# Excess Energy Management of a Hybrid Standalone Renewable Energy Power System

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**ABSTRACT**

Many rural areas in the Palestinian territories (PT) continue to suffer from frequent power supply interruptions. This implements stand-alone systems as a feasible option. Better sizing of stand-alone systems increases feasibility and reduces the simple back period. Excess energy causes technical problems for the systems and reduces their feasibility. The base case is a stand-alone hybrid system that includes PV, Diesel Generator (DG), and battery energy storage system (BESS). The load is for a small residential community in Jericho, comprising 10 households. Utilizing HOMER Pro software, the optimum design was modeled and achieved. Actual solar radiation, the proposed residential load profile, and the cost of all equipment are used. The Cost of energy is USD 0.194 /kWh with 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 utilise the excess electrical energy produced from the base case, including the water pumping system, fuel cell (FC) system, boiler water heating system, and hybrid boiler water heating and water pumping system. The results showed the best hybrid system is PV/DG/BESS with hybrid boiler water heating and Water Pumping System. The COE is USD 0.214/kWh. The proposed system provides residential, pumping, and heating loads with minimal interruption to the power supply. This configuration enables energy management to reduce surplus electricity from 13.8% to 5.3%. Sensitivity analysis is used to study the impact and effect of varying parameters like PV cost, costs of extra equipment, and diesel fuel price.

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## 1. Introduction

Management of excess energy has become an important issue when energy efficiency, reliability, and economic feasibility are considered, especially in hybrid standalone RE systems. RE sources that combine PV systems, wind energy systems, and other sources often provide more energy than needed during low demand, requiring proper management to avoid wasting this extra energy. Off-grid power solutions are sustainable with effective excess energy management strategies that help to maximise energy utilisation and minimise curtailment. PT is offered high solar radiation potential and about 3000 sunshine hours. The annual average daily solar radiation is about 5.6 kWh/$m^2$ on a horizontal surface. The wind energy potential is generally low, but there is an adequate potential in specific locations that can be exploited in small-scale mechanical WES (Nassar et al., 2024). Management of excess energy in different configurations of hybrid standalone power systems based on RE resources can be achieved by several methods, particularly by combining different energy storage modes. In some cases, especially off-grid systems, the storage systems may include heating water, pumping water, and space heating or cooling, which is a productive way to improve system efficiency and reduce energy waste. The main objective of this work is to improve the feasibility of standalone hybrid PV systems by managing the excess energy instead of dumping it, performing techno-economic analysis for each option. This study investigates different approaches to managing 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, also known as thermal management, is imperative due to its high necessity. A deep study of the available literature supports the identification of advancements and gaps in hybrid standalone renewable energy systems. This section analyzes some recent studies regarding energy management strategies, hybrid systems' configurations, and use of surplus energy for storage or additional applications. Researchers (Alnejaili et al., 2015) have performed an energy management study for a stand-alone system to control the energy flow, and used simulation models utilising Matlab/Simulink software to evaluate the performance and effectiveness of dynamic controllers from the management strategy. The results show the efficiency of the proposed strategy, as it increases system reliability and improves its power balance. It enables the reduction of the ON-OFF switching cycle of the fuel cell, thereby increasing the life of both the battery and the fuel cell. Additionally, it prevents deep battery discharge under heavy loads and adverse weather conditions. Their study was limited to examining the strategy and did not consider the redundant capacity of the battery and the system. Another researcher (Kusakana, 2016) has studied an overview of research improvements in the area of optimal operation control applied to hybrid RES, discussing different challenges encountered by hybrid systems and future improvements to enhance them. The results indicate that several research papers address the optimal sizing of hybrid systems; however, few studies have focused on optimal operation control of hybrid renewable energy systems. In a study performed by Omar (2024) based on PV/BESS/DG dedicated to electrifying a community consisting of 25 households with an everyday demand of 50.0 kWh and simulated using HOMER software, the COE reaches 0.297 USD/kWh. The study found that investment in such systems is feasible if the $CO_2$ mechanism is applied. A HOMER-based study investigated a hybrid system based on PV/Wind/Micro Gas Turbine/BESS for supplying electric and thermal load simultaneously, utilising the excess electricity and recovered waste heat produced from the Micro Gas Turbine set. A thorough assessment, encompassing both techno-economic and environmental indicators, is conducted to compare meeting the electric load only with synchronised electric and thermal loads under different approaches (Das & Hasan, 2021). A group of researchers presented a methodology for decision-making to size and manage a cogeneration system. About 35 potential scenarios have been studied, depending on the excess electricity, the holding of intermediate hydrogen and methane storage, and thermal demand. This study aims to design and resize energy storage and operation facilities based on energy conversion to gas. It also addresses possible limitations and operating conditions, providing a technical basis for future control algorithms (Bailera et al., 2018). A hybrid standalone RE system based on PV, WES, DG, and electrolyser to supply a specific amount of electricity, a specific amount of hydrogen, and thermal energy. An innovative method is considered to recover extra electricity for heat production and reduce emissions. The analysis is done utilizing HOMER software. A decrease in fuel consumption, emissions, and COE, as well as an increase in the renewable fraction of the hybrid RE system, is achieved without increasing the project's size. A DG was installed to overcome the interruption in the power supply. Results prove that recovering extra electricity can modify the renewable fraction and bring down COE and $CO_2$ (Akhtari & Baneshi, 2019). A study was conducted based on PV/BESS, utilising excess power for water pumping to meet the demand of residential units. The sizing of the system is verified by varying the number of PV systems, BESS capacity, and the surplus is used for water pumping (Bhayo et al., 2019). Salameh et al. (2020) designed and developed control strategies of the standalone RE sources to meet the residential load. The excess power is used for the electrolyser, and the fuel cell will operate to meet the load. The results show that PV/FC with an electrolyzer for hydrogen production shows the best performance. Aziz et al. (2018) 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. The proposed system is chosen for its environmental friendliness, characterised by low emissions of gases. The multi-year unit has been found to produce more reliable results than the one-year unit. Mandal et al. (2018) examined the ability to meet the simultaneous electrical demand and convection of a stand-alone system with different scenarios. The model considers the use of excess energy, the excess heat recovered, and different energy management strategies using the HOMER program. The size of the hardware components was reduced by meeting the thermal demand through surplus electricity and the use of a waste heat recovery unit. The hybrid system features both a convection control unit and a heat recovery option, resulting in lower energy costs and a higher renewable energy breakthrough compared to the system that only utilises excess energy through the conventional controller. Yasin and Alsayed (2020) proposed an off-grid system to electrify an 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, water pumping, and the cost of all equipment. The results showed the best strategy is a hybrid PV system with energy storage and a diesel generator. Sensitivity analysis was used to study the effect of PV cost, diesel fuel price, and maximum annual capacity shortages. The maximum annual capacity shortages have no effect. Utilising energy management procedures to minimize excess electricity consumption. Rad et al. (2023) presented practical solutions for reducing electricity surplus in off-grid units include classification of effective methodologies and technologies based on performance concepts, Efficiency surplus in efficient stand-alone hybrid systems should be less than 10%, This study provides a comparison based on energy cost, renewable energy share, and surplus potential, and it highlights practical global constraints in managing surplus energy. Basnet et al. (2023) present an all-inclusive review, along with a description of a recent stand-alone and grid-integrated hybrid RE sources that are composed of different RE generation and storage units: PV/WES/BESS/DG, PV/WES/BESS/DG/Hydrogen, PV/WES/BESS/Hydrogen, and PV/WES/Hydrogen. The study analyzes the four systems in terms of the optimum excess energy saved. After reviewing the literature review above, this paper proposes modified and comprehensive configurations to manage excess energy in hybrid stand-alone RE systems by incorporating various energy storage configurations and applying supplementary load management to overcome the main limitations identified in previous work. The study examines four distinct configurations, each comprising main power sources such as PV, DG, and energy storage, primarily based on BESS, FC systems, Water Pumping Systems, and boilers for heating water. The Paper is organised as follows: Section 1 presents the introduction, which provides an overview, motivation, objectives, and literature review. Section 2 outlines the work methodology, and Section 3 explains the key features of HOMER Pro software. Section 4 details the structure of the base system used as a reference for analysis. Section 5 illustrates the features of the site, and Section 6 explains the analysed configuration. Finally, section 7 summarized the conclusion of the research paper.

## 2. Methodology

This research aims to utilize the excess energy in a hybrid standalone system based on PV/BESS/DG system. The methodology is briefly shown in Figure 1.

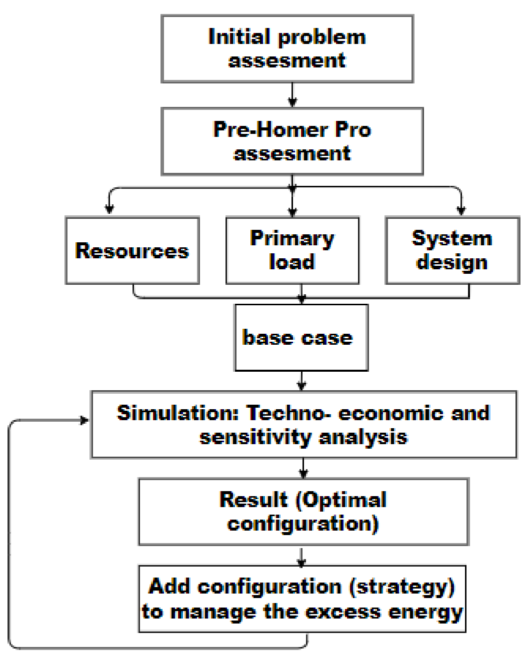



**Figure 1:** Methodology of the Research

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 (DG), BESS, and the converter. Homer Pro software is utilized to obtain the optimum design with lowest excess energy and lowest net cost and COE. The research aims to implement specific strategies to exploit excess energy and use it in specific applications at the lowest possible prices and highest efficiency. At the same time, the least COE is not necessarily the best one, as excess energy can be utilized in other applications.

The proposed strategies are:

- PV/DG/BESS with Water Pumping System.
- PV/DG/BESS with FC system.
- PV/DG/BESS with boiler water heating system.
- PV/DG/BESS with hybrid boiler water heating and Water Pumping System

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

## 3. HOMER Pro Software

Designing hybrid RE systems based on PV, BESS, DG, and other different subsystems is complex. HOMER Pro software can efficiently find optimal solutions for problems encountered in various power systems through sensitivity analysis. HOMER stands for a hybrid optimisation model for electric renewable energy. The software deals with LCOE, COE, and NPV. NPV is calculated using equation (1).

$$NPV = Initial\ cost + Annual\ Cost\ (\frac{(1+i)^N - 1}{i\ (1+i)^N}) \qquad \text{.................. (1)}$$

The most important one is COE in USD/kWh which is a good value to compare with other alternatives energy resources and systems. The cost of energy can be calculated using (2).

$$COE = \frac{NPV \frac{i\ (1+i)^N}{(1+i)^N - 1}}{\text{El+Edef}} \qquad \text{.................... (2)}$$

Where El and Edef are the total amounts of primary and deferrable load, respectively. 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

## 4. Structure of the Base System

Figure 2 shows the diagram of the base system, which contains the primary load, PV, converter, BESS, and DG.

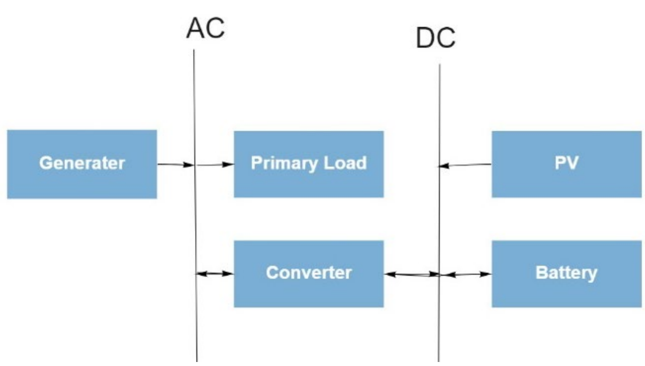



**Figure 2:** Base System Configuration PV/BESS/DG

The proposed base system will supply electricity to the residential load, and water energy will operate a pump as proposed. The chosen community includes about 10 homes. 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 3.

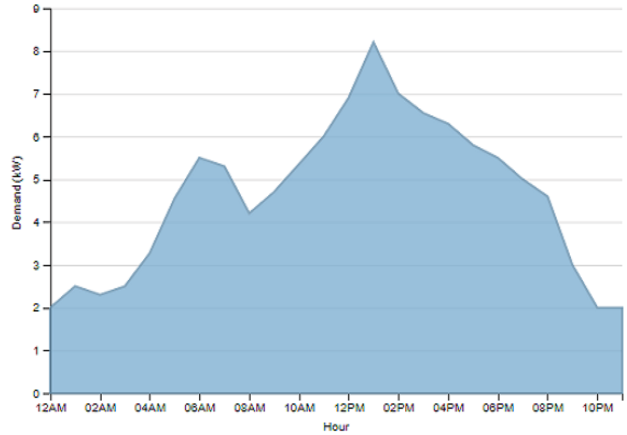



**Figure 3:** Average Power Demand for Residential Load

In addition to the PV system, a DG is included, used as a part of spots without connection with a power grid, or as an emergency power (backup) supply. 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 (2025) was about US \$ 1.56 / litre. Figure 4 shows a curve illustrates the efficiency of the DG with respect to output power.

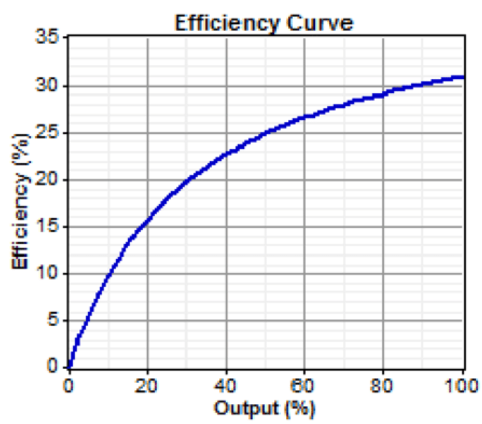



**Figure 4:** Efficiency of the DG

As shown in Figure 2 a BESS is included. Solar batteries are a crucial solution for reducing reliance on the electrical grid and saving on electricity costs. 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 AC to be used in electrical devices; for this reason, inverters are used. The efficiency of the used inverter is shown in Figure 5.

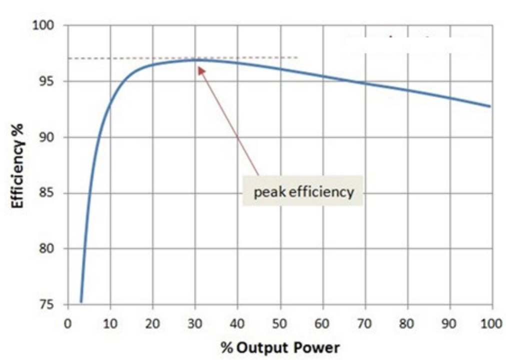



**Figure 5:** Efficiency of the Inverter

Designing RE systems for small grids is a complex process that requires exact values.

## 5. Site Selection

The case study is located in Jericho. Jericho is located in the Jordan Valley, and it is bounded on the east by the Jordan River and on the west by Jerusalem. The daily average of solar radiation was measured to be 5.45kWh/$m^2$ day. Figure 6 presents the monthly average daily solar radiation input data for the selected proposed site (Jericho) in HOMER software, derived from a special procedure using NASA's meteorology and solar energy database for a specific day, and the monthly solar radiation of Jericho city is shown in Figure 6. The hourly average temperature during the day ranges from 20 to 27°C, as shown in Figure 7.

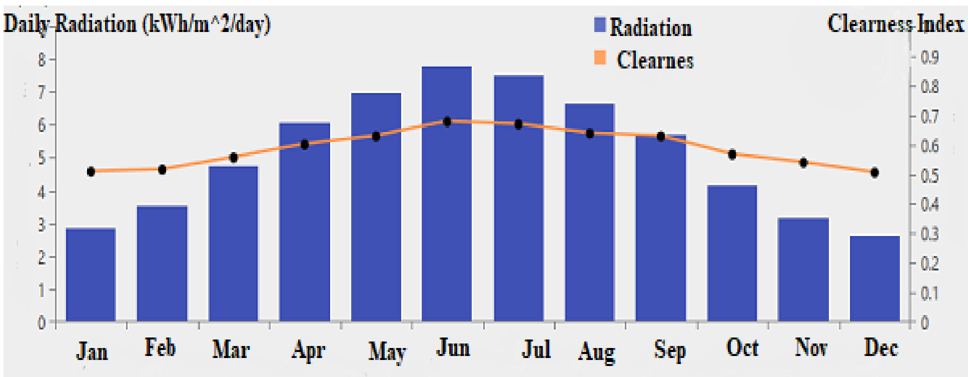



**Figure 6:** Monthly Average Daily Solar Radiation Input Data of the Selected from the NASA Meteorology and Solar Energy Database

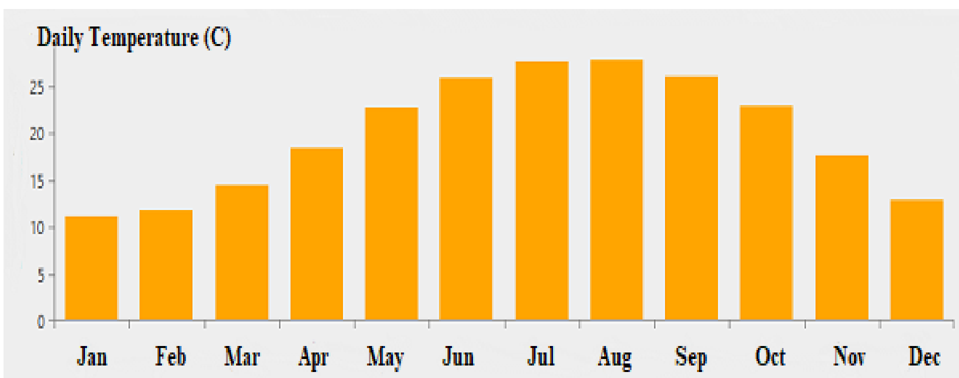



**Figure 7:** Hourly Average Temperature During the Day in Jericho from NASA Meteorology and Solar Energy Database

Wind energy potential in PT is limited. Therefore, wind turbines will not be considered in this study. Figure 8 shows the average wind speed in PT.

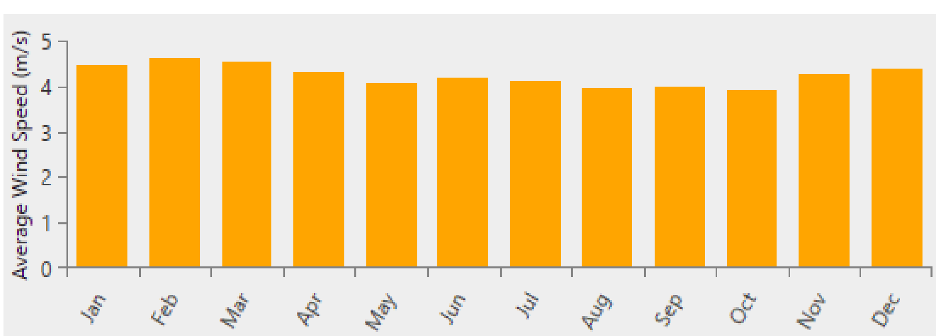



**Figure 8:** Average wind speed in PT from the NASA meteorology and solar energy database

## 6. The Homer Configuration of the Base System

The base configuration of the hybrid system studied in this research is presented in Figure 9. It consists of PV, BESS and DG. The analysis of a system is performed by using the HOMER pro program. The technical specifications and the cost of all components are considered and specified according to local prices in the PT for the year 2024. Firstly, a standalone solar PV system was designed with a BESS to store the energy produced and a DG to generate energy.

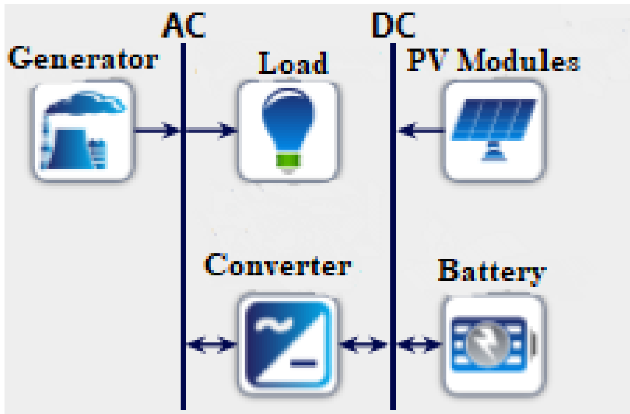



**Figure 9:** A Schematic of the Proposed Base System

This work aims to analyse the excess energy in the base configuration system, reduce it, and utilize it through an adding strategy to manage the excess energy. The PV panels, which are the basis of the system to generate electric power from Trina Tallmax M Plus, were added with an efficiency of 17.8%. Through the analysis, it was found that the best value for solar panels is 30 kilowatts. The results will be explained in detail later. A 3-kW diesel generator was added. The operation and maintenance costs are considered. 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 needed to operate the generator to ensure that no overload occurred and that no ample excess power occurred. The converter was added within the range of 18 kilowatts, and through analysis, operational and maintenance costs are considered. It was found that the best value of the converter was at the lowest value of the excess energy, the lowest total price, and the price for the energy produced. Added Surrette 6 CS 25P battery with 6V voltage per battery, 1150 Ah electric capacity for one battery, operation and maintenance costs are considered, each series contains 4 batteries. Batteries within a specific range have been added, with an initial charge state of 100% and a minimum charge of 10%. After analysis, it was found that the best number of batteries at the lowest value of excess energy is 40 batteries. The results of the base system (Primary proposed system) show the amount of excess energy. Figure 10 shows the average excess energy distributed throughout the year for each month by averaging the excess energy on the interval from 9:00 AM to 2:00 PM (6 Hours). Then, the average is calculated for every day in each month.

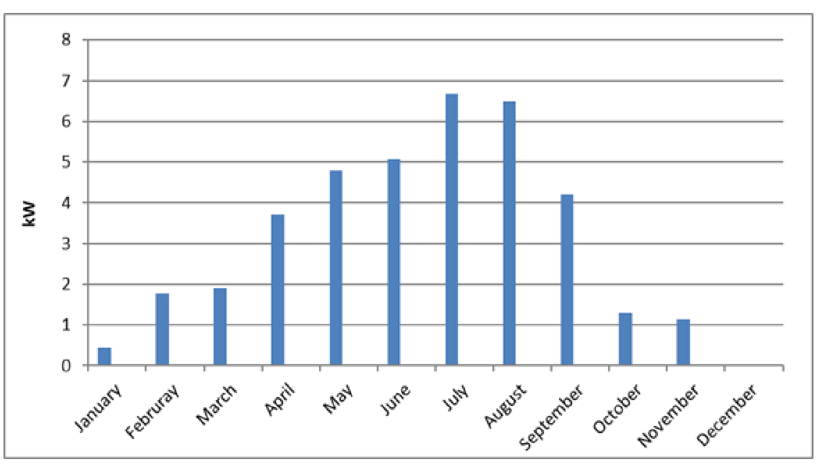



**Figure 10:** The Amount of Excess Energy Distributed Throughout the Year

It is possible to know the amount of excess energy in any month during the year by focusing on the required period and understanding the excess energy specifically at a specific time. For instance, it concentrated on July to determine the exact amount of this energy during that 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 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.

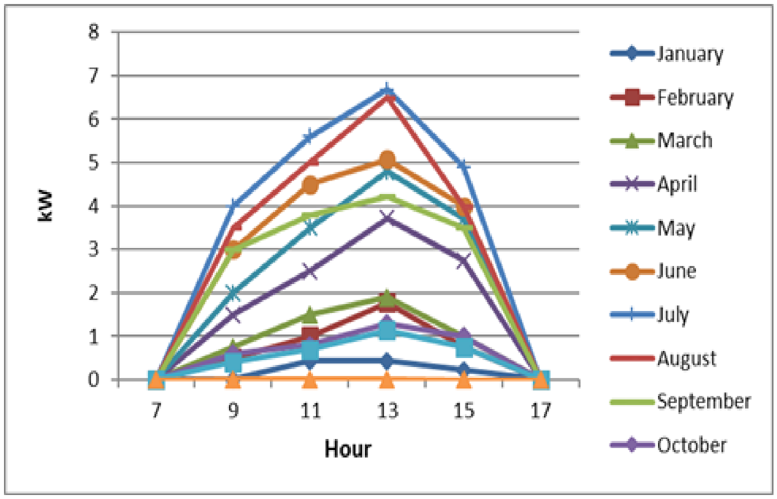



**Figure 11:** Surplus Electrical Distribution in Each Month Through the Day

Figure 12 shows the hourly excess electrical power distribution throughout the year (the area under the curve represents energy distribution). This data is essential for utilizing the excess energy.

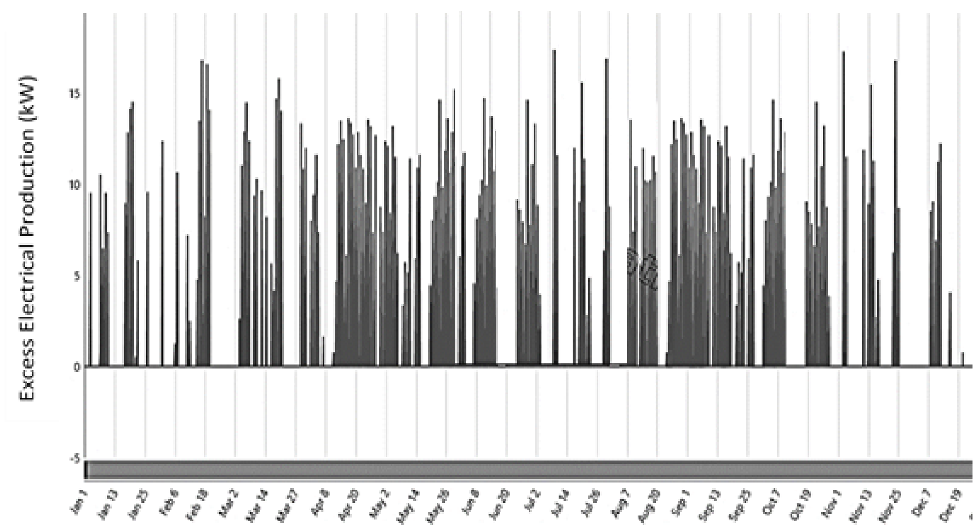



**Figure 12:** Hourly Distribution of Excess Energy for all the Months of the Year

Figure 13 presents the economic results of the cash flow summary for the net present cost of the main components of the proposed base system, which is USD 101,361. The COE is USD 0.194 /kWh. The contribution of RE is 92.2%. The excess electricity is 7469 kWh/year, which is about 13.8%. To assess the effect of the main issues on the NPC and COE, a sensitivity analysis was implemented. The cost of diesel fuel and the Maximum Annual Capacity Shortage (MACS) were analysed, while solar radiation was excluded due to its historical stability in the PT region.

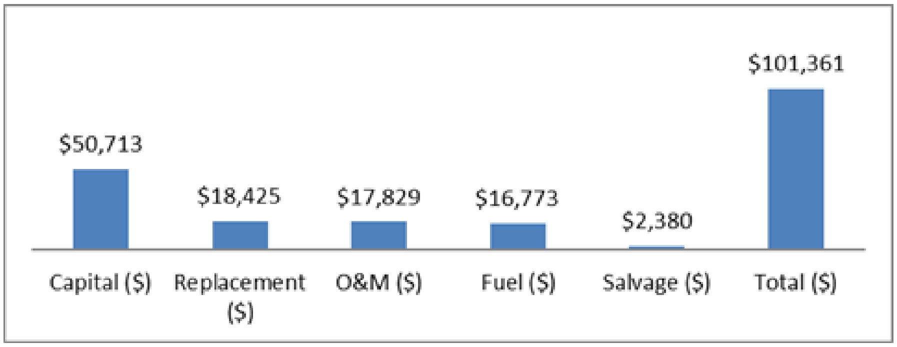



**Figure 13:** Simulation Economic Results: Cash Flow Summary of Base System

Figure 14 includes four different analyses that demonstrate the influence of numerous cost factors. A rise in the cost of PV modules, BESS, diesel generators, and fuel all lead to consistent growth in both NPC and COE.

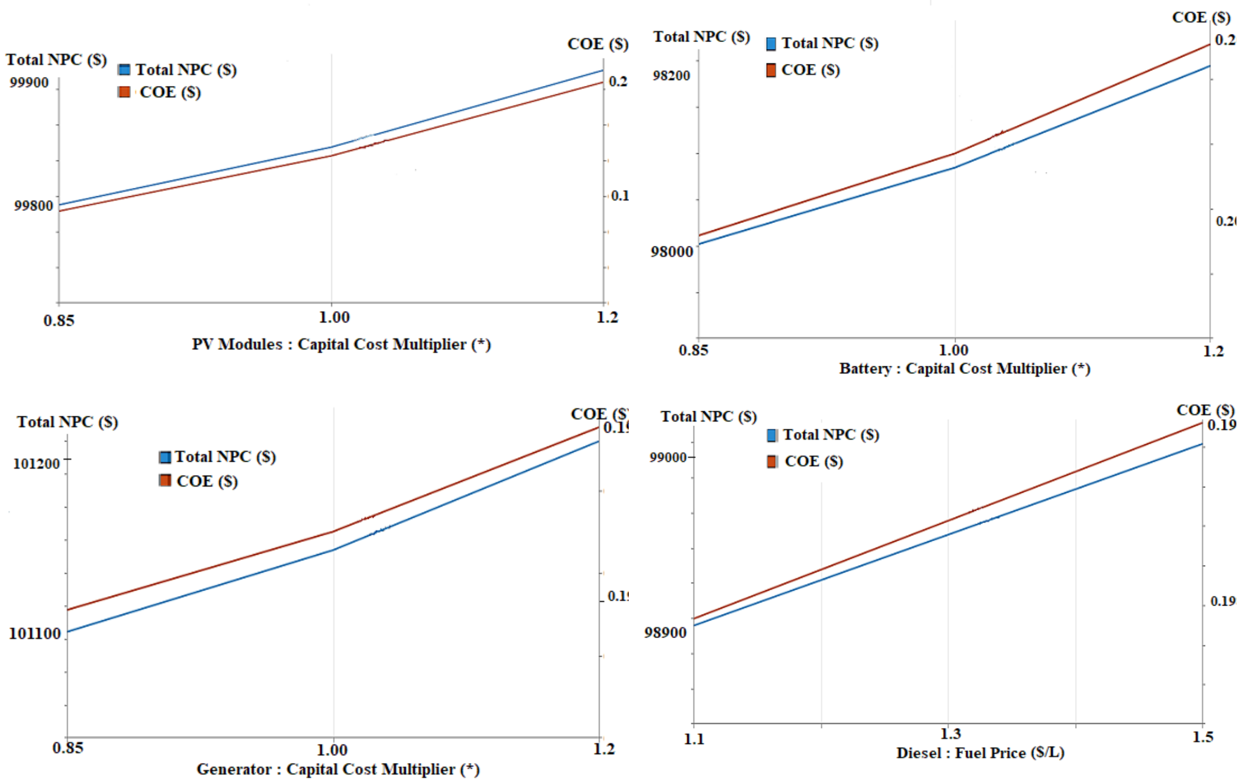



**Figure 14:** Sensitivity Analysis of Capital Cost of PV Modules, BESS, DG and Fuel Price

## 7. Results and Discussion: Energy Management of Excess Energy

Different strategies and configurations can be used to benefit from the excess electrical energy:

### 7.1 PV/Diesel Generator/BSS with Water Pumping System

In certain situations, there is potential to utilise excess energy for water pumping. These circumstances are available in rural areas. The water pumping system's potential energy is stored by holding water in a tank at a certain height. The tank is situated at a specific height, and water flows by gravity, with the occasional use of a small pump. 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. 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 specific frequency, voltage, etc. The load profile of the pump is shown in Figure 15.

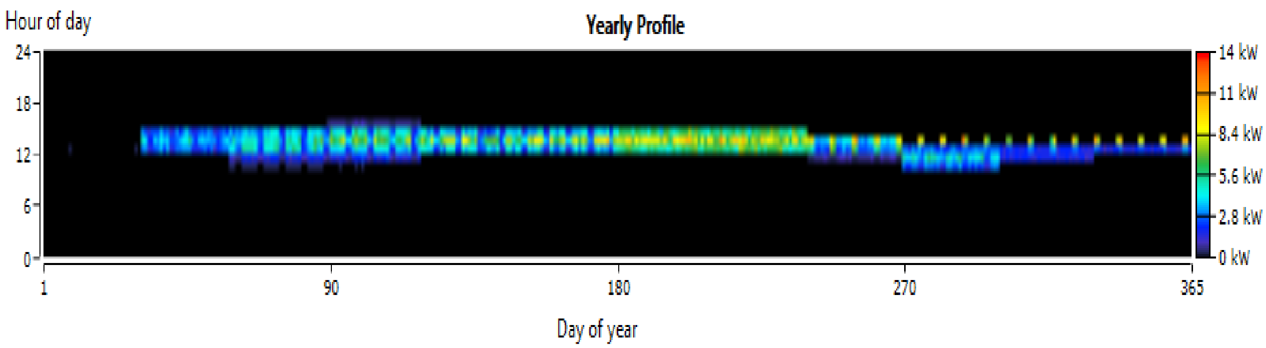



**Figure 15:** Load Profile for Proposed Pump Load from Homer Pro Software

A schematic of the proposed pump load with the base system is shown in Figure 16. The system consists of photovoltaic cells, a diesel generator, batteries, a water pump, and a power conditioning 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%.

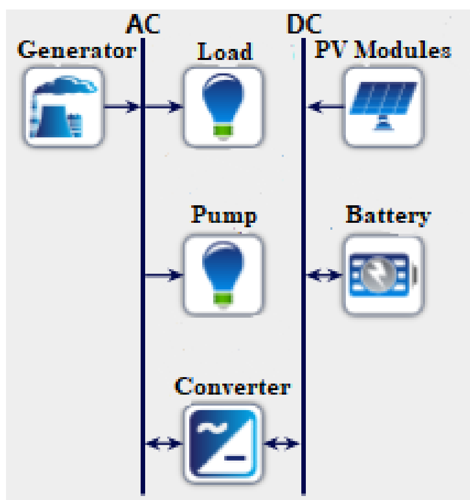



**Figure 16:** A Schematic Diagram of PV/DG/BESS with Water Pumping System

Table 1 shows the effect of adding a pump to the base system.

**Table1:** The Effect of Adding a Pump on the Base System

| | With 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 1 shows that the COE is USD 0.212/kWh with a pump, while the COE without a pump is USD 0.194/kWh. This is because of the reduction in the renewable fraction. The power generation from PV modua les decreases when the diesel generator is used. Figure 17 shows the amount of excess energy for the base proposed system and the system with pump.

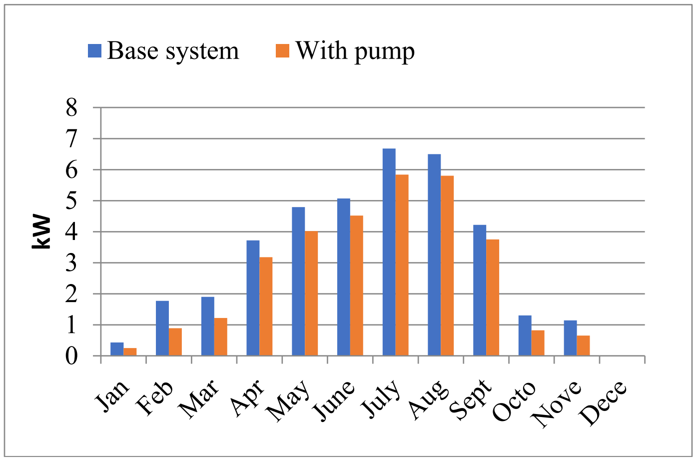



**Figure 17:** The Excess Energy for Base System with Pump and without Pump

Figure 18 shows the cash flow summary of the base proposed system with pump load.

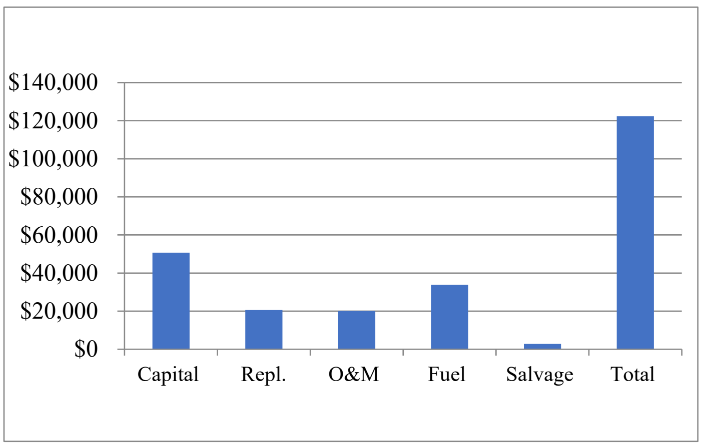
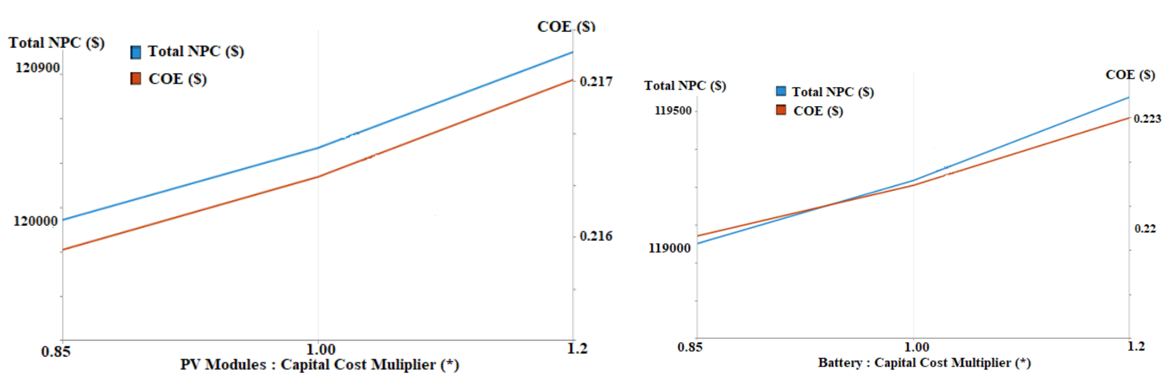



**Figure 18:** Simulation Economic Results: Cash Flow Summary of Base Proposed System with Pump Load

To assess the effect of the main issues on the NPC and COE, a sensitivity analysis was implemented. The cost of diesel fuel and MACS were analysed, while solar radiation was excluded due to its historical stability in the PT region. Figure 19 includes four different analyses that demonstrate the influence of numerous cost factors. A rise in the cost of PV modules, BESS, diesel generators, and fuel all lead to consistent growth in both NPC and COE.



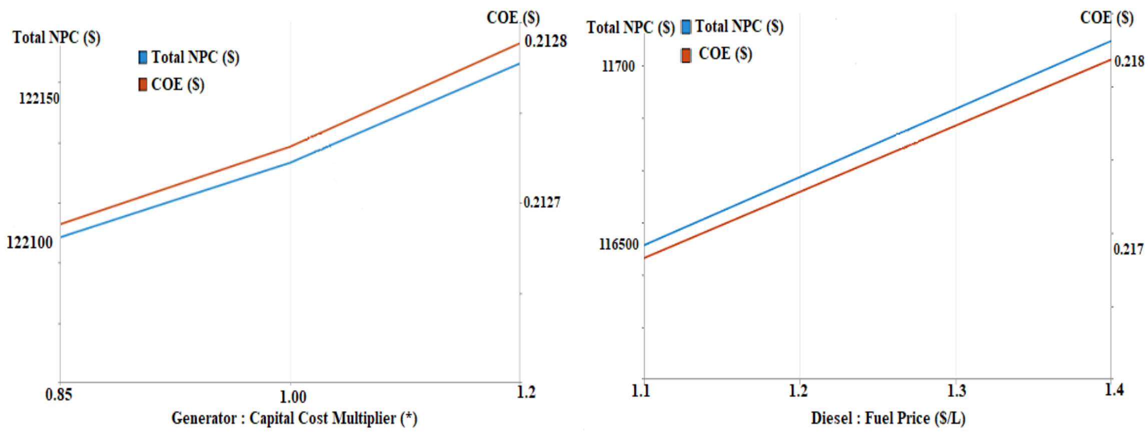



**Figure 19:** Sensitivity Analysis of Capital Cost of PV Modules, Battery, DG and Fuel Price

### 7.2 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 FC. It operates in a closed water loop, using electricity to separate water into hydrogen and oxygen through a process called electrolysis. Oxygen is released into the atmosphere or stored in tanks to supply other industrial processes or medical gases. Hydrogen gas can be stored in a hydrogen tank (HT) as a compressed gas or liquefied. It can then be used to power any hydrogen fuel cell electric application. PV/DG/BESS with FC proposed system is shown in Figure 20. FC with specific costs and a size of 1 kilowatt was chosen to use hydrogen to react with the existing oxygen and produce energy. Also, the electrolyser, with a size of 15 kW, was selected to analyze water and obtain separate hydrogen for use in the FC. If an excess amount of hydrogen is available, it is stored in special tanks under certain conditions, with 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%.

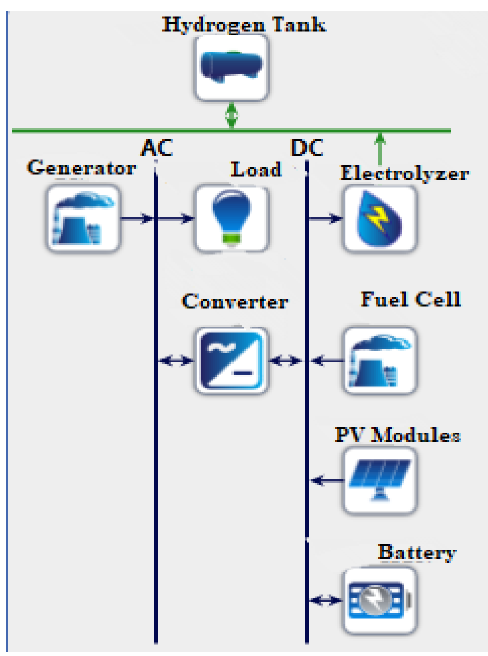



**Figure 20:** A Schematic Diagram of the Micro Grid Hybrid Power System with Electrolyser, FC and Hydrogen Tank (HT)

Table 2 shows the difference in the amount of excess energy of the base system with pump and Electrolyzer, FC and hydrogen tank.

**Table 2:** The Difference in the Amount of Excess Energy of the Base System with the Presence of a Pump, Electrolyser, FC, 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 21 illustrates the differences in the effects of two strategies on the base system compared to the proposed base system.

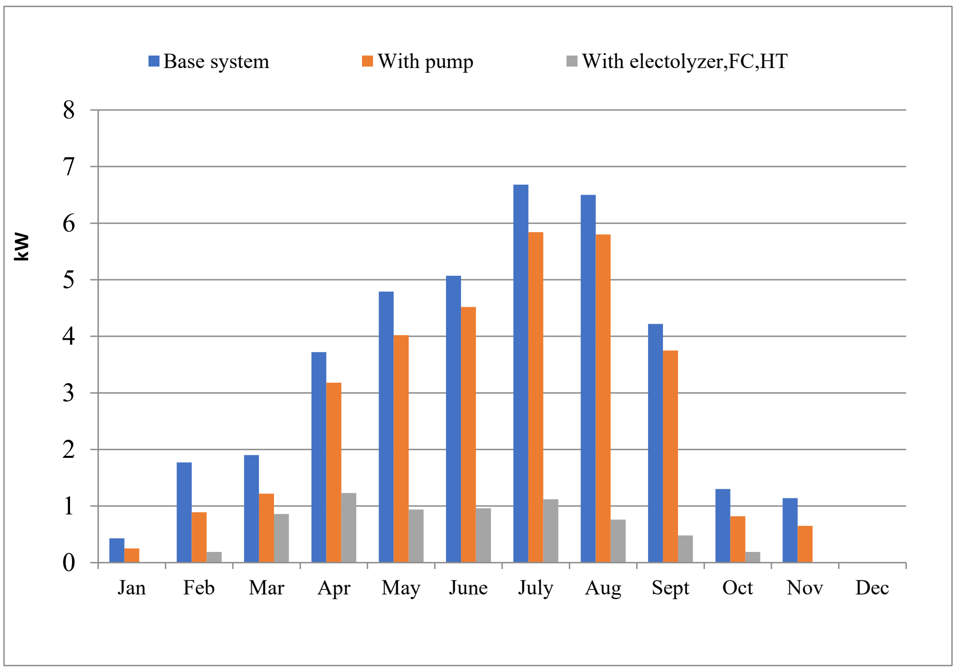



**Figure 21:** Differences between Two Strategies with Base Proposed System

### 7.3 PV/DG/BESS with Boiler Water Heating System.

The heater converts electrical energy into thermal energy, which is used for heating water. This process involves an electric current flowing through a thermal conductive material with high resistance to electricity. The thermal preservation electric heater of this type is the most widespread in domestic use. It is a cylindrical heat conservation tank containing a thermal resistance that heats the water, along with an insulated thermal coil located at the bottom or one side of the tank. It also contains a Thermostat (such as a sensor), through which the heating temperature is controlled, so that the current is cut off, to stop the heating process. The heater features a column of magnesium to handle water, protect the heater from corrosion, and includes safety valves to prevent hot water from mixing with cold water. In this strategy, adding a heater load and a boiler at times when there is excess energy allows for its use as much as possible. A boiler with specific costs was chosen to convert electrical energy to thermal energy. Also, a thermal load of 11.26 kWh/d was decided (by calculations on Homer Pro software). Figure 22 shows a schematic diagram of PV/DG/BESS with Boiler Water Heating System. The net present cost is USD 138,499. The COE is USD 0.213 /kWh. The contribution of RE 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.

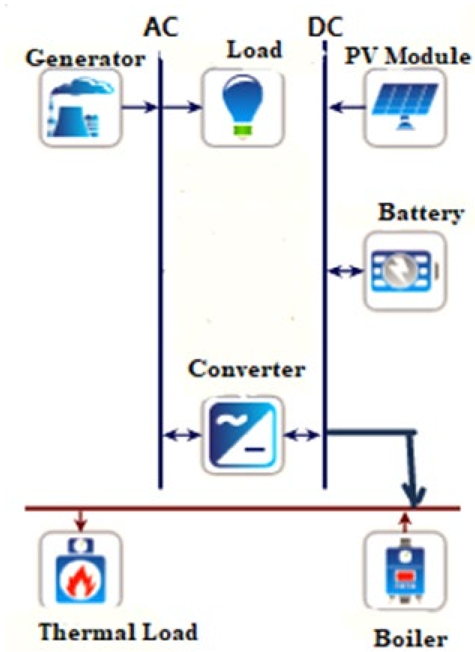



**Figure 22:** Schematic Diagram of PV/DG/BESS with Boiler Water Heating System

Figure 23 shows the difference in the amount of excess energy of the proposed base system with the presence of a pump, electrolyze, FC, hydrogen tank and boiler.

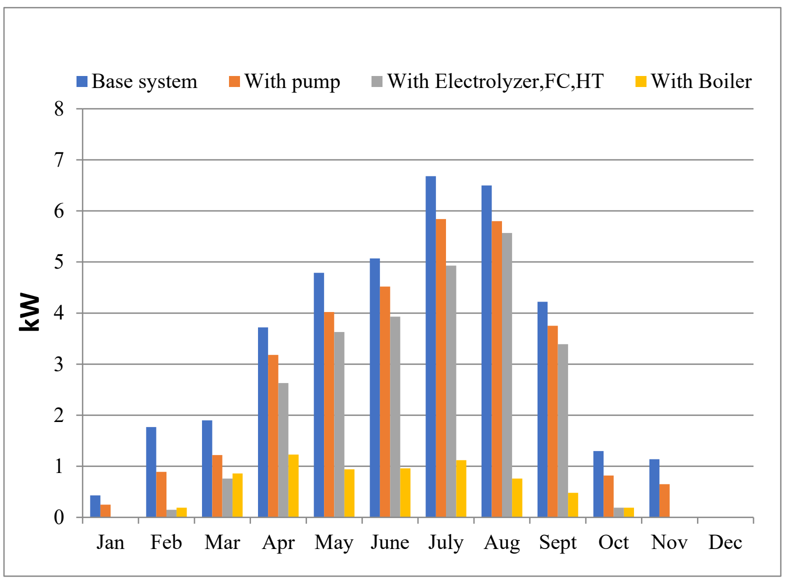



**Figure 23:** The Difference in the Amount of Excess Energy of the Proposed System with the Presence of a Pump, Electrolyser, FC, HT, and Boiler.

The boiler is a crucial strategy due to its ease of use and scalability, thanks to its working principle, which relies on a DC voltage. Although applying it to the program in detail is challenging, the results have been satisfactory. With an electric heater (thermal load), the most significant possible amount of excess energy is consumed during its operation, as dictated by the boiler's nature of work. It can be operated in multiple ranges, offering great flexibility in operation. This allows for the benefit of excess energy at a very high rate, potentially reaching 90%, and the exploitation of 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 relatively 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 specific frequency and voltage, etc.

### 7.4 PV/DG/BESS 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 it is needed, and we may benefit from the boiler in its applications. The decline in the price of the boiler has had a significant impact on the economic aspect. Figure 24 shows a schematic diagram of PV/DG/BESS with hybrid boiler water heating and a Water Pumping System. The results obtained indicate that the net present cost of the main components of a system is USD 140,220. The COE is USD 0.214 /kWh. The contribution of RE is 81.9%. The excess electricity is 3182 kWh/year which is about 5.29%. The unmet electric load is about 0.89%. Values indicate that the excess energy after adding the pump and boiler loads with the primary system decreased by approximately 8.5%. And this percentage is actually perfect.

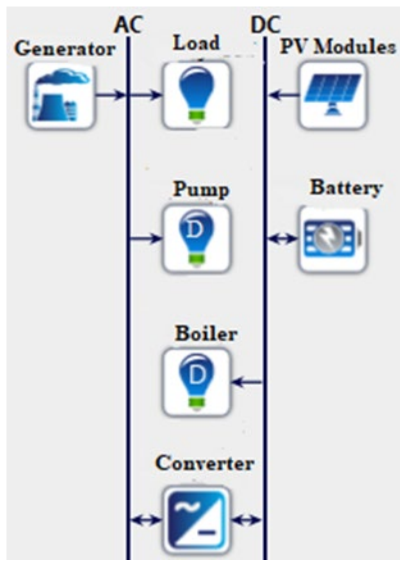



**Figure 24:** A Schematic Diagram of PV/DG/BESS with Hybrid Boiler Water Heating and Water Pumping System

Table 3 shows the difference in the amount of excess energy and other indicators for all proposed configurations.

**Table 3:** Comparison between the Proposed Configurations and the Base Case

| The Configuration of the System | Base System | With Electrolyzer, FC and Hydrogen Tank | With Pump | With Boiler | With Hybrid Boiler and Water Pumping |
|---|---|---|---|---|---|
| NPC (USD) | 101,361 | 129,368 | 122,346 | 138,499 | 140,220 |
| COE (USD/kWh) | 0.194 | 0.210 | 0.212 | 0.213 | 0.214 |
| Excess Energy (%) | 13.8 | 8.8 | 11.3 | 5.57 | 5.29 |
| Excess Energy (kW/year) | 7469 | 5119 | 6483 | 3334 | 3182 |
| RE Fraction (%) | 92.2 | 85.2 | 85.9 | 82.3 | 81.9 |
| Unmet Electric Load (%) | 0.385 | 0.745 | 0.733 | 1.02 | 0.89 |

A sensitivity analysis was implemented to study the of main issues on the NPC and COE. The cost of diesel fuel and MACS were analyzed. A rise in the price of PV modules, BESS, DG, and fuel all lead to consistent growth in both NPC and COE. As shown in Table 3, the COE of the proposed configurations is slightly higher than the base case; however, the primary purpose of the research is verified, which is reducing the excess energy. The excess energy is one of the significant challenges of RE system in stand-alone systems. Good management of excess energy enhanced system consistency, reduced DG reliance, and facilitated effective storage utilization.

## 8. Conclusion

The study purposes a procedure for excess energy management to increase the chance of using RE systems. After studying the excess power distribution and the demand of residential loads, the water pump, and the 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 have been studied for economic purposes, they are not the primary objectives of this research. All that happened can be summarized as follows:

- The PV/DG/BESS 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 USD0.212/kWh. The NPC is USD122,347. The PV system is 30 kW, comprising 40 batteries of 1150 Ah each, and a 3 kW DG.
- The PV/ DG /BESS with FC System reduces the surplus energy from (13.8%) to (8.8%), about 8%. This percentage is actually good. The COE is USD0.21/kWh. The NPC is USD129,368. The PV system is 30 kW, comprising 40 batteries of 1150 Ah each, and a 3 kW DG.
- The PV/ DG /BESS 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 USD0.213/kWh. The NPC is USD138,499. The PV system is 30 kW, comprising 40 batteries of 1150 Ah each, and a 3 kW DG.
- The PV/DG/BESS with hybrid boiler water heating and Water Pumping System is the most economical scenario to electrify the load, reducing the surplus energy from (13.8%) to (5.2%), about 8.5%. This percentage actually very good. The COE is USD0.214/kWh. The NPC is USD140,220. The PV system is 30 kW, comprising 40 batteries of 1150Ah each, and a 3kW DG. The hybrid power system provides the residential and pumping load and heating load with no interruption to the power supply

## References


Akhtari, M. R., & Baneshi, M. (2019). Techno-economic assessment and optimization of a hybrid renewable co-supply of electricity, heat and hydrogen system to enhance performance by recovering excess electricity for a large energy consumer. *Energy Conversion and Management*, *188*, 131-141. https://doi.org/10.1016/j.enconman.2019.03.067

Alnejaili, T., Drid, S., Mehdi, D., Chrifi-Alaoui, L., Belarbi, R., & Hamdouni, A. (2015). Dynamic control and advanced load management of a stand-alone hybrid renewable power system for remote housing. *Energy Conversion and Management*, *105*, 377-392. https://doi.org/10.1016/j.enconman.2015.07.080

Aziz, A. S., Tajuddin, M., & Adzman, M. (2018). Feasibility analysis of PV/wind/battery hybrid power generation: A case study. *International Journal of Renewable Energy Research*, *8*(2), 661-671. https://www.researchgate.net/profile/Mohd-Rafi-Adzman/publication/326235631_Feasibility_analysis_of_PVWindBattery_hybrid_power_generation_A_case_study/links/5ba84be292851ca9ed211aec/Feasibility-analysis-of-PV-Wind-Battery-hybrid-power-generation-A-case-study.pdf

Bailera, M., Peña, B., Lisbona, P., & Romeo, L. M. (2018). Decision-making methodology for managing photovoltaic surplus electricity through Power to Gas: Combined heat and power in urban buildings. *Applied energy*, *228*, 1032-1045. https://doi.org/10.1016/j.apenergy.2018.06.128

Basnet, S., Deschinkel, K., Le Moyne, L., & Péra, M. C. (2023). A review on recent standalone and grid-integrated hybrid renewable energy systems: System optimisation and energy management strategies. *Renewable Energy Focus*, *46*, 103-125. https://doi.org/10.1016/j.ref.2023.06.001

Bhayo, B. A., Al-Kayiem, H. H., & Gilani, S. I. (2019). Assessment of standalone solar PV-Battery system for electricity generation and utilization of excess power for water pumping. *Solar Energy*, *194*, 766-776. https://doi.org/10.1016/j.solener.2019.11.026

Das, B. K., & Hasan, M. (2021). Optimal sizing of a stand-alone hybrid system for electric and thermal loads using excess energy and waste heat. *Energy*, *214*, 119036. https://doi.org/10.1016/j.energy.2020.119036

Kusakana, K. (2016). Overview of different approaches used in optimal operation control of hybrid renewable energy systems. *World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering*, *10*(6), 811-818.

https://publications.waset.org/10004846/overview-of-different-approaches-used-in-optimal-operation-control-of-hybrid-renewable-energy-systems?utm_source=chatgpt.com

Mandal, S., Das, B. K., & Hoque, N. (2018). Optimum sizing of a stand-alone hybrid energy system for rural electrification in Bangladesh. *Journal of Cleaner Production*, *200*, 12-27. https://doi.org/10.1016/j.jclepro.2018.07.257

Nassar, Y. F., El-Khozondar, H. J., Elnaggar, M., El-batta, F. F., El-Khozondar, R. J., & Alsadi, S. Y. (2024). Renewable energy potential in the State of Palestine: Proposals for sustainability. *Renewable Energy Focus*, *49*, 100576. https://doi.org/10.1016/j.ref.2024.100576

Omar, M. A. (2024). Green mechanism: Opportunities for corporate investment in PV/battery/diesel hybrid systems with techno-economic and environmental analysis. *Energy Exploration & Exploitation*, *42*(6), 2125-2149. https://doi.org/10.1177/01445987241269009

Rad, M. A. V., Kasaeian, A., Niu, X., Zhang, K., & Mahian, O. (2023). Excess electricity problem in off-grid hybrid renewable energy systems: A comprehensive review from challenges to prevalent solutions. *Renewable Energy*, *212*, 538-560. https://doi.org/10.1016/j.renene.2023.05.073

Salameh, T., Ghenai, C., Merabet, A., & Alkasrawi, M. (2020). Techno-economical optimization of an integrated stand-alone hybrid solar PV tracking and diesel generator power system in Khorfakkan, United Arab Emirates. *Energy*, *190*, 116475. https://doi.org/10.1016/j.energy.2019.116475

Yasin, A., & Alsayed, M. (2020). Optimization with excess electricity management of a PV, energy storage and diesel generator hybrid system using HOMER Pro software. *Int. J. Appl. Power Eng.(IJAPE)*, *9*, 267-283. https://doi.org/10.11591/ijape.v9.i3