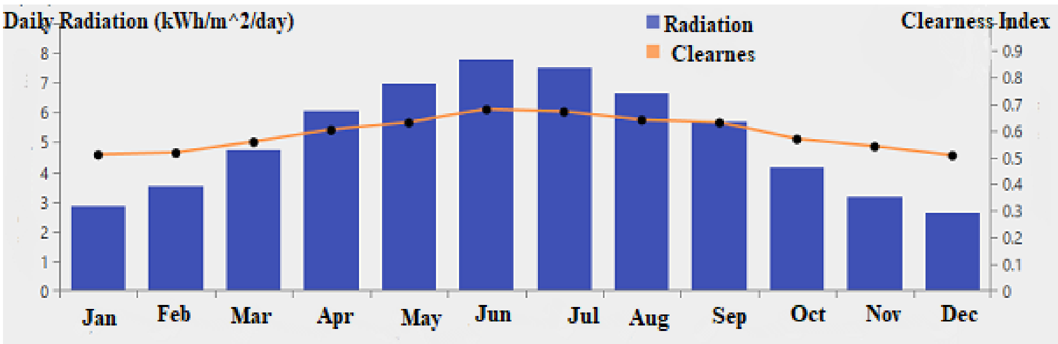

Figure 4.6: Monthly average daily solar radiation input data of the selected from NASA meteorology and solar energy data base.

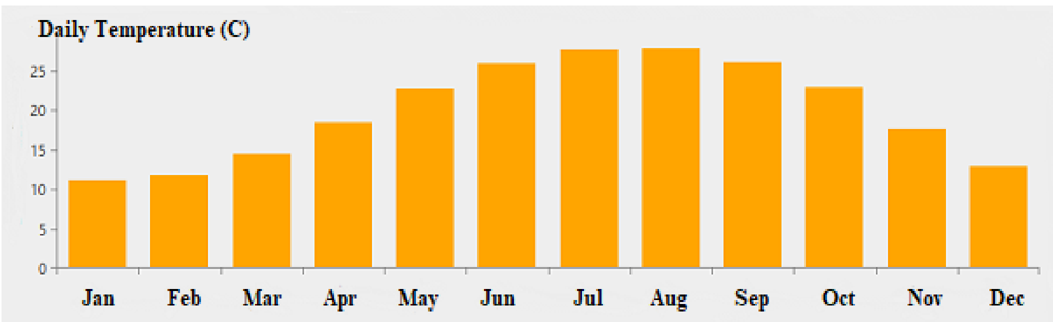

Figure 4.7: Hourly average temperature during the day in Jericho from NASA meteorology and solar energy data base.

4.2.3 Wind speed profile

Wind energy potential in PT is limited. Therefore, wind turbines will not be taken into account in this study. Figure (4.8) shows average of wind speed in PT.

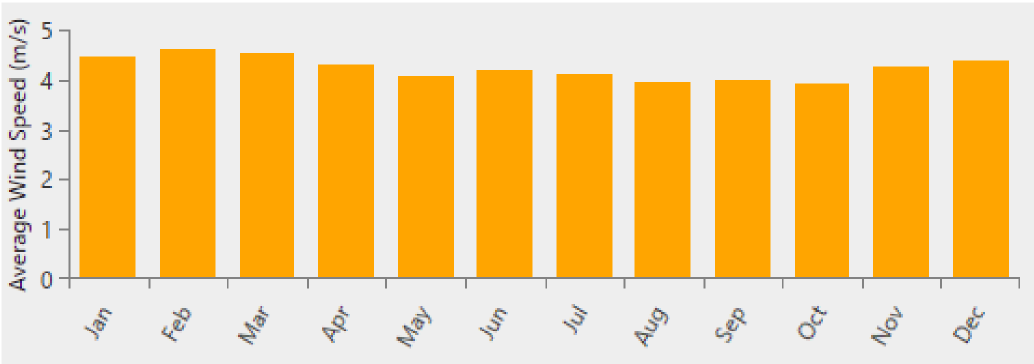

Figure 4.8: Average wind speed in PT from NASA meteorology and solar energy data base.

4.3 The Homer Configuration of the base system

The base proposed configuration of the hybrid system studied in this research is presented as it consists of PV, a battery storage system and a diesel generator. The analysis of a system by using the HOMER pro program. The technical specifications and the cost of all components are used will be illustrated, according to local prices in the PT for the year 2020.

Firstly, a standalone solar PV system was designed with batteries to store the energy produced and a diesel generator to generate energy. Figure (4.9) shows the schematic base system on Homer pro.

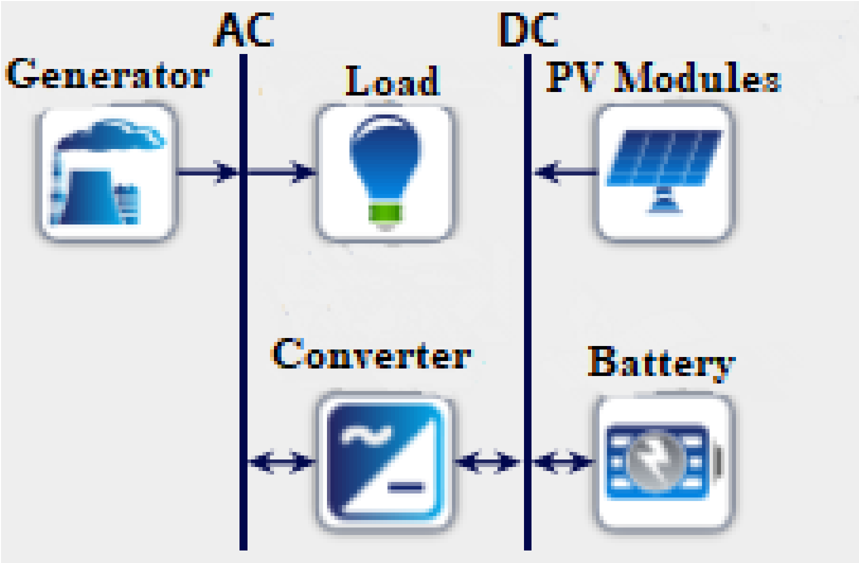

Figure 4.9: A schematic of the proposed base system

The aim of this work is to analyze the excess energy in the base configuration system to reduce this excess energy and use it with adding strategy to manage the excess energy.

The solar photovoltaic panels, which are the basis of the system to generate electric power from *Trina Tallmax M Plus* were added with efficiency 17.8 %, with capital cost 360$/kW, operation and maintenance cost 15$/ year were added (All components prices are listed by a Palestinian company[32]). Through the analysis, it was found that the best value for solar panels is 30 kilowatts. The results will be explained in detail later. The solar photovoltaic specifications are given in the appendix.

A 3 kW diesel generator was added with capital cost 550$. The operation and maintenance cost is 0.036$/operational hour. As for the period of operation of the generator, it was based on the analysis of the program and the selection of the best operating times according to the required inputs and loads, as the program determined the hours required to operate the generator to ensure that no overload occurred and that no large excess power occurred.

The converter was added within the range of 18 kilowatts and through analysis, with capital cost 1390$, operational and maintenance cost 15$/year. It was found that the best value of the converter was at at the lowest value of the excess energy and the lowest total price and price for the energy produced.

Added Surrette 6 CS 25P battery with 6v voltage per battery, 1150 Ah electric capacity for one battery, with capital cost 550$, operation and maintenance cost 15$/year, each series contains 4 batteries. Batteries within a certain range have been added 72 batteries, initial charge state 100% and minimum charge state 10%. After analysis, it was found that the best number of batteries at the lowest value of excess energy is 40 batteries. Table (4.2) shows the summary of components of base system.

Table 4.2: Components of base system

Component	PV modules	BSS	System Converter	Diesel Generator
Capital cost	360 $/kW	550 $ each one	1390 $/kW	550 $/kW
Replacement	360 $/kW	550 $ each one	1390 $/kW	550 $/kW
O&M	15 $/year	15 $/year	15 $/year	0.036 $/op.h
Range	0-35 kW	0-72 battery	0-15 kW	0-5 kW

The results of the base system (Primary proposed system) show the amount of excess energy. Figure (4.10) shows the average excess energy distributed throughout the year for each month by average the excess energy on the interval where is it from 9:00 AM to 14:00 PM (6 Hours). Then the average for all of days in each month.

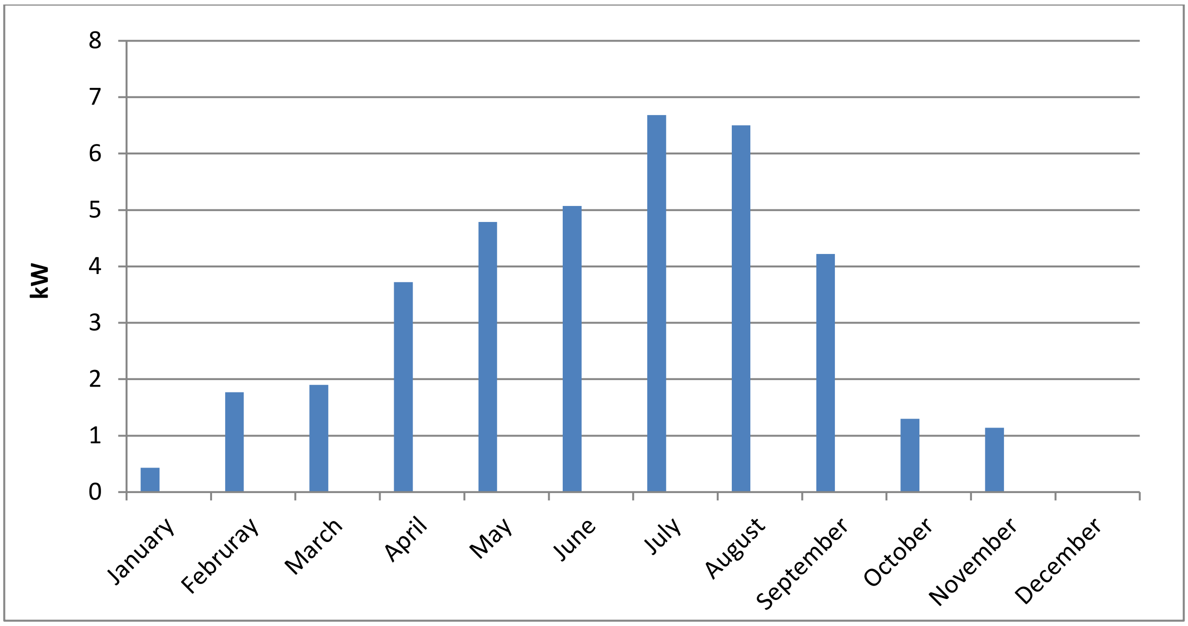

Figure 4.10: The amount of excess energy distributed throughout the year

It is possible to know the amount of excess energy in any month during the year by focusing on the required period and knowing the excess energy specifically at a specific time. As an example, it focused on the month of July to know the amount of this energy exactly just zoom on the period. When the amount of excess energy is known, it is easy to design other configurations that will be added to the proposed system and analyze the results and their feasibility.

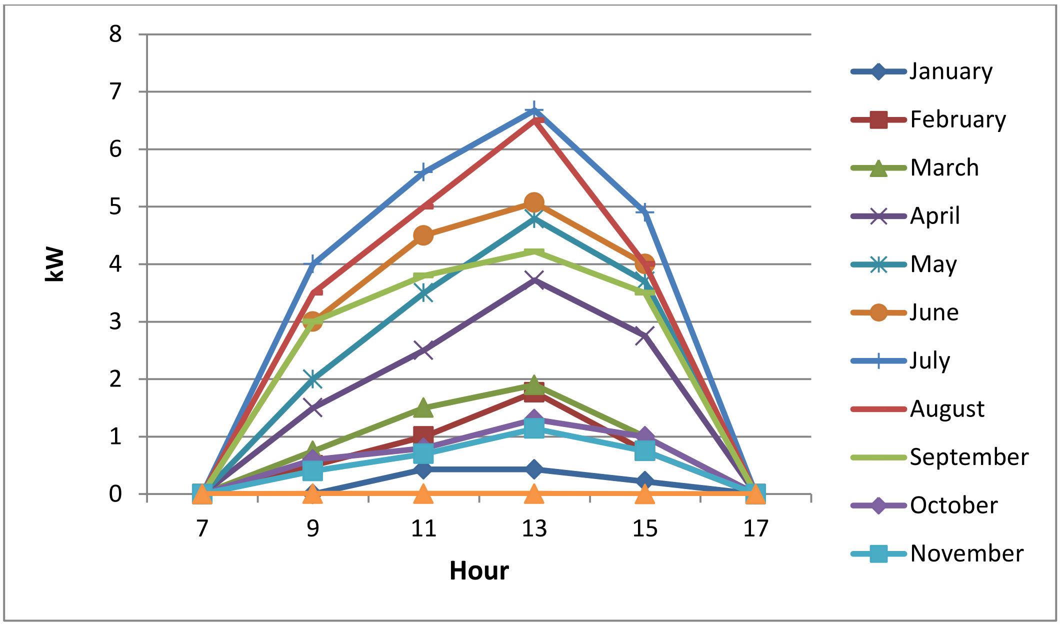

Figure 4.11: Surplus electrical distribution in each month through the day

Figure (4.11) shows the surplus electrical distribution in each month through the day, as it facilitates the management of excess energy at these times in several different configurations, study and analysis of each configuration separately, knowledge of economic feasibility, sensitivity analysis for several variables, and the extent to which the excess energy is exploited. Figure (4.12) shows the hourly excess electrical power distribution all the year with time (The area under the curve represents energy distribution).

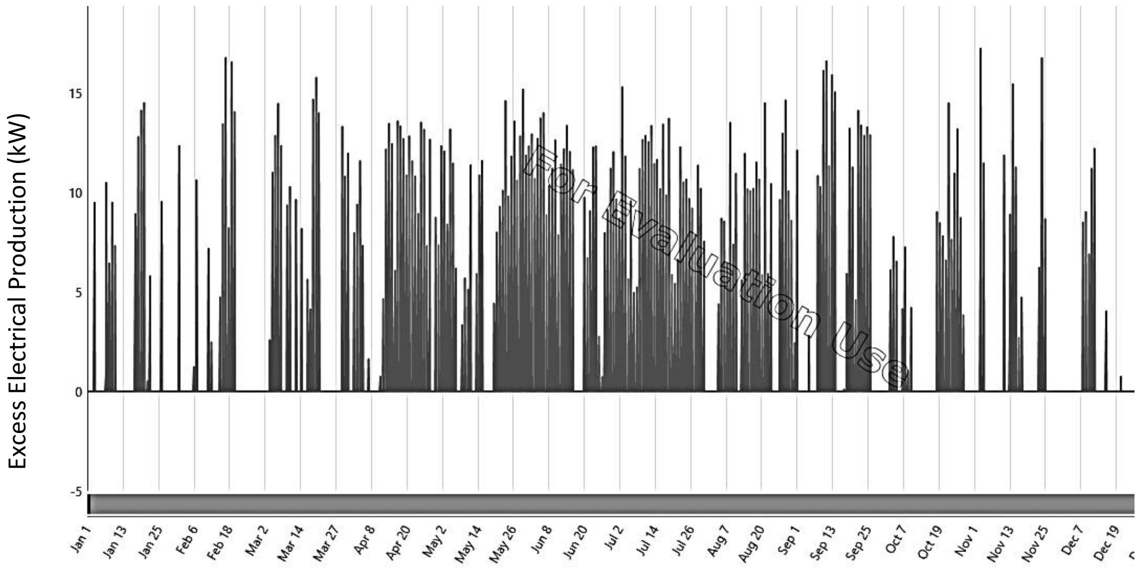

Figure 4.12: Hourly distribution of excess energy all the months of year

Figure (4.13) shows the economic result of cash flow summary of the net present cost of the main components of the proposed base system. The net present cost of the main components of a system USD 101,361. The COE is USD 0.194 /kWh. The contribution of renewable energy is 92.2%. The excess electricity is 7469 kWh/year which is about 13.8%.

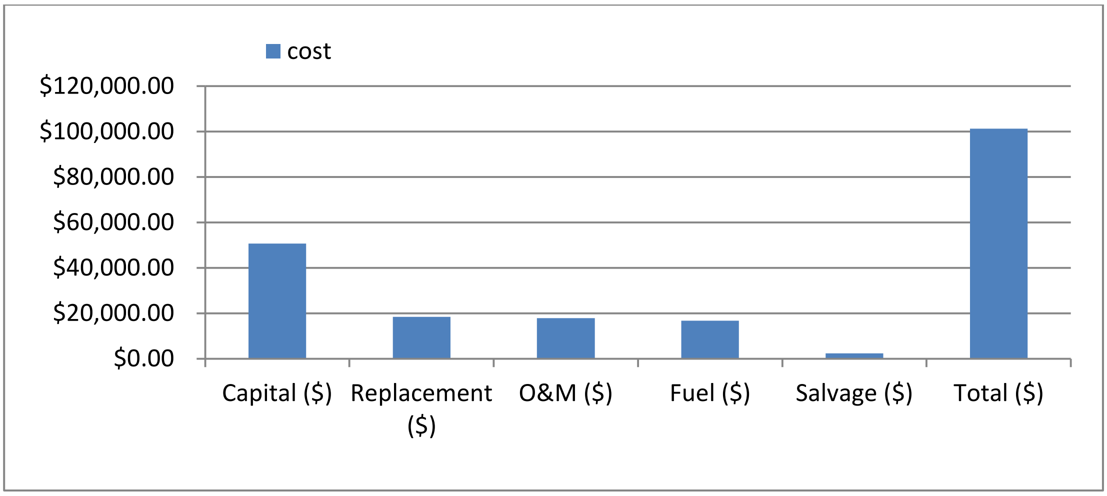

Figure 4.13: Simulation economic results: Cash flow summary of base system.

Table (4.3) shows a summarization of the results of the base proposed system. The data was taken from Homer pro analysis.

Table 4.3: A summarization of the results of the base proposed system

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Diesel Generator	1,650.00	1,397.75	1,986.75	16,773.59	248.36	21,559.72
Battery	22,000.00	10,127.42	7,756.51	0.00	833.08	39,050.84
System Converter	16,263.00	6,899.97	2,268.78	0.00	1,298.64	24,133.10
PV modules	10,800.00	0.00	5,817.38	0.00	0.00	16,617.38
Total System	50,713.00	18,425.13	17,829.42	16,773.59	2,380.09	101,361.05

Emissions

Emissions are very important in all regulations, as there are tax on emissions values in many countries, so it is important to study these emissions according to each country. The following Table (4.4) shows the amount of air pollutants produced in the configuration. The data from report of this project on Homer pro.

Table 4.4: Emissions from base system

Pollutant	Quantity Unit
Carbon Dioxide	2,613 kg/yr
Carbon Monoxide	16.3 kg/yr
Unburned Hydrocarbons	0.719 kg/yr
Particulate Matter	0.0978 kg/yr
Sulfur Dioxide	6.40 kg/yr
Nitrogen Oxides	15.3 kg/yr

Sensitivity Analysis

In order to conclude the effect of each criteria on other parameters (the COE and NPC) choose to perform sensitivity analysis.

The effect of cost of diesel fuel is calculated. The effect of maximum annual capacity shortage (MACS) is calculated. The solar radiation in PT according to historical data is constant most of the year and then not subjected to sensitivity analysis [28].

Figure (4.14) shows the sensitivity analysis result is effect of cost PV modules on NPC & COE. NPC and COE increase with the cost of PV modules.

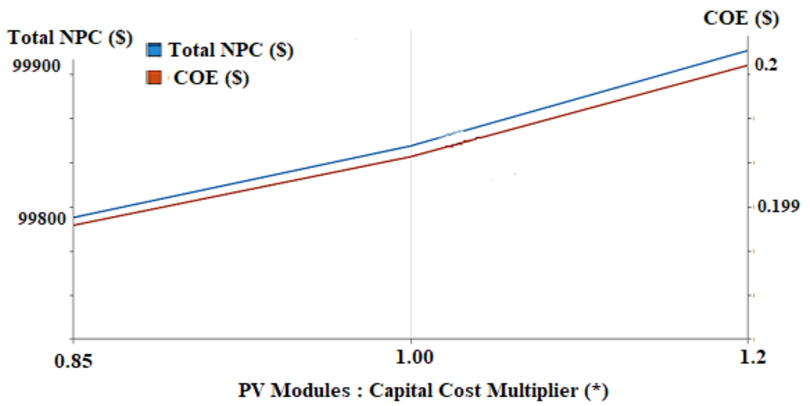

Figure 4.14: Sensitivity analysis result: effect of cost PV modules on NPC & COE

Figure (4.15) shows the sensitivity analysis result about effect of cost battery on NPC & COE.NPC and COE increase with the cost of battery.

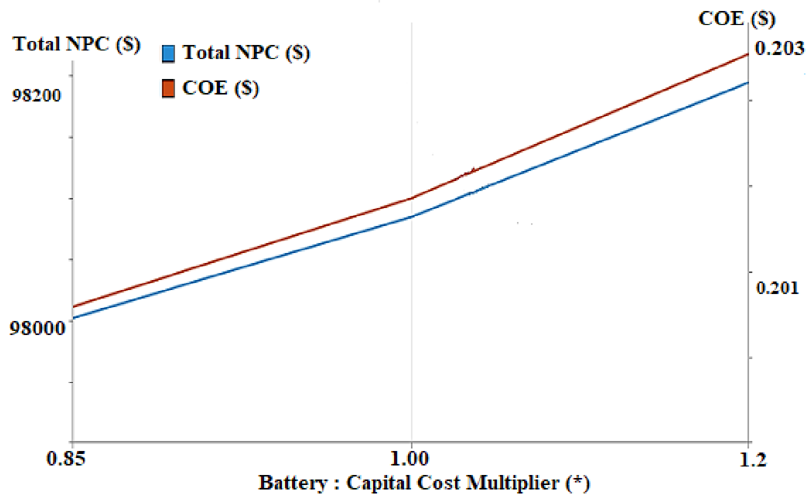

Figure 4.15: Sensitivity analysis result: effect of cost battery on NPC & COE.

Figure (4.16) shows the sensitivity analysis result about effect of cost generator on NPC & COE.NPC and COE increase with the cost of diesel generator.

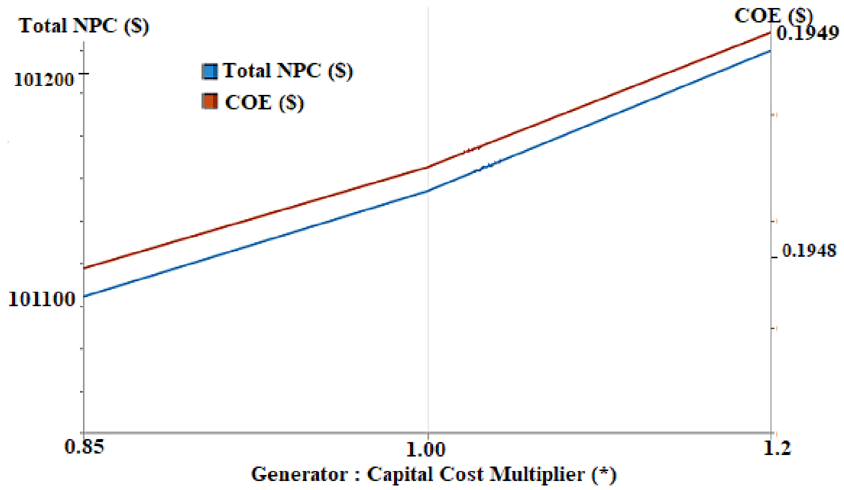

Figure 4.16: Sensitivity analysis result : effect of cost diesel generator on NPC & COE

Figure (4.17) shows the sensitivity analysis result about effect of cost of fuel on NPC & COE.NPC and COE increase with the cost of fuel.

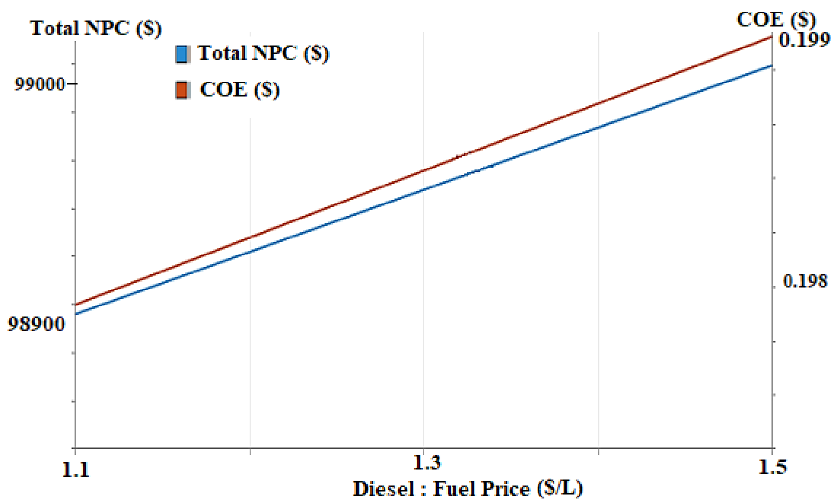

Figure 4.17: Sensitivity analysis result : effect of cost of fuel on NPC & COE

Chapter Five

Energy Management of Excess Energy

Not utilizing the excess energy increases the COE and causes technical problems as the distortion in the system voltage and frequency. The efficient use of additional energy will increase the applicability of these systems. Managing the excess of electrical power is very important in standalone system. In this thesis different configuration and strategies will be analyzed to reduce the amount of excess electrical power. In order to take advantage of the excess electrical power and thus reduce unit-owned equipment, the study proposes an energy management measure.

There are different strategies and configurations that can be used to benefit from the excess electrical energy:

- PV/Diesel Generator/BSS with Water Pumping System.
- PV/Diesel Generator/BSS with Fuel cell system.
- PV/Diesel Generator/BSS with boiler water heating system.
- PV/Diesel Generator/BSS with hybrid boiler water heating and Water Pumping System

5.1 PV/Diesel Generator/BSS with Water Pumping System

In some circumstances, there is a potential to utilize the excess energy for water pumping. These circumstances are available in rural area. Water pumping system potential energy is by storing water in a tank at a certain height. The tank is located at a certain height and the water is flowing by gravity and sometimes small pump is used. The flow rate is the amount of water that flows in or out (cubic meters per second).

The initial charge state determines the portion of the storage tank full of water at the start of the simulation. Figure (5.1) shows the hydro pump system with based system.

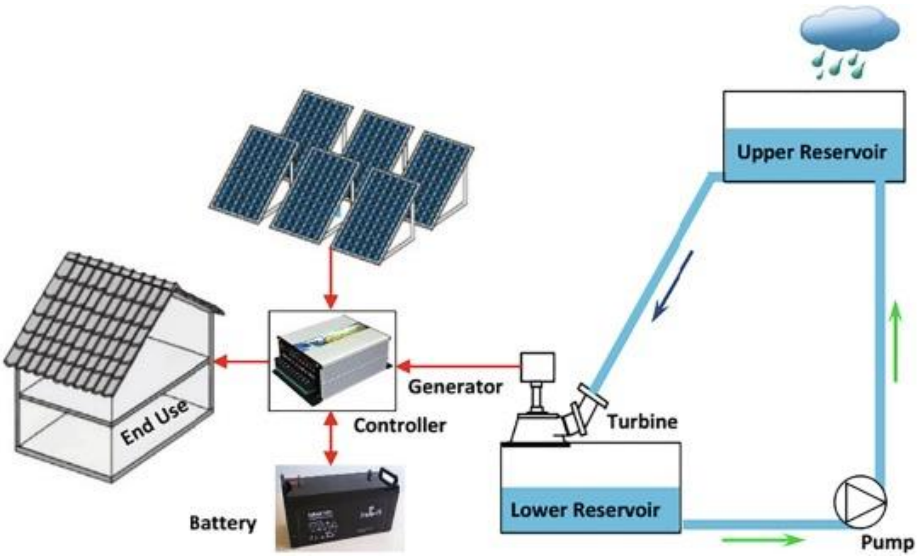

Figure 5.1: Hydro pump system[30]

HOMER pro displays results by showing the least cost proposed configuration within each scenario. The program proposes different configurations, where the components will be installed at the lowest costs and the least excess energy (base case). Then add other system configurations and compare the results in terms of cost and excess energy. After running a large number of simulations, the results appear as follows: The pump will be added when there is excess energy, and that energy is used as much as possible.

After analyzing the distribution of the excess energy, it is not easy to deal with the all fluctuations of the excess energy, the pump cannot run at any time for the excess power, such as 1 kW in 11:00 or 2 kW at 14:00. The operation of the pump in a fixed range, there is no flexibility in operation, due to the principle of operation, which depends on the motor where there is a certain frequency, voltage, etc. The load profile of pump load as shown in Figure (5.2).

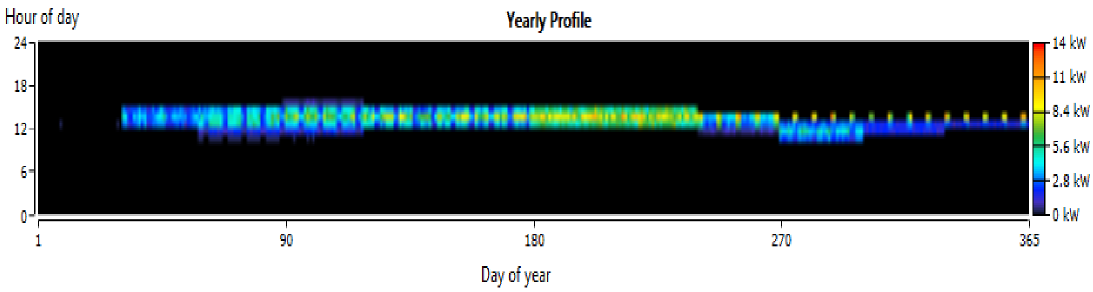

Figure 5.2: Load profile for proposed pump load from Homer pro software

A schematic of proposed pump load with base system is shown in Figure (5.3). The system is consists of photovoltaic cells, a diesel generator, batteries, water pump, and power conditioning system.

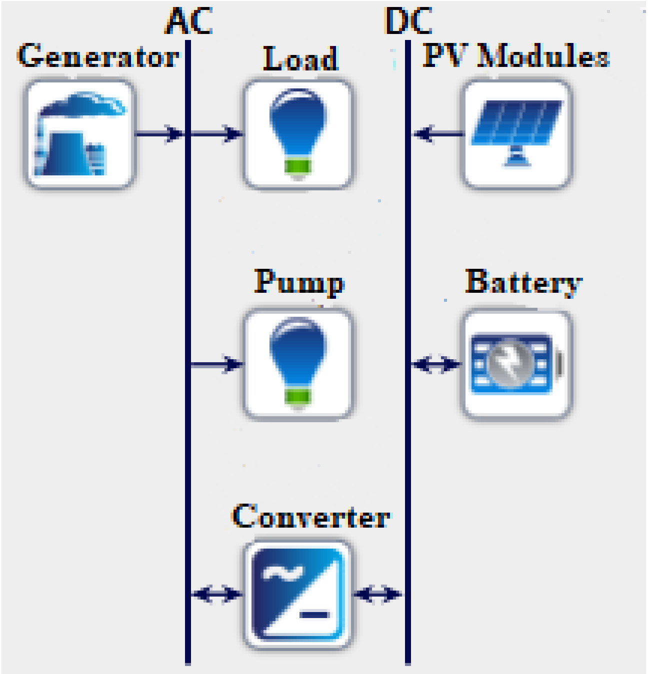

Figure 5 3: A schematic diagram of PV/Diesel Generator/BSS with Water Pumping System

The results indicate that the excess energy is reduced after adding the pump load, provided that the system elements remain constant. The excess energy percentage decreased by approximately 2.5%. Table (5.1) shows the effect of adding pump on the base system.

Table 5.1:The effect of adding pump on the base system.

	With adding pump	Without pump
No. of battery	40	40
NPC ($)	122,347	101,361
COE ($/kWh)	0.212	0.194
Excess energy(%)	11.3	13.8
Excess energy (kWh/year)	6483	7469
Renewable energy fraction (%)	85.9	92.2
Unmet electric load (%)	0.733	0.385

Table 5.1 shows that COE is USD 0.212/kWh with pump while COE without pump is USD 0.194/kWh. This is because the reduction in

renewable fraction. The power generation from PV modules is reduced with increase from diesel generator.

Figure (5.4) shows the amount of excess energy for the base proposed system and the system with pump.

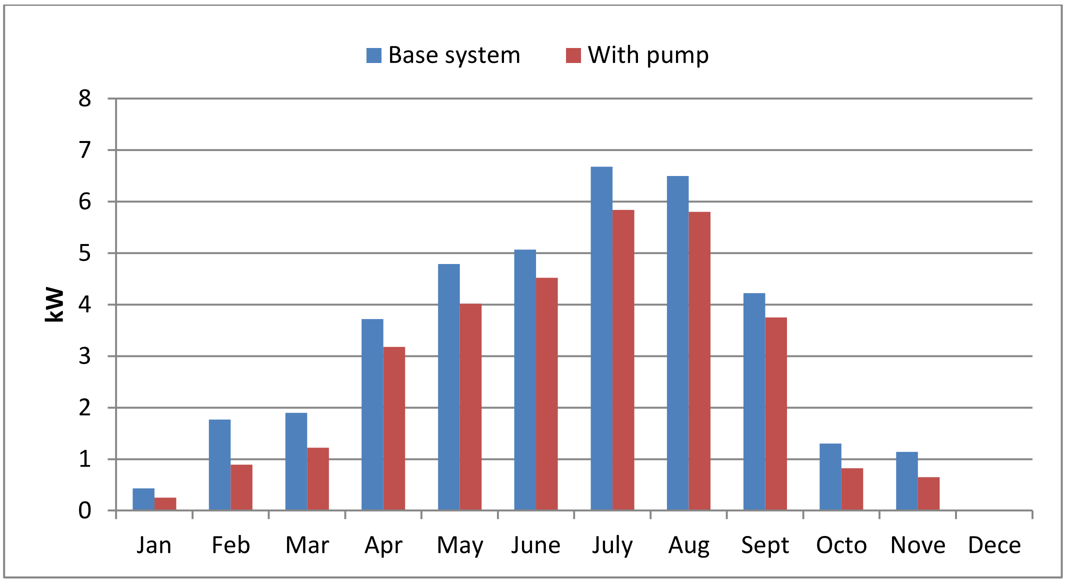

Figure 5.4:The excess energy for base system with pump and without pump.

Figure (5.5) shows the cash flow summary of base proposed system with pump load.

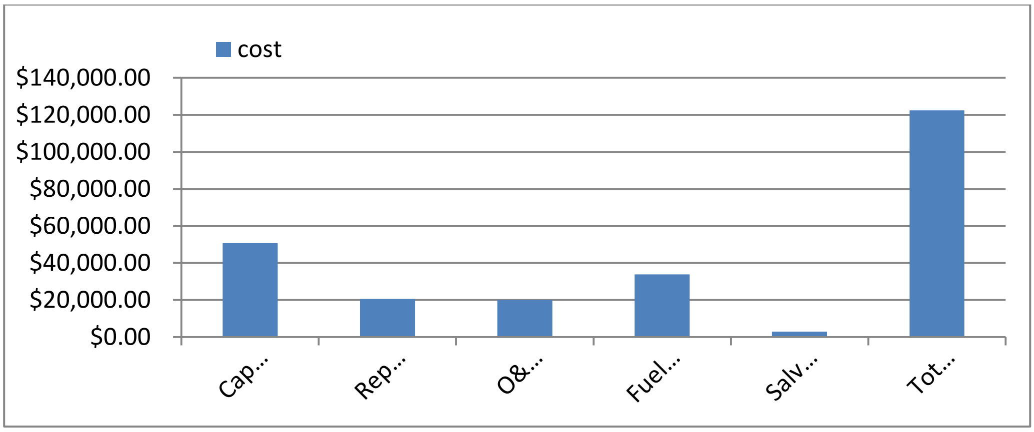

Figure 5.5: Simulation economic results: Cash flow summary of base proposed system with pump load

Table (5.2) shows summarizes the results of PV/Diesel Generator/BSS with Water Pumping System for each component.

Table 5.2: A summarization of the results of the base proposed system with pump load

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Diesel Generator	1,650.00	3,811.34	4,217.83	33,853.55	381.44	43,151.29
Battery	22,000.00	9,853.3	7,756.51	0.00	1,164.71	38,445.1
System Converter	16,263.00	6,899.97	2,268.78	0.00	1,298.64	24,133.10
PV modules	10,800.00	0.00	5,817.38	0.00	0.00	16,617.38
Total System	50,713.00	20,564.6	20,060.51	33,853.55	2,844.79	122,346.87

Emissions

The amount of the air pollution control fee is charged based on the type, composition and quantity of fuel as defined in the country, and will be calculated according to the type of fuel, installation and property standards. In this study will show the amount of air pollution regardless of taxes.

Table (5.3) shows the amount of air pollutants produced in the proposed configuration.

Table 5.3: Emissions from PV/Diesel Generator/BSS with Water Pumping System

Pollutant	Quantity Unit
Carbon Dioxide	2,613 kg/yr
Carbon Monoxide	16.3 kg/yr
Unburned Hydrocarbons	0.719 kg/yr
Particulate Matter	0.0978 kg/yr
Sulfur Dioxide	6.40 kg/yr
Nitrogen Oxides	15.3 kg/yr

Sensitivity Analysis

The effect of variation in the cost of diesel fuel is monthly varied is calculated. The effect of maximum annual capacity shortage (MACS) is calculated. The solar radiation in PT according to historical data is constant and so not subjected to sensitivity analysis [28]. When the cost of PV modules increased the NPC & COE will increase as well as shown in Figure (5.6).

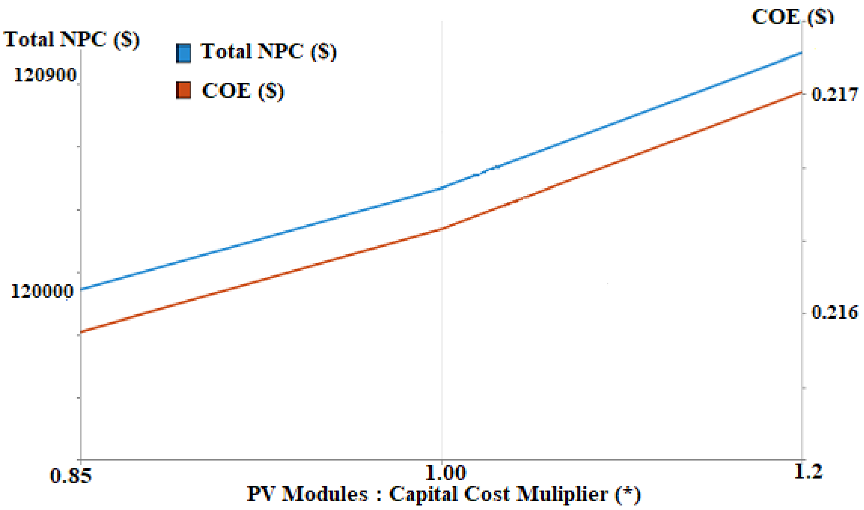

Figure 5.6: Sensitivity analysis result : effect of cost PV modules on NPC & COE

Figure (5.7) and Figure (5.8) show the effect of cost of battery and generator on NPC & COE. Increase in the cost of diesel generator increases NPC and COE. This is true for BSS.

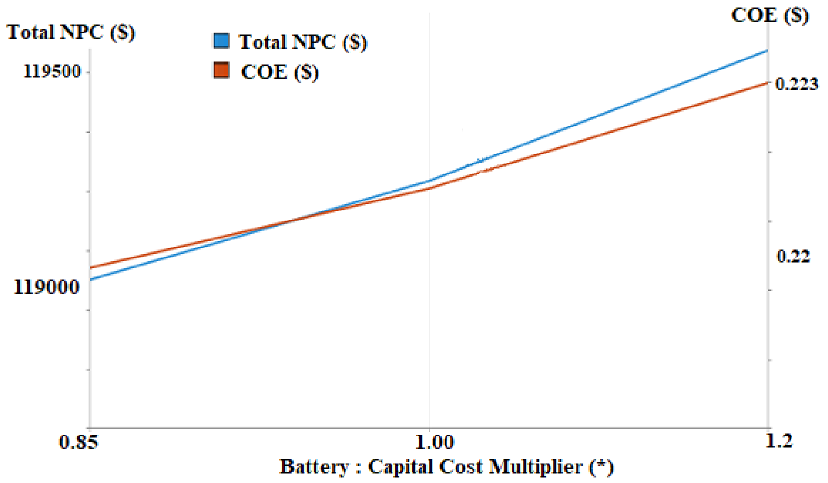

Figure 5.7: Sensitivity analysis result: effect of cost battery on NPC & COE

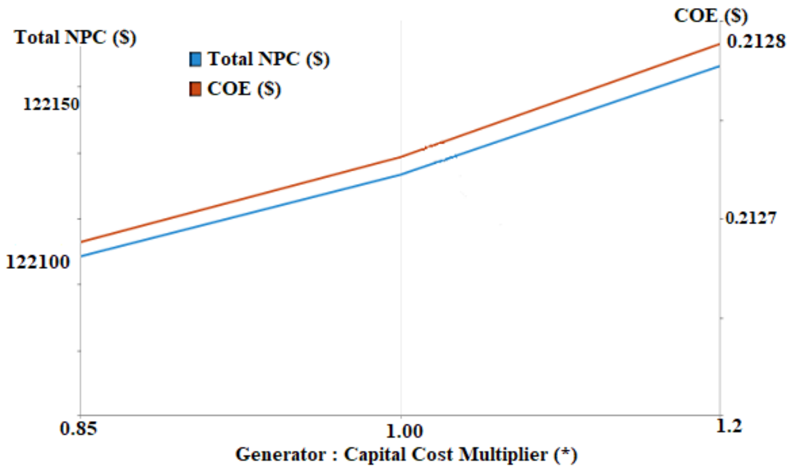

Figure 5.8: Sensitivity analysis result : effect of cost generator on NPC & COE

Figure (5.9) shows the effect of diesel fuel price on NPC & COE.

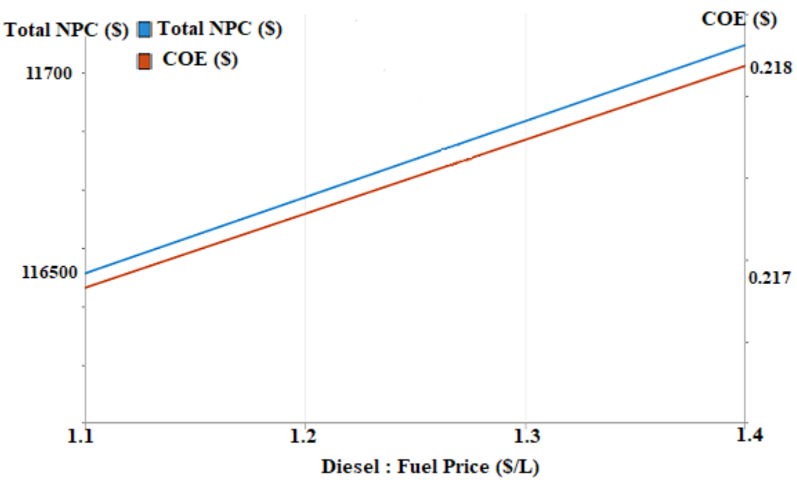

Figure 5.9: Sensitivity analysis result : effect of diesel fuel price on NPC & COE

5.2. PV/Diesel Generator/BSS with Fuel Cell System

An electrolyzer is a storage system that consists of a proton-exchange membrane (PEM) electrolyzer, hydrogen and oxygen storage, and a PEM fuel cell. It operates in a closed water loop uses electricity to separate water into hydrogen and oxygen with heat in a process called electrolysis. The oxygen released into the atmosphere or stored in tanks to supply in other industrial processes or even medical gases. The hydrogen gas can be stored as a compressed gas or liquefied carefully, it can be used to give power any hydrogen fuel cell electric application.

A fuel cell is a cell that produces a direct electric current from a chemical reaction and an electrolyzer is a technology that uses a direct electric current (DC) to drive a non-automatic chemical reaction.

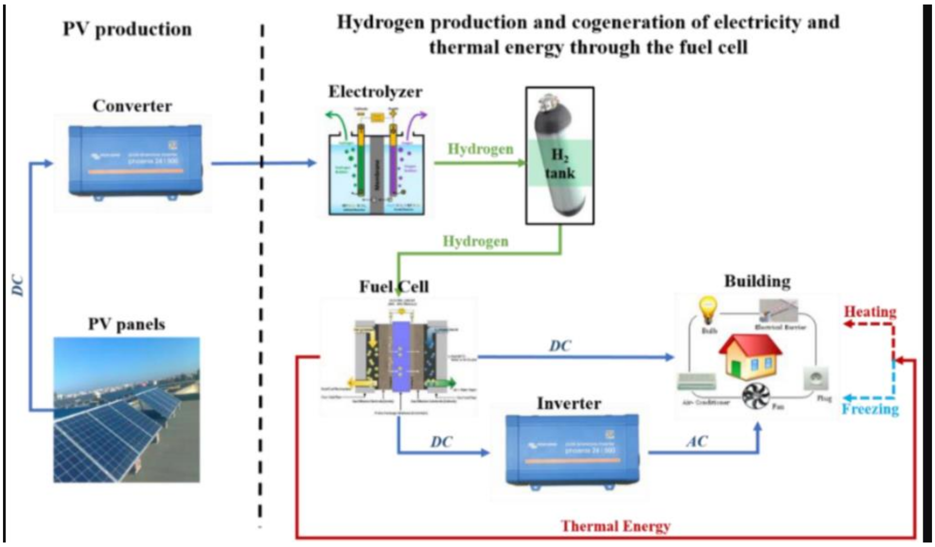

Figure 5.10: Hydrogen production and cogeneration of electricity and thermal energy through the fuel cell [31]

By electrochemical reaction(reverse electrolysis) fuel cells generate electricity. This reaction between hydrogen and oxygen produce water vapor, heat and electricity, can be used by the fuel cell system. The water vapor can be used to add hydrogen and the electricity goes into an external uses where it is used by any electric appliance [31].

For a fuel cell system three main components. The hydrogen source, the fuel cell stacks and the unit of power condition. The hydrogen gas can be reformed from fossil fuels or the unit can be coupled to a renewable energy source and generate hydrogen by separation of water. The fuel cell stack used to convert the hydrogen and oxygen into electricity, water vapor and heat. The last component is the power conditioner, that inverts the DC current from the fuel cell into AC current which many household appliances operate on [31].

This strategy adding electrolyzer, fuel cell and hydrogen tank where is amount of excess energy, as this energy is used as much as possible. PV/Diesel Generator/BSS with Fuel Cell proposed system is shown in Figure (5.11).

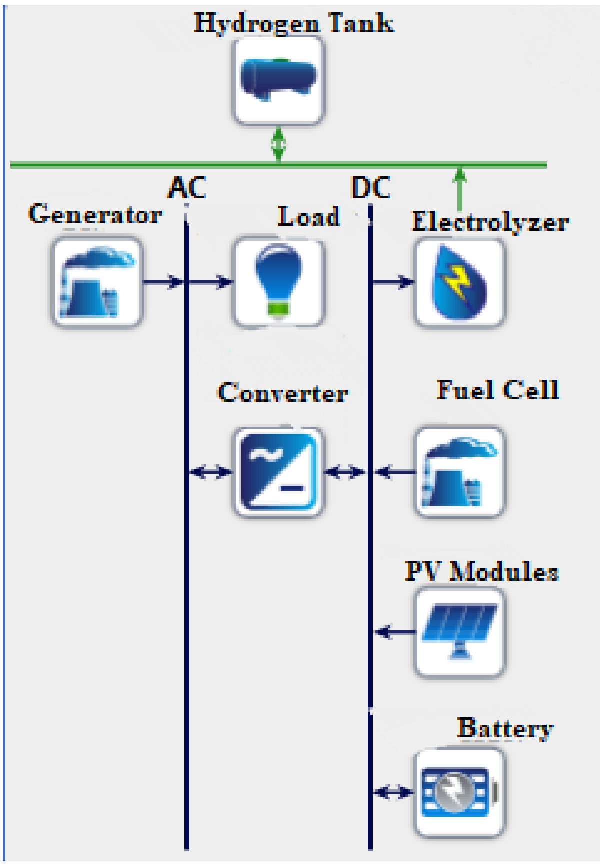

Figure 5.11: A schematic diagram of the microgrid hybrid power system with Electrolyzer, Fuel cell and hydrogen tank

A fuel cell with specific costs and a size of 1 kilowatts was chosen in order to use hydrogen to react with the existing oxygen and produce energy. Also, the electrolyzer with a size of 15 kilowatts was chosen to analyze water and obtain separate hydrogen for use in the fuel cell, and in the event that an excess amount of hydrogen is available, it is stored in special tanks under certain conditions and a size ranging up to 4 kg.

The results indicate that the excess energy is reduced after adding the fuel cell, provided that the system elements remain constant. The excess energy percentage decreased by approximately 5%. The net present cost is USD 129,368. The COE is USD 0.21 /kWh. The contribution of renewable energy is 85.2%. The excess electricity is 5119 kWh/year which is about

8.8%. The unmet electric load is about 0.745%. Table (5.4) shows the difference in the amount of excess energy of the base system with pump and Electrolyzer, Fuel cell and hydrogen tank.

Table 5.4: The difference in the amount of excess energy of the base system with the presence of a pump, Electrolyzer, Fuel cell and hydrogen tank.

The configuration of the system	Base system	With pump	With Electrolyzer, Fuel cell and hydrogen tank
No. of battery	40	40	40
NPC ($)	101,361	122,346	129,368
COE ($)	.194	0.212	.21
Excess energy(%)	13.8	11.3	8.8
Excess energy (kW/year)	7469	6483	5119
Renewable energy fraction (%)	92.2	85.9	85.2
Unmet electric load (%)	.385	.733	.745

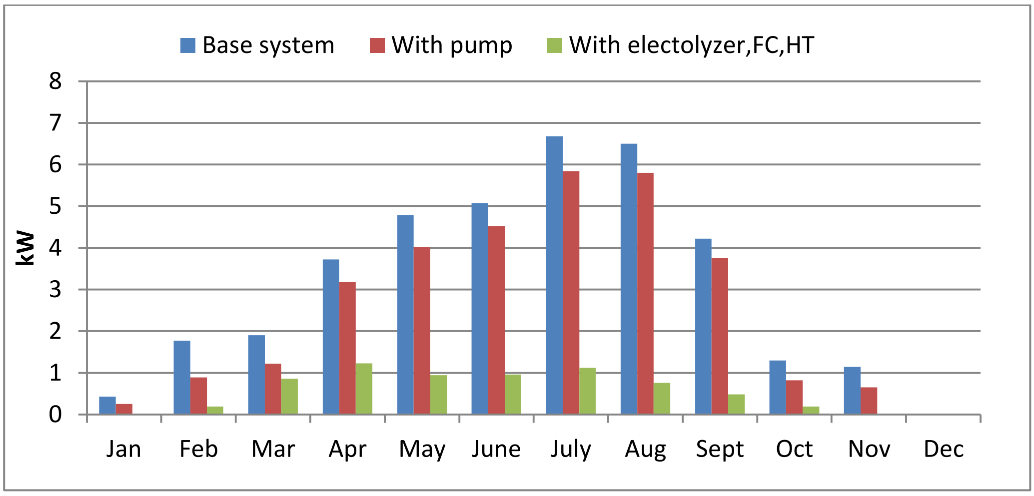

Figure 5.12: Differences between two strategies with base proposed system.

Figure (5.12) shows the differences effects of two strategies on base system with base proposed system.

The cost of each component in details showed in Table (5.5).

Table 5.5: A summarization of the results of the base proposed system with FC, HT and electrolyzer

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic Electrolyzer	$24,750.00	$8,273.34	$5,817.38	$0.00	($1,557.13)	$37,283.60
Generic Fuel Cell	$53.00	$53.27	$773.58	$4,801.34	-$0.102	$5,681.08
Generator	$1,650.00	$404.64	$851.66	$6,274.08	($388.68)	$8,791.70
Hydrogen Tank	$1,400.00	$0.00	$387.83	$0.00	$0.00	$1,787.83
Battery	$22,000.00	$8,213.72	$7,756.51	$0.00	($2,896.69)	$35,073.54
System Converter	$16,263.00	$6,899.97	$2,268.78	$0.00	($1,298.64)	$24,133.10
PV modules	$10,800.00	$0.00	$5,817.38	$0.00	$0.00	$16,617.38
System	$76,916.00	$23,844.93	$23,673.13	$11,075.42	($6,141.24)	$129,368.23

Sensitivity Analysis

It is important to conclude the effect of each parameter on other parameters (COE and NPC).

The effect of variation in the cost of diesel fuel is monthly varied is calculated. The effect of maximum annual capacity shortage (MACS) is calculated. The solar radiation in PT according to historical data is constant, so not subjected to sensitivity analysis [28].

The sensitivity analysis shows the COE and NPC increases with increase the price of fuel and PV system increases as shown in Figure (5.13).

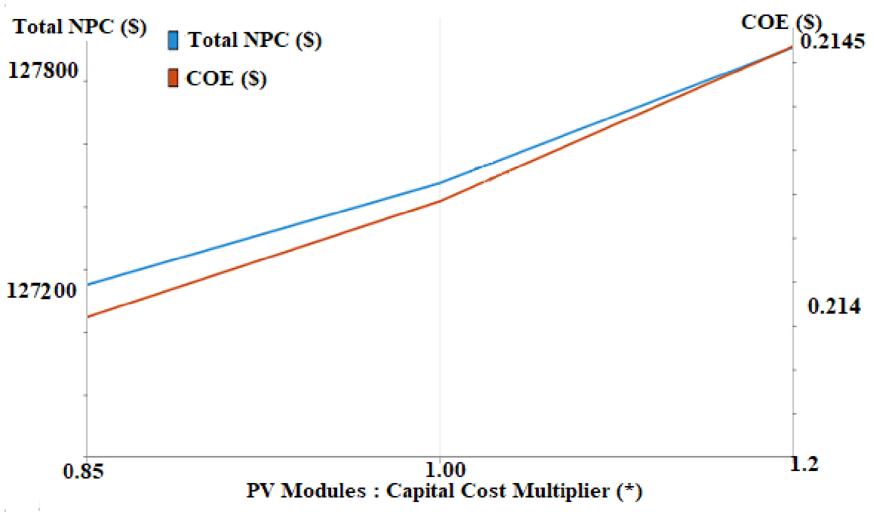

Figure 5.13: Sensitivity analysis result: effect of cost PV modules on NPC & COE.

Figure (5.14) shows the effect of cost battery on NPC & COE, while any increase or decrease in cost of battery will increase or decrease in NPC and COE.

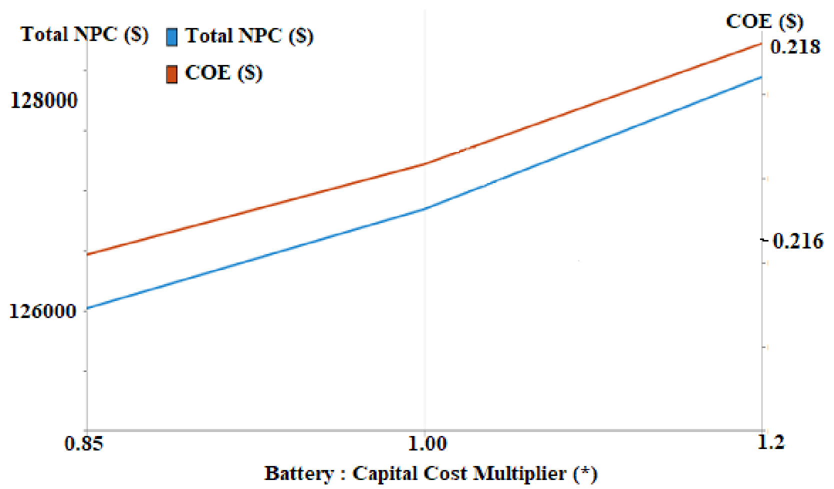

Figure 5.14: Sensitivity analysis result: effect of cost battery on NPC & COE

Figure (5.15) shows the effect of cost generator on NPC & COE, while any increase or decrease in cost of generator will increase or decrease in NPC and COE.

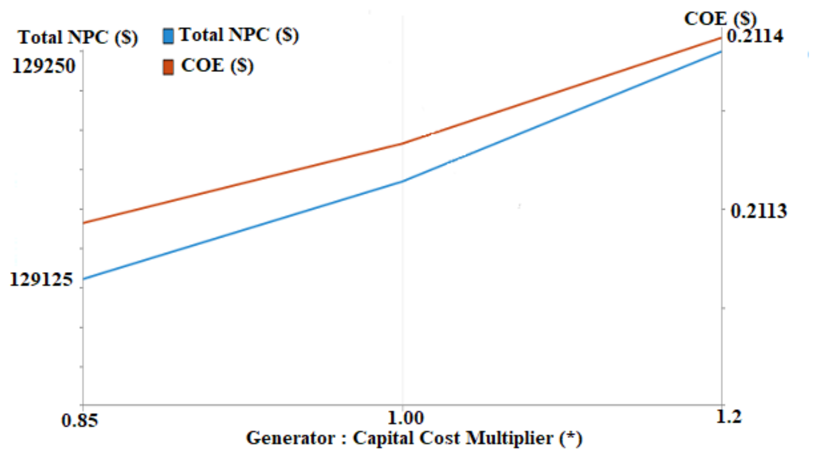

Figure 5.15: Sensitivity analysis result: effect of cost generator on NPC & COE

Figure (5.16) shows the NPC & COE increase with increase in the price of diesel fuel.

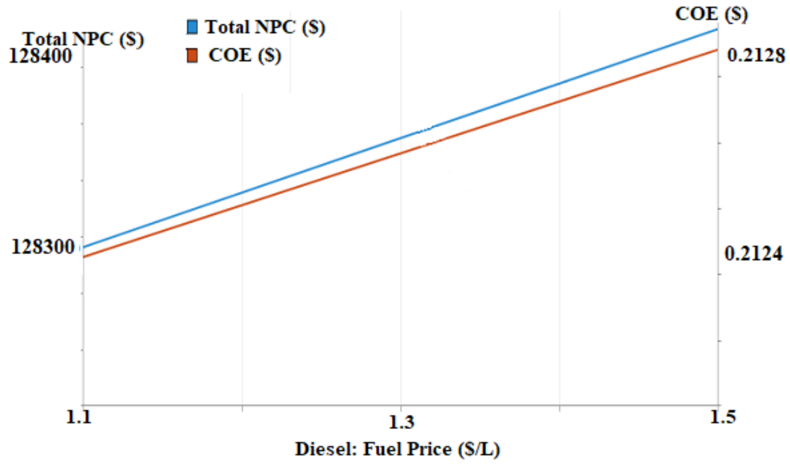

Figure 5.16: Sensitivity analysis result: effect of cost dieselfuel on NPC & COE

5.3. PV/Diesel Generator/BSS with Boiler Water Heating System

The heater converts electrical energy into thermal energy, that used in heating water, where an electric current flows in a thermal conductive material, with high resistance to electricity.

Thermal preservation electric heater of this type is the most widespread in domestic uses, and it is a cylindrical heat conservation tank, containing a thermal resistance, which heats the water, an insulated thermal coil, at the bottom or one side of the tank, and it also contains Thermostat (such as a sensor), through which the heating temperature is controlled, so that the current is cut off, to stop the heating process, and the heater contains a column of magnesium, to deal with water, protect the heater from corrosion, and contains safety valves, to prevent hot water from mixing with cold. Figure (5.17) shows the boiler and its most important elements.

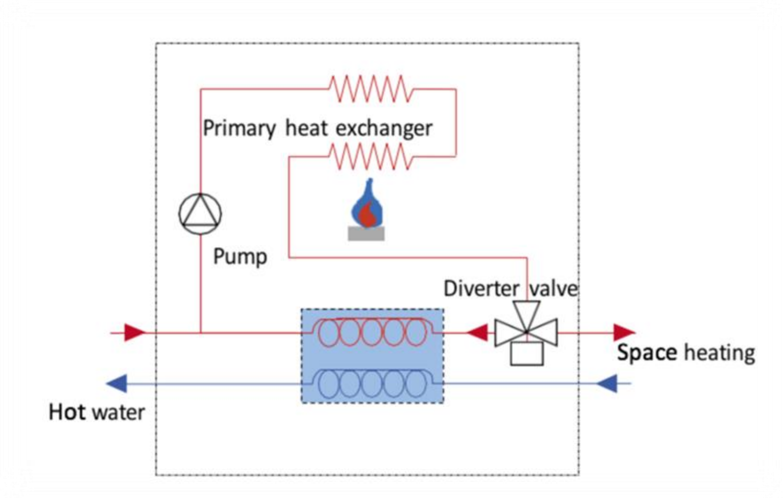

Figure 5.17: Components of boiler [31]

In this strategy adding a heater load and a boiler at times where is amount of excess energy, as this energy is used as much as possible. A boiler with specific costs was chosen in order to convert electrical energy to thermal energy. Also thermal load 11.26 kWh/d was chosen(by calculations on Homer pro software).

Figure (5.18) shows a schematic diagram of PV/Diesel Generator/BSS with Boiler Water Heating System.

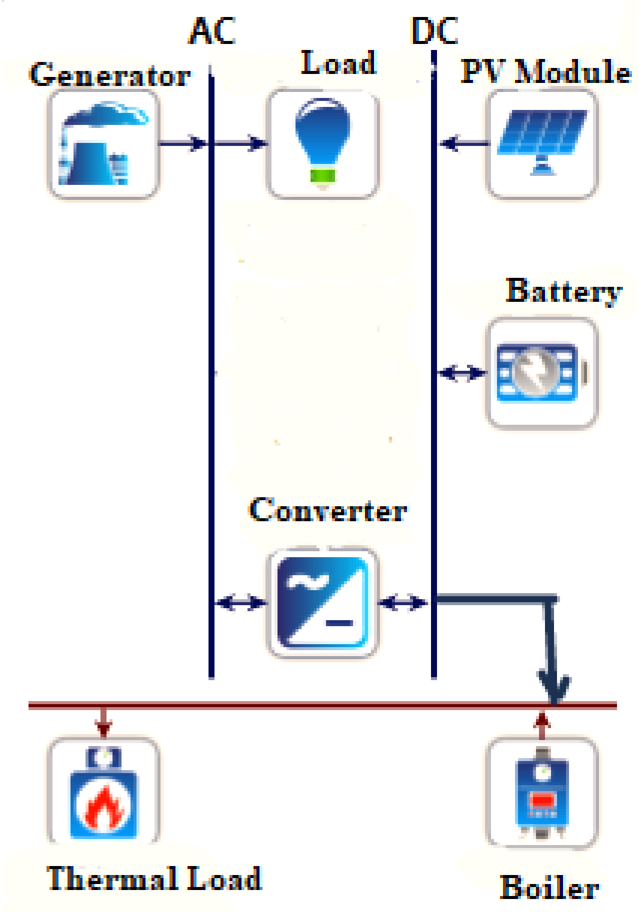

Figure 5.18: A schematic diagram of PV/Diesel Generator/BSS with Boiler Water heating System

The net present cost is USD 138,499. The COE is USD 0.213 /kWh. The contribution of renewable energy is 82.3%. The excess electricity is 3334 kWh/year which is about 5.57%. The unmet electric load is about 1.02%.

The excess energy percentage decreased by approximately 8%. And this percentage is actually good.

Table (5.6) shows the difference in the amount of excess energy of the proposed system with a pump, Electrolyzer, FC, HT and boiler.

Table 5.6: The difference in the amount of excess energy of the proposed base system with the presence of a pump, Electrolyzer, FC,HT and boiler.

The configuration of the system	Base system	With Electrolyzer, Fuel cell and hydrogen tank	With pump	With Boiler
No. of battery	40	40	40	40
NPC ($)	101,361	129,368	122,346	138,499
COE ($)	.194	.21	0.212	0.213
Excess energy(%)	13.8	8.8	11.3	5.57
Excess energy (kW/year)	7469	5119	6483	3334
Renewable energy fraction (%)	92.2	85.2	85.9	82.3
Unmet electric load (%)	.385	.745	.733	1.02

Figure (5.19) shows the difference in the amount of excess energy of the proposed base system with the presence of a pump, electrolyzer, FC, HT and boiler.

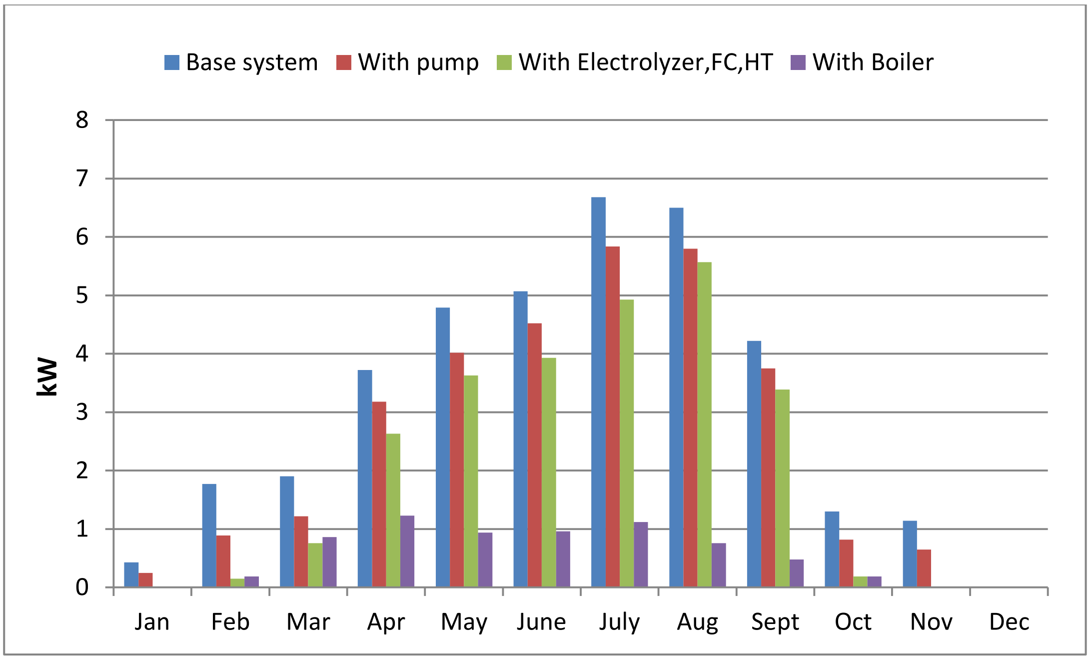

Figure 5.19: The difference in the amount of excess energy of the proposed system with the presence of a pump, electrolyzer, FC,HT and boiler.

The boiler is one of the most important strategies, as it is easy to use and easy to apply on a large scale because of its working principle, which depends on it being a dc voltage, despite the difficulty of applying it in detail to the program effectively, but good results have been obtained. With an electric heater (thermal load), where the largest possible amount of excess energy is consumed in the times of its existence, according to the nature of the work of the boiler. It can be operated in more than one range, there is great flexibility in operation, where it is possible to benefit from the excess energy at a very high rate that may reach 90% of the excess energy and to exploit the fluctuation in it.

As for the pump, it is not easy to deal with it within all the variances of the excess power, as it is not flexible in dealing with it to take advantage of all the excess power that exists as there is a fluctuation of the excess power, and we cannot operate it at any time for the excess power, such as 1 kW at 11:00 or 2 kW at 14:00, as the operation of the pump is fairly stable in a fixed range, there is no flexibility in operation, due to its principle of operation that depends on the motor where there is a certain frequency and voltage and etc.

The cost of each component is included in Table (5.8). Economic study very important to know each component how effect in whole cost of system.

Table 5.7: A summarization of the results of the base system with boiler

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Boiler	$950.00	$950.00	$380.00	0.00	0.00	$2,280
Generator	$1,650	$3,837.27	$4,844.47	$47,029.33	$301.72	$56,109.36
Battery	$22,000	$10,264.63	$7,756.51	$0.00	$661.71	$39,359.43
System Converter	$16,263	$6,899.97	$2,268.78	$0.00	$1,298.64	$24,133.10
PV Modules	$10,800	$0.00	$5,817.38	$0.00	$0.00	$16,617.38
System	$51,663	$21,000	$21,067.15	$47,029.33	$2,262.08	$138,499.27

Emissions

Table (5.9) shows the emissions from boiler configuration, the values indicate the quantity unit of each pollutant from the system, and it's very important in each country, according the policies of air pollution. The values different from the base system without boiler that means the boiler caused more air pollution.

Table 5.8: Emissions from boiler with base system

Pollutant	Quantity Unit
Carbon Dioxide	7,326 kg/yr
Carbon Monoxide	45.7 kg/yr
Unburned Hydrocarbons	2.01 kg/yr
Particulate Matter	0.274 kg/yr
Sulfur Dioxide	17.9 kg/yr
Nitrogen Oxides	43.0 kg/yr

Sensitivity Analysis

The effect of variation in the cost of diesel fuel is monthly varied is calculated. The effect of maximum annual capacity shortage (MACS) is calculated. The solar radiation in PT according to historical data is constant, so not subjected to sensitivity analysis [28].

The sensitivity analysis shows the COE and NPC increases as the price of fuel and PV system increases as shown in Figure (5.20).

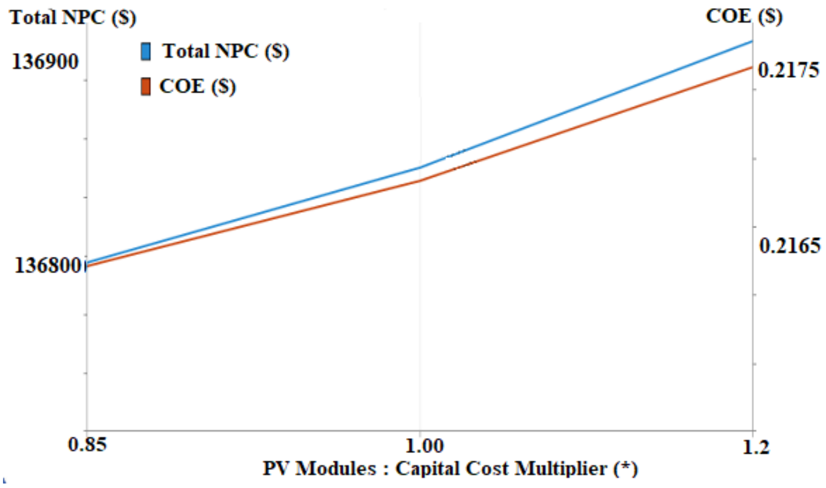

Figure 5.20: Sensitivity analysis result: effect of cost PV modules on NPC & COE

The NPC and COE are affected with cost of battery as shown in Figure (5.21).

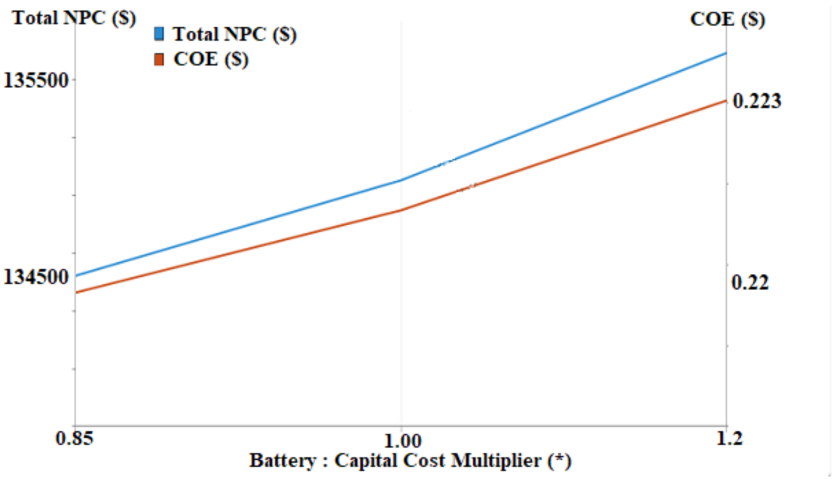

Figure 5.21: Sensitivity analysis result: effect of cost battery on NPC & COE

Figure (5.22) Shows the effect of generator cost on NPC and COE.

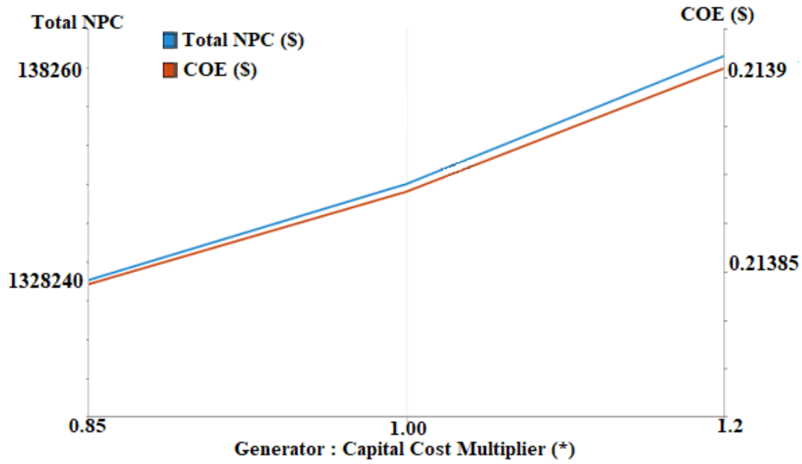

Figure 5.22: Sensitivity analysis result: effect of cost generator on NPC & COE

Sensitivity analysis shows that NPC and COE is linearly varied with diesel cost as shown in Figure (5.23).

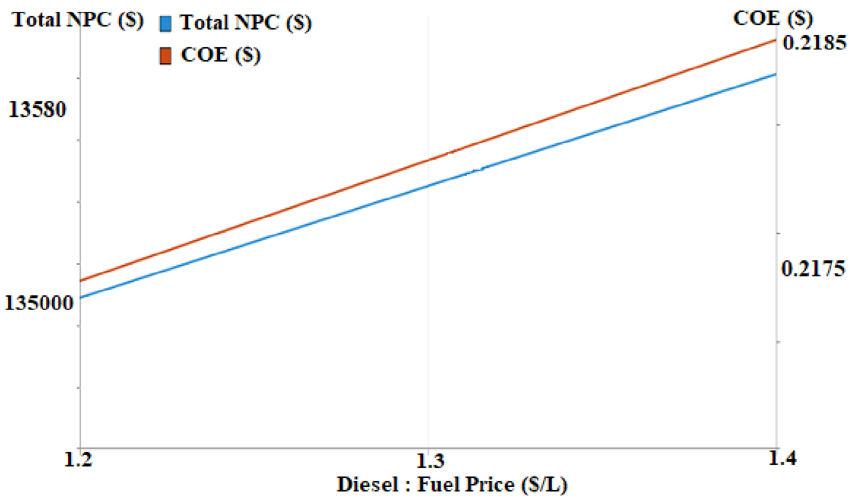

Figure 5.23: Sensitivity analysis result : effect of diesel fuel price on NPC and COE

5.4 PV/Diesel Generator/BSS with hybrid boiler water heating and Water Pumping System

In this configuration, a pump with a boiler was added to the proposed basic system, where the pump benefits from the surplus energy as much as possible according to its working principle, and any excess energy that was not utilized by the pump can be used in the boiler, as here the boiler works for a shorter period than it is only present. In this case, we may benefit from the pump when the use of the pump is needed, and we may benefit from the boiler in its applications. Without the significant impact on the economic aspect of the decline in the price of the boiler.

Figure (5.24) shows a schematic diagram of PV/Diesel Generator/BSS with hybrid boiler water heating and Water Pumping System.

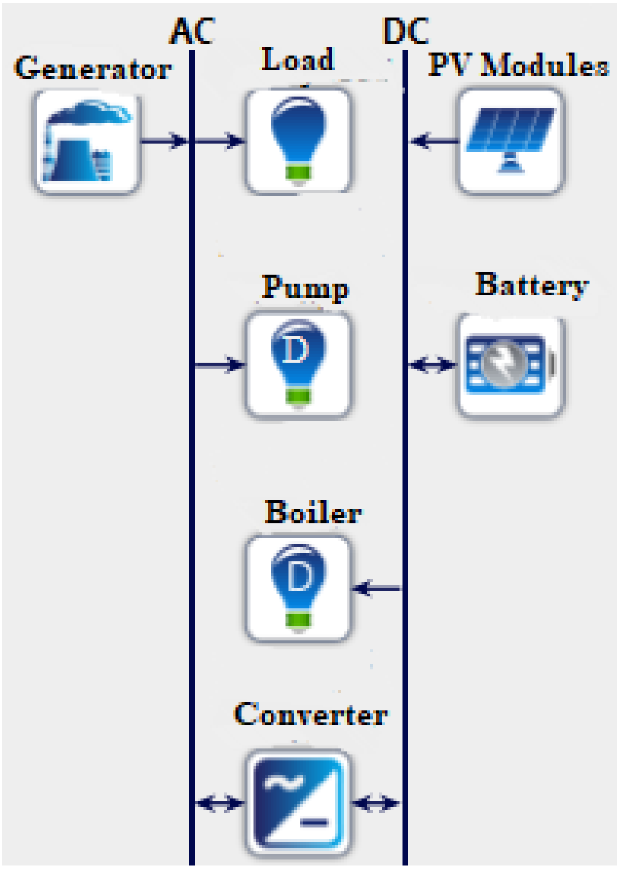

Figure 5.24: A schematic diagram of PV/Diesel Generator/BSS with hybrid boiler water heating and water pumping system.

The results obtained the net present cost of the main components of a system USD 140,220. The COE is USD 0.214 /kWh. The contribution of renewable energy is 81.9%. The excess electricity is 3182 kWh/year which is about 5.29%. The unmet electric load is about 0.89%, As shown in Table (5.10).

Table 5.9: A summarization of the results of the base system with hybrid boiler water heating and Water Pumping System

Components	Capital	Replacements	O&M	Fuel	Salvage	Total
Pump	$650	$1,950	$0.00	$0.00	$0.00	$2,570
Boiler	$950.00	$950.00	$380.00	$0.00	$0.00	$2,280
Generator	$1,650.00	$4,861.51	$4,970.91	$48,421.01	$242.43	$60,040.22
Battery	$22,000.00	$10,295.66	$7,756.51	$0.00	$622.44	$39,429.73
Converter	$16,263.00	$6,899.97	$2,268.78	$0.00	$1,298.64	$24,133.10
PV Modules	$10,800.00	$0.00	$5,817.38	$0.00	$0.00	$16,617.38
System	$50,713.00	$22,057.14	$21,192.80	$48,421.01	$2,163.52	$140,220.44

Values indicate that the excess energy after adding the pump and boiler loads with primary system, the excess energy percentage decreased by approximately 8.5%. And this percentage is actually very good.

Emissions

Table 5.10: Emissions from pump and boiler with base proposed system

Pollutant	Quantity Unit
Carbon Dioxide	7,542 kg/yr
Carbon Monoxide	47.1 kg/yr
Unburned Hydrocarbons	2.07 kg/yr
Particulate Matter	0.282 kg/yr
Sulfur Dioxide	18.5 kg/yr
Nitrogen Oxides	44.2 kg/y

Sensitivity Analysis

The effect of variation in the cost of diesel fuel is monthly varied is calculated. The effect of maximum annual capacity shortage (MACS) is calculated. The solar radiation in PT according to historical data is constant and so not subjected to sensitivity analysis [28]. The capital cost of PV modules linearly affects on NPC and COE as shown in Figure (5.25).

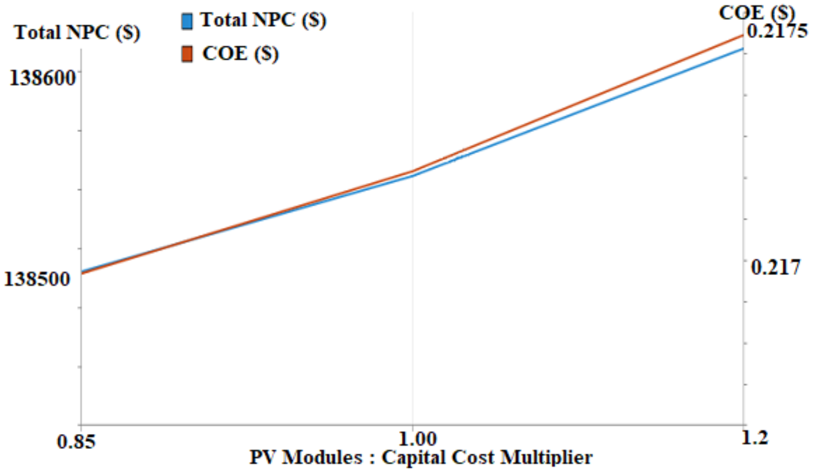

Figure 5.25: Sensitivity analysis result: effect of cost PV Modules on NPC & COE

Figure (5.26) shows the effect of battery cost on NPC and COE .

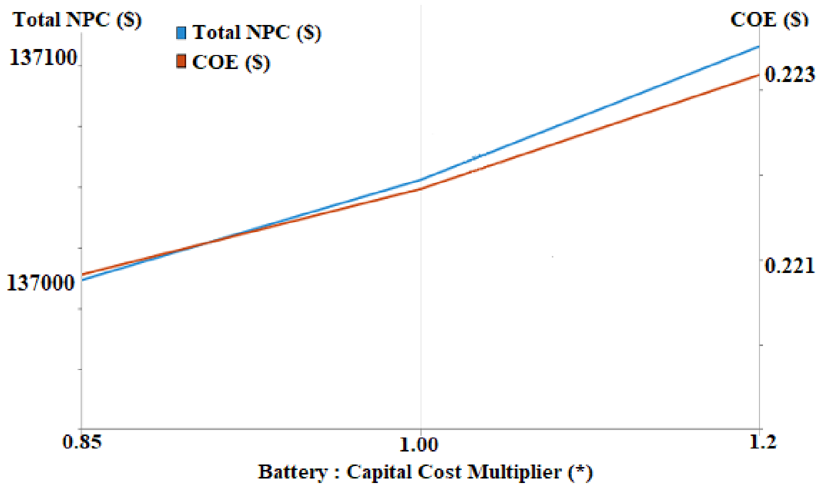

Figure 5.26: Sensitivity analysis result: effect of cost battery on NPC & COE

Figure (5.27) and Figure (5.28) show that cost of diesel generator and fuels linearly affect COE and NPC

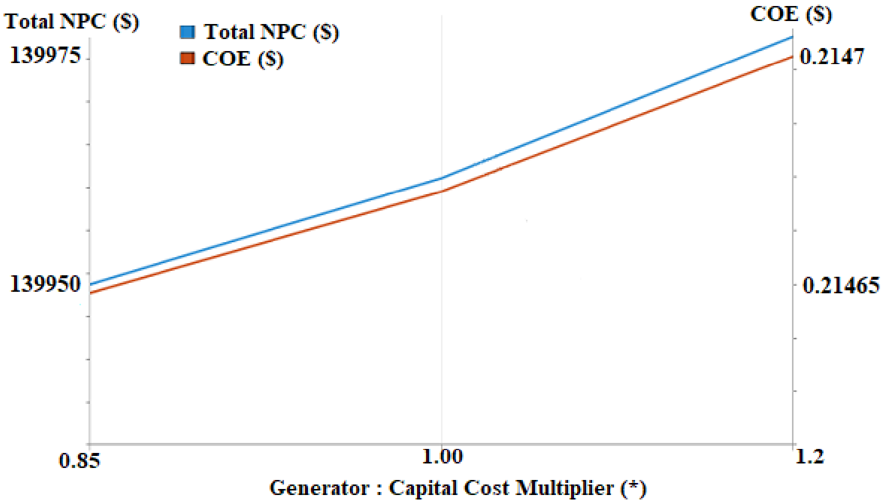

Figure 5.27: Sensitivity analysis result: effect of cost generator on NPC & COE.

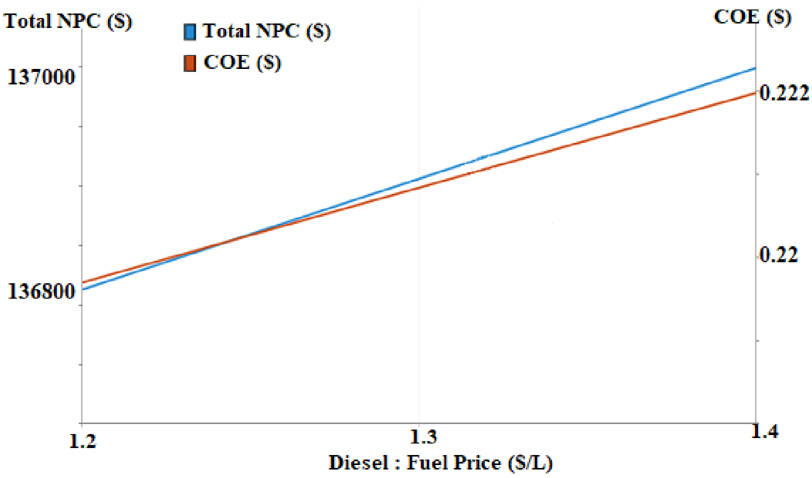

Figure 5.28: Sensitivity analysis result: effect of creteria diesel fuel price on NPC & COE .

Chapter Six

Conclusion and Recommendation

6.1 Conclusion

The study purposes a procedure for excess energy management to increase the chance of using RES. After studying the excess power distribution and studying the demand of the residential loads and the water pump and storage tank. The simulation results show actual improvement in the amount of excess energy. This is one of the objectives of the research regardless of NPC and COE. While the NPC & COE that been studied to economical study just, not objectives of this research.

All that happened can be summarized as follows:

- The PV/Diesel Generator/BSS with Water Pumping System reduces the surplus energy from (13.8%) to (11.3%) equivalent to 2.5%. This percentage actually very small. The COE is USD 0.212/kWh. The NPC is USD $122,347. The PV system is 30 kW, 40 batteries of 1150 Ah each and 3 kW DG.

- The PV/Diesel Generator/BSS with Fuel Cell System reduces the surplus energy from (13.8%) to (8.8%) about 8%. This percentage is actually good. The COE is USD 0.21/kWh. The NPC is USD $129,368. The PV system is 30 kW, 40 batteries of 1150 Ah each and 3 kW DG.

- The PV/Diesel Generator/BSS with Boiler Water Heating System reduces the surplus energy from (13.8%) to (5.57%) about 8.3%. This percentage actually good . The COE is USD 0.213/kWh. The NPC is USD $138,499. The PV system is 30 kW, 40 batteries of 1150 Ah each and 3 kW DG.

- The PV/Diesel Generator/BSS with hybrid boiler water heating and Water Pumping System is the most economical scenario to electrify the load, reduces the surplus energy from (13.8%) to (5.2%) about 8.5%. This percentage actually very good. The COE is USD 0.214/kWh. The NPC is USD $140,220. The PV system is 30 kW, 40 batteries of 1150 Ah each and 3 kW DG. The hybrid power system provides the residential and pumping load and heating load with no interruption to the power supply.

6.2. Recommendations

There are several suggestions and ideas that may help in developing the performance of the system.

- Use other techniques to exploit excess energy especially Flywheel Configuration.

- Practically implementing the system and compare the results.

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Appendices

Appendix A

FLOODED DEEP CYCLE BATTERIES

6 CS 25P

6 VOLTS

CONTAINER: (INNER)	Polypropylene
COVER: (INNER)	Polypropylene - heat sealed to inner container
CONTAINER: (OUTER)	High Density Polyethylene
COVER: (OUTER)	High Density Polyethylene snap fit to outer container
TERMINALS:	Flag with stainless steel nuts & bolts
HANDLES:	Molded

WEIGHT DRY:	115 kg	254	Lbs.
WEIGHT WET:	144 kg	318	Lbs.
LENGTH:	559 mm	22	Inches
WIDTH:	286 mm	11 1/4	Inches
HEIGHT:	464 mm	18 1/4	Inches

PLATE HEIGHT:	273 mm	10.750 Inches
PLATE WIDTH:	143 mm	5.625 Inches
THICKNESS (POSITIVE):	6.60 mm	0.260 Inches
THICKNESS (NEGATIVE):	4.57 mm	0.180 Inches

POSITIVE PLATE DOUBLE WRAPPED WITH SLYVER
ENVELOPED WITH HEAVY DUTY SEPARATOR

Certified System
SAI GLOBAL
ISO 9001
Quality

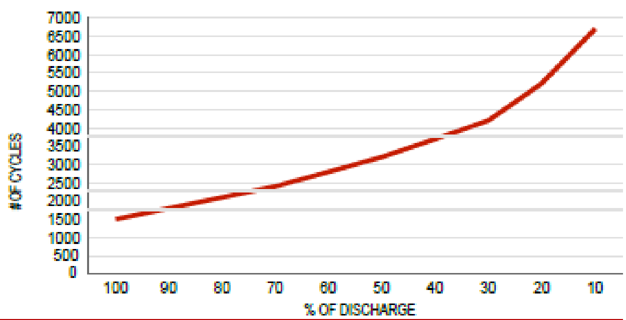
CELLS:	25 Plates/Cell	3	Cell
SEPARATOR THICKNESS:	3 mm	0.105	Inches
GLASS MAT INSULATION:	1 mm	0.020	Inches
ELECTROLYTE RESERVE: ABOVE PLATES	95 mm	3.75	Inches

COLD CRANK AMPS (CCA):	0°F / -17.8°C	2184
MARINE CRANK AMPS (MCA):	32°F / 0°C	2610
RESERVE CAPACITY (RC @ 25A):	1624	Minutes

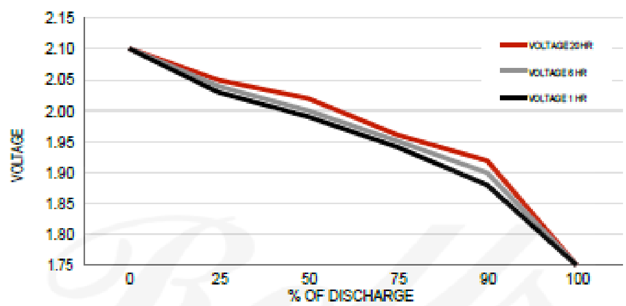
CAPACITY 820 AH

HOUR RATE:	SPECIFIC GRAVITY	CAPACITY / AMP HOUR	CURRENT / AMPS
@ 100 HOUR RATE	1.280	1156	11.56
@ 72 HOUR RATE	1.280	1091	15.15
@ 50 HOUR RATE	1.280	1009	20.17
@ 24 HOUR RATE	1.280	853	35.53
@ 20 HOUR RATE	1.280	820	41.00
@ 15 HOUR RATE	1.280	763	50.84
@ 12 HOUR RATE	1.280	713	59.45
@ 10 HOUR RATE	1.280	681	68.06
@ 8 HOUR RATE	1.280	640	79.95
@ 6 HOUR RATE	1.280	582	97.03
@ 5 HOUR RATE	1.280	549	109.88
@ 4 HOUR RATE	1.280	508	127.10
@ 3 HOUR RATE	1.280	459	153.07
@ 2 HOUR RATE	1.280	394	196.80
@ 1 HOUR RATE	1.280	279	278.80

CYCLE LIFE VS. DEPTH OF DISCHARGE



VOLTAGE VS. DEPTH OF DISCHARGE



Amphere Hour capacity ratings based on specific gravities of 1.280. Reduce capacities 5% for 1.265 specific gravity and 10% for specific gravities of 1.250

WWW.ROLLSBATTERY.COM SURRETTE BATTERY COMPANY 1 STATION RD SPRINGHILL, NS CANADA B0M 1X0

SPEC 01 1/1/2014 REV. 1

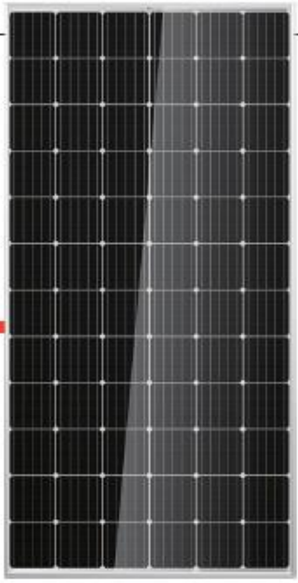
Appendix B

Mono Multi Solutions

THE

TALLMAX plus

FRAMED 72-CELL MODULE (1500V)



72 CELL
MONOCRYSTALLINE MODULE

340-380W
POWER OUTPUT RANGE

19.5%
MAXIMUM EFFICIENCY

0~+5W
POSITIVE POWER TOLERANCE

Founded Founded in 1997, Trina Solar is the world's leading total solutions provider for solar energy. With local presence around the globe, Trina Solar is able to provide exceptional service to each customer in each market and deliver our innovative, reliable products with the backing of Trina as a strong, bankable brand. Trina Solar now distributes its PV products to over 100 countries all over the world. We are committed to building strategic, mutually beneficial collaborations with installers, developers, distributors and other partners in driving smart energy together.

Comprehensive Products And System Certificates

IEC61215/IEC61730/UL1703/IEC61701/IEC62716
ISO 9001: Quality Management System
ISO 14001: Environmental Management System
ISO14064: Greenhouse gases Emissions Verification
OHSAS 18001: Occupation Health and Safety Management System

Trinasolar

Ideal for large scale installations

- **Reduce BOS cost by connecting more modules in a string**
- 1500V UL/1500V IEC certified

Maximize limited space with top-end efficiency

- Up to 193 W/m² power density
- Low thermal coefficients for greater energy production at high **operating temperatures**

Highly reliable due to stringent quality control

- **Over 30 in-house tests (UV, TC, HF etc)**
- **Increased module robustness to minimize micro-cracks**
- **PID resistant and free of snail trails**
- Internal test requirement of Trina more stringent than certification authority

Certified to withstand the most challenging environmental conditions

- **2400 Pa** negative load
- **5400 Pa** positive load

LINEAR PERFORMANCE WARRANTY

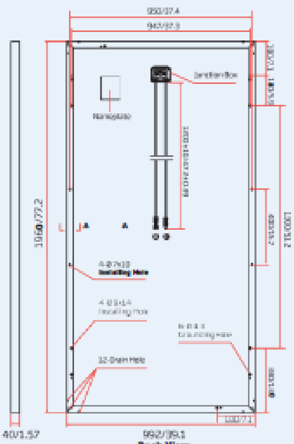
10 Year Product Warranty · 25 Year Linear Power Warranty

TALLMAX M plus

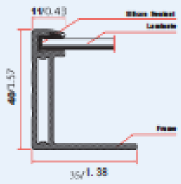
FRAMED 72-CELL MODULE (1500V)

PRODUCTS	POWER RANGE
TSM-DE14A(II) STD MONO	340-365W
TSM-DE14A(II) PERC MONO	370-380W

DIMENSIONS OF PV MODULE(mm/inches)

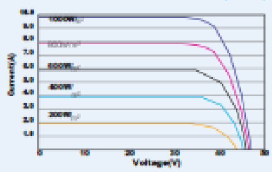


Back View

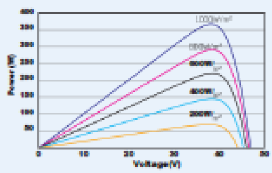


(A-A)

I-V CURVES OF PV MODULE(365W)



P-V CURVES OF PV MODULE(365W)



ELECTRICAL DATA (STC)

Peak Power Watts-P_{MAX} (Wp)*	340	345	350	355	360	365	370	375	380
Power Output Tolerance-P_{MAX} (W)	0 ~ +5								
Maximum Power Voltage-V_{MPP} (V)	38.2	38.5	38.7	38.8	39.0	39.3	39.7	40.0	40.3
Maximum Power Current-I_{MPP} (A)	8.90	8.96	9.04	9.14	9.24	9.30	9.33	9.37	9.43
Open Circuit Voltage-V_{OC} (V)	46.2	46.7	47.0	47.4	47.7	48.0	48.3	48.5	48.8
Short Circuit Current-I_{SC} (A)	9.50	9.55	9.60	9.65	9.70	9.77	9.83	9.88	9.94
Module Efficiency η_m (%)	17.5	17.7	18.0	18.3	18.5	18.8	19.0	19.3	19.5

STC: Irradiance 1000W/m², Cell Temperature 25°C, Air Mass AM1.5
*Measuring tolerance: ±3%.

ELECTRICAL DATA (NOCT)

Maximum Power-P_{MAX} (Wp)	253	257	261	264	268	272	276	279	283
Maximum Power Voltage-V_{MPP} (V)	35.4	35.7	35.9	36.0	36.2	36.4	36.8	37.1	37.2
Maximum Power Current-I_{MPP} (A)	7.15	7.20	7.26	7.34	7.42	7.47	7.50	7.53	7.60
Open Circuit Voltage-V_{OC} (V)	42.9	43.4	43.7	44.1	44.3	44.6	44.9	45.1	45.3
Short Circuit Current-I_{SC} (A)	7.67	7.71	7.75	7.79	7.83	7.89	7.94	7.98	8.03

NOCT: Irradiance at 800W/m², Ambient Temperature 20°C, Wind Speed 1m/s.

MECHANICAL DATA

Solar Cells	Monocrystalline 156.75 × 156.75 mm (6 inches)
Cell Orientation Module	72 cells (6 × 12)
Dimensions	1960 × 992 × 40 mm (77.2 × 39.1 × 1.57 inches)
Weight	22.5 kg (49.6 lb)
Glass	3.2 mm (0.13 inches), High Transmission, AR Coated Tempered Glass
Encapsulant Material	EVA (White/Transparent)
Backsheet	White
Frame	Silver Anodized Aluminium Alloy
J-Box	IP 67 or IP 68 rated
Cables	Photovoltaic Technology Cable 4.0mm² (0.006 inches²)
	1200 mm (47.2 inches)
Connector	Trina TS4
Fire Type	Type 1 or Type 2

TEMPERATURE RATINGS

NOCT (Nominal Operating Cell Temperature)	44°C (±2°C)
Temperature Coefficient of P_{MAX}	- 0.39%/°C
Temperature Coefficient of V_{OC}	- 0.29%/°C
Temperature Coefficient of I_{SC}	0.05%/°C

MAXIMUM RATINGS

Operational Temperature	-40~+85°C
Maximum System Voltage	1500V DC (IEC)
	1500V DC (UL)
Max Series Fuse Rating	15A (Power ≤350W)
	20A (Power ≥355W)

(DO NOT connect Fuse in Combiner Box with two or more strings in parallel connection)

WARRANTY

10 year Product Workmanship Warranty

25 year Linear Power Warranty

(Please refer to product warranty for details)

PACKAGING CONFIGURATION

Modules per box: 27 pieces

Modules per 40' container: 648 pieces

Trinasolar

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

Version number: TSM_EN_2019_MAY

www.trinasolar.com

جامعة النجاح الوطنية

كلية الدراسات العليا

إدارة الطاقة الزائدة لأنظمة الطاقة المتجددة الهجينة المستقلة عن الشبكة

إعداد

مي عبد اللطيف محمد عبدو

إشراف

د. أيسر ياسين

قدمت هذه الرسالة استكمالاً لمتطلبات الحصول على درجة الماجستير في برنامج هندسة الطاقة النظيفة وترشيد الاستهلاك، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2021

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إعداد

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الملخص

تعاني الأراضي الفلسطينية من نقص كبير في الطاقة التقليدية وتستورد جميع احتياجاتها من البترول حوالي 90٪ من احتياجاتها من الطاقة الكهربائية من شركات الطاقة الإسرائيلية. يتزايد استغلال الطاقة المتجددة في مناطق المحيط الهادئ وينتشر على نطاق واسع. لا تزال هناك الكثير من المناطق الريفية في PT تعاني من الانقطاع المستمر لإمدادات الطاقة. هذا يجعل تنفيذ أنظمة الطاقة المتجددة المستقلة قائمة بذاتها خيارًا ممكنًا. يؤدي التحجيم الأفضل للأنظمة المستقلة إلى زيادة الجدوى وتقليل فترة العودة البسيطة، حيث تتسبب الطاقة الزائدة في حدوث مشكلات فنية للأنظمة كما تقلل من جدواها. الهيكل الأساسي عبارة عن نظام هجين قائم بذاته يتضمن الخلايا الكهروضوئية، ومولدات الديزل، ونظام تخزين طاقة البطارية (BSS)، والحمل مخصص لمجتمع سكني صغير في أريحا يتألف من 10 منازل. متوسط الطلب على طاقة الحمل هو 111 كيلو وات ساعة/ يوم. تم تصميم التصميم الأمثل وتحقيقه باستخدام برنامج HOMER Pro. لقد أخذ في الاعتبار الإشعاع الشمسي الحقيقي، والطلب على الكهرباء للمجتمع وتكلفة السوق لجميع المعدات.

يتكون النظام الأساسي من الوحدات الكهروضوئية والبطاريات ومولد الديزل والحمل والمحول، وتبلغ التكلفة الحالية الصافية للمكونات الرئيسية للنظام 101361 دولارًا أمريكيًا. سعر المعدات المملوكة هو 0.194 دولار أمريكي / كيلوواط ساعة. في مثل هذه الأنظمة، يكون جزء الطاقة المتجددة 92.2٪. الكهرباء الزائدة 7469 ك.و.س/ سنة أي ما نسبته 13.8٪. الحمل الكهربائي غير المغطى حوالي 0.385٪.

تم اقتراح استراتيجيات وتكوينات مختلفة لتقليل واستخدام الطاقة الكهربائية الزائدة الناتجة من العلبة الأساسية: مع نظام ضخ المياه ونظام خلايا الوقود ونظام تسخين مياه الغلايات ونظام تسخين مياه الغلايات الهجين ونظام ضخ المياه. أظهرت النتائج أن أفضل نظام هجين من بين جميع التكوينات الممكنة هو (PV / Diesel Generator / BSS مع تسخين مياه الغلايات الهجينة ونظام ضخ المياه). بعد دراسة توزيع الطاقة الزائدة ودراسة الطلب المحلي للسكان وكذلك سعة مضخة المياه وخزان التخزين، يُفترض حمولة قابلة للتأجيل. تشير نتائج المحاكاة إلى تحسن معقول في مقدار الطاقة الزائدة، وهذا هو الغرض الرئيسي من هذا البحث بغض النظر عن تكلفة النظام الكلي وتكلفة سعر الطاقة في الساعة، تمت دراستهم فقط من اجل الغرض الاقتصادي.

يعد نظام PV / Diesel Generator / BSS المزود بتسخين مياه الغلايات الهجين ونظام ضخ المياه هو النظام الهجين الأكثر اقتصادا لكهربة الحمل المحدد في هذه الدراسة. تبلغ تكلفة المعدات المملوكة للوحدات 0.214 دولارًا أمريكيًا للكيلووات في الساعة، تكلفة النظام الكلي هو 140،220 دولار أمريكي. تبلغ قدرة النظام الكهروضوئي 30 كيلوواط، 40 بطارية كل منها 1150 أمبير، ومولد ديزل بقدرة 3 كيلو وات. يوفر نظام الطاقة الحمل السكني والضخ المحدد وحمل التدفئة دون أي انقطاع تقريبًا في مصدر الطاقة. تم تحليل الحساسية لدراسة تأثير التغيرات في التكلفة الكهروضوئية وتكاليف المعدات الإضافية وسعر وقود الديزل. يتم اتباع إجراءات إدارة الطاقة من خلال هذا التكوين لتقليل الكهرباء الزائدة من 13.8٪ إلى 5.3٪.