Hybrid power supply system of a selected residential building based on innovative renewable sources

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***Abstract*- The growth in the demand for energy knows no end. Yet there is pressure more than ever before to meet this growing demand in the cleanest possible ways. This creates an attractive opportunity especially in countries still dealing with energy poverty like Nigeria to fill the energy gap with energy from clean sources. This thesis evaluates the potential for hybrid power systems comprising of renewable sources to meet the electrical load requirement of a selected residential building at the lowest possible cost. The building is located in Warri, Nigeria where power supply is still largely unreliable and very dependent on fossil sources. The hybrid power systems studied in this thesis combine various scenarios of wind turbine, photovoltaic array, gasoline generator, and fuel cell to produce electricity. Energy storage is applied as well. These systems are designed and simulated with HOMER Pro which is a software for optimizing microgrid design for residential, industrial, and commercial applications. HOMER Pro runs several simulations in other obtain the optimal sizes of the components of the various scenarios that satisfy the electrical load requirements at the lowest net present cost. A base scenario comprising solely of a gasoline generator is simulated as well for the purpose of comparison. HOMER Pro also calculates the net emission from these systems. The results suggest that hybrid power systems offer cost and emission benefits when compared to the base scenario. After they are evaluated, a wining scenario is selected for the building.**

I. Introduction

For over a century the tradition of burning coal, oil and gas has made it possible for humanity to achieve high standards of living through many outstanding innovations in the world of energy science and technology yet in recent decades, the need for a global shift from fossil driven systems of energy production and consumption to clean and sustainable driven systems have been heightened. A major catalyst for this transition is the impact of greenhouse emissions from these systems. Combusting fossil fuel to produce energy has been named as one of the major causes of increased atmospheric carbon dioxide [8]. Atmospheric carbon dioxide has been increasing at an alarming rate. Over the last 60 years the increase is about 100 times more than the increase in the previous years from natural causes. These emissions have been linked to climate change, air pollution and respiratory diseases [2]. At the same time the world energy demand is also on the increase. It is expected to grow by nearly 50% from 2018 to 2050 [4]. Although this increased demand reflects across all major sectors of the economy, it is pertinent to note that industry and buildings alone accounts for about 75 percent of the growth in energy demand [3]. According to Bp's energy outlook 2020 Edition, most of this growth will come from emerging economies largely due to increasing population, prosperity, and increased access to electricity.

Nigeria is an emerging economy with an estimated population of 200 million people. According to the world bank, about 43 percent of its population still lacks access to electricity, and those who have access, suffer from erratic supply. This is why off-grid power generation is commonplace in Nigeria. Most residential buildings have diesel or gasoline generating sets.

These generators cost a lot more to operate and maintain, create excruciating noise pollution, and emit tons of greenhouse gases to the atmosphere [6]. Various studies have been carried out on off grid renewable energy solutions. Promising renewable energy technologies include wind, solar, geothermal, biomass and hybrid systems of two or more technologies to meet the energy demands of residential buildings.

Hybrid power systems (HPS) combine more than one generating unit to meet the load requirement [5]. HPS can exist as standalone systems or grid connected. Stand-alone systems are installed with storage devices to satisfy load requirements while grid-connected systems can feed excess generation to the grid or acquire supply from the grid in times of deficiency [7]. In recent times, HPS consisting solely of renewable energy sources is gaining more application, due to higher efficiency and lower net present cost. An added advantage of HPS comprising solely of renewable sources is that at times when one renewable source is not in abundance and cannot supply the needed power, the other can complement for it. Asides the benefits of sustainability, quietness, and cost effectiveness, hybrid power supply systems for residential buildings offer a viable alternative to achieving the desired full nationwide electrification in Nigeria. In this thesis several hybrid power systems are analyzed for a selected residential building to select a system that meets the load requirement at the least possible net present cost.

This thesis is structured as follows: Chapter 2 discusses the basic concepts of hybrid power systems and renewable energy resources that can be utilized in designing and installing hybrid systems. Chapter 3 discusses the concept of energy storage. The methodology applied in this study is described in chapter 4. Chapter 5 presents and discusses the results of this study while the main conclusions are drawn in chapter 6 alongside future studies.

II. Case study

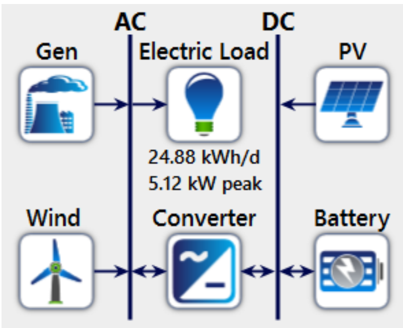
A. Scenarios

In this study, some hybrid power systems are modeled. The systems comprise of wind, gasoline generating set, photovoltaic, fuel cell and batteries. The systems utilize different combination of all the above-mentioned components to meet the electric load of a residential building. The models are designed and simulated in HOMER Pro microgrid software by HOMER Energy. HOMER (Hybrid Optimization of Multiple Electric Renewables) Pro is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to help in designing of micropower systems for residential, community, commercial and industrial applications [13]. The tasks performed in HOMER are design, simulation, and optimization. This study was carried out bearing in mind the following assumptions: discount rate of 10%, lifetime of 25 years, inflation rate of 2%, and simulation time step of one hour.

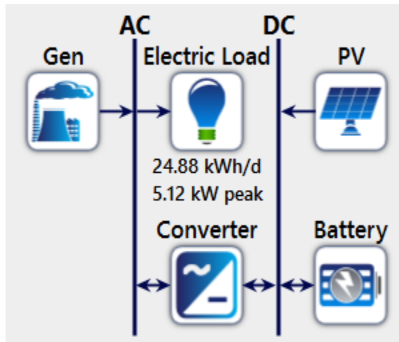
The design is accomplished by selecting from the HOMER Pro library, the proposed resources, components (PV panels, wind turbine, generating sets) and specifying the load (heat, electricity, hydrogen). Homer Pro will tabulate the most optimal sizes of the components of each scenario that meets the electric load by comparing the economics, energy balance and emissions. Fig 1. depicts the schematic of the different hybrid systems studied within the context of this thesis.

- Scenario 1: Solar PV, Converter, Wind turbine, Battery Storage, Gasoline Generator
- Scenario 2: Solar PV, Converter, Battery Storage, Gasoline Generator
- Scenario 3: Wind turbine, Battery Storage, Gasoline Generator
- Scenario 4: Wind turbine, Battery Storage, Solar PV, converter
- Scenario 5: Solar PV, Wind turbine, Converter, Fuel Cell, Hydrogen Tank, Electrolyzer

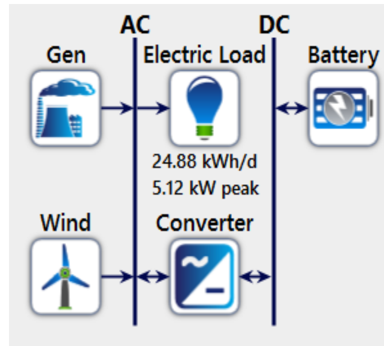
Scenario 1 is composed of a solar PV, wind turbine, battery storage, gasoline generator. The battery and solar PV are installed on the DC bus. Thus, the need for a well sized converter to relay the power to the AC load. Scenario 2 is made up of solar PV, battery storage, and gasoline generator. Scenario 3 is composed of wind turbine, battery storage, and gasoline generator. Scenarios 4 and 5 are entirely renewable models.



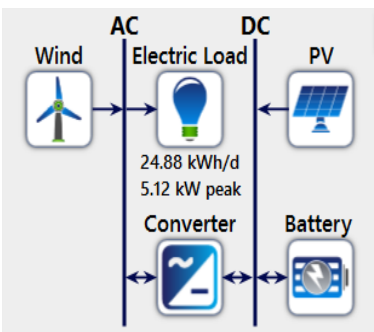
Scenario 1



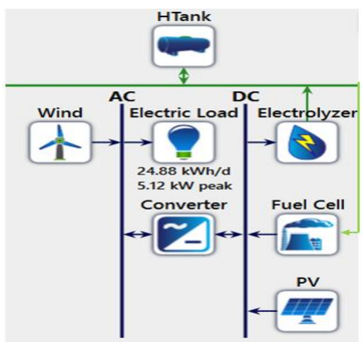
scenario 2



Scenario 3



Scenario 4



Scenario 5

Fig. 1. Hybrid system composed of WT, PV, FC, and battery storage to serve AC load [Screenshots from Homer Pro Software]

Scenario 4 is made up of wind turbine, battery Storage, Solar PV. It is important that the size of the battery is optimized to cope with the peak load for a short period of time. Scenario 5 incorporates hydrogen storage into its mix. It is composed of solar PV, wind turbine, fuel cell, Hydrogen Tank, and electrolyzer. The size of the hydrogen tank is optimized to meet the daily generated hydrogen. The specifications of the components of the different scenario are highlighted in tables below. The data was provided by the HOMER Pro software.

B. Control strategy

HOMER Pro models two types of control strategy; load following LF and cycle charging CC. Cycle charging is a type of dispatch strategy where the load requirement is met primarily by a generator operating at full capacity when a generator is in use and only surplus electrical production is channeled to meet lower priority objectives like meeting the deferrable load, power bank charging, and serving the electrolyzer. In the load following strategy, whenever a generator set is in use it only produces enough power to meet the load requirements. Other objectives like power bank charging and meeting the deferrable load are served by renewable sources. In cases where there is grid connection, the generating set can still be ramped up to sell to the grid if it is economically viable.

C. Object and load description

The Residential building for which the hybrid installation will be designed is a fully detached bungalow located in Warri, Delta State Nigeria (5º33 .3N 5º47.6 E). It comprises 4 rooms, a living and dining area and has an area of 309.67 m^2. The building is connected to the grid. However, power supply is erratic, and it relies almost entirely on gasoline generator to meet its electricity. All heating and cooling demands are also met by electrical appliances and as such are included in the total electric demand. Fig 2. shows the view of the building.

Fig. 2. View of the residential building for which hybrid system is to be installed

The annual electric demand for building is 9079.80 kWh. Table 1. shows the load specification.

Table 1. Load specification

Electric load	Value
Average [KWh/day]	24.88
Average [KW]	1.04
Average [KWh/year]	9079.80

Fig 3. shows the seasonal load profile. The load is determined by summing up the ratings of all appliances used and multiplied by the number of hours used. January records the highest electrical demand (2.23kW). June records the lowest electrical demand (1.35kW).

D. Meteorological data

Meteorological data relevant to this study are the hourly solar radiation, wind speed, and the monthly average temperature. They have been derived from NASA Surface meteorology and Solar Energy database [13]. Fig.4.-Fig.6. shows the monthly variations in solar radiation and clearness index, wind speed, and the monthly average temperature. This fluctuation affects systems' output.

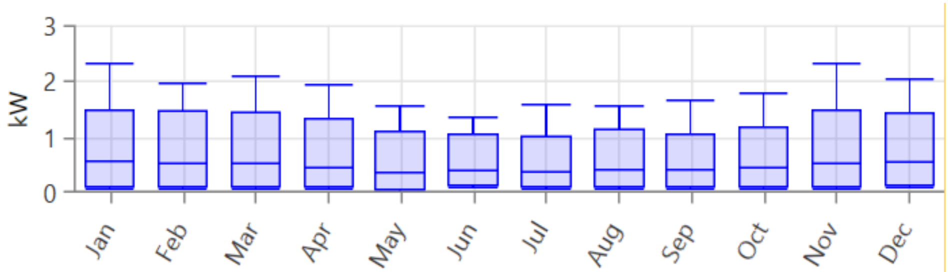


Fig. 3. Seasonal profile [Screenshots from Homer Pro Software]

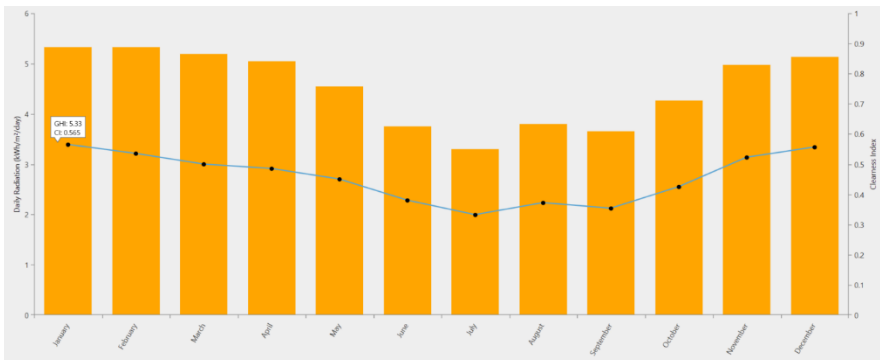


Fig. 4. Monthly average solar radiation and clearness index [13]

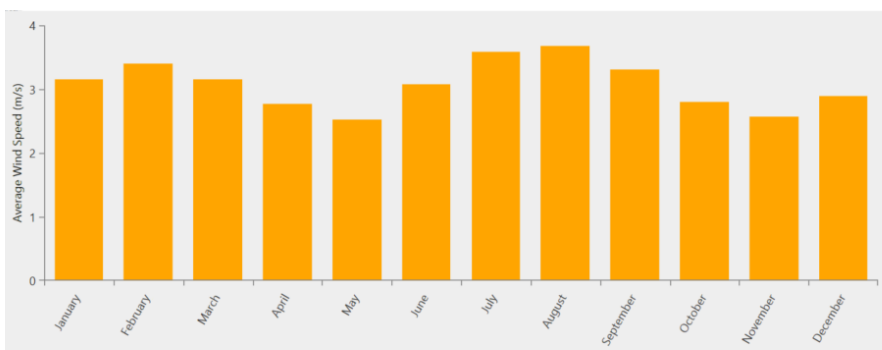


Fig. 5. Monthly average wind speed [13]

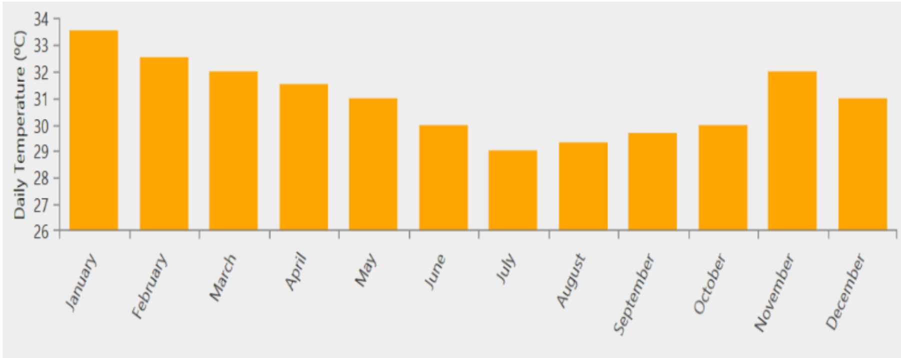


Fig. 6. Monthly average temperature [13]

III. Simulation and results

The simulation and optimization results of the scenarios are presented in this chapter.

Scenario 1:

This scenario utilizes power from wind, solar and a generating set. Storage is provided by the lead acid battery. The Optimization results for this scenario are displayed in table 2. HOMER Pro chooses a 5kW solar installation alongside 6kW wind turbines and 63 lead acid batteries as the optimal mix to satisfy the load requirements. The configuration uses a cycle charging dispatch strategy. The generating set capacity is fixed at 3kW because this generating already exists at the location. The NPC of the entire system is $208 816, and the initial capital is $69 525. Scenario 1 satisfies the load requirements with an excess of 384 kWh/yr. 76% of the electricity generated is from renewable sources. Fig. 7. illustrates the monthly electric production from the different sources.

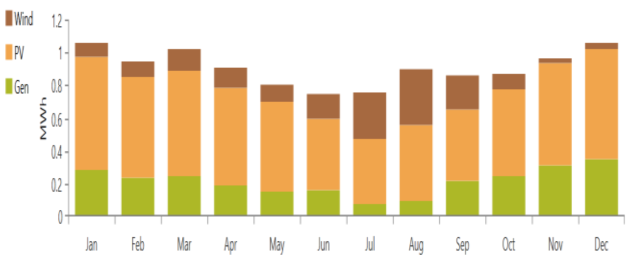


Fig. 7. Monthly electric production of Scenario 1

Scenario 2:

This scenario utilizes power from solar and a generating set. lead acid batteries store energy for better load balancing. The optimal size from the simulation is a 5kW solar PV array alongside the 3kW generating set. Table 3 shows the results of the simulation. Scenario 2 meets the load requirements and produces an excess of 157 KWh/yr. The renewable fraction is 62%. The monthly electric production from the different power sources is shown in Fig. 8.[1]

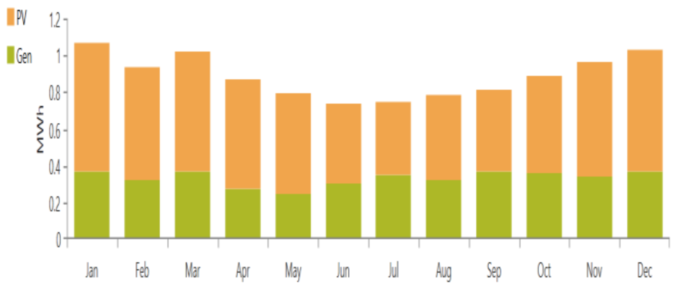


Fig. 8. Monthly electric production of Scenario 2

Scenario 3:

This scenario is a hybrid system composed of a generating set and wind turbines. HOMER found the optimal sizes to satisfy the load requirements to be 15 kW wind turbine alongside the 3kW generating set. The simulation results are shown in Table 4. The NPC of the system is $477 149. It cost a total of $101 350 to install. The system satisfies the electric load

[1] *$ Used in this study refer to US dollars.*

with an excess production of 1012 kWh/yr. It has a renewable fraction of 36%. Due to insufficient windspeed, the generating set supplies more of the electric load about 63% in contrast to scenario 1 and 2. The monthly electricity production from the components is illustrated in Fig.9.

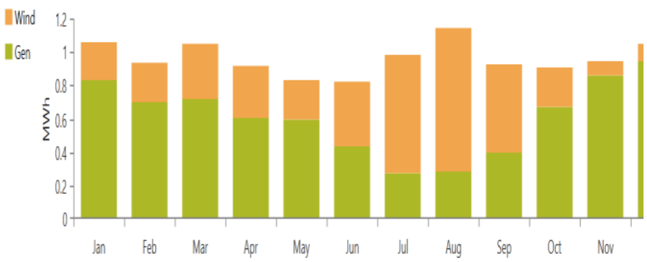


Fig. 9. Monthly electricity production from scenario 3

Scenario 4:

Scenario 5 was designed to have the load requirement met entirely by renewable sources. HOMER chooses 10kW of solar PV, 3kW wind and 58 lead acid batteries as the optimal sizes to satisfy the load. The results are shown in Table 5.

Table 2. Optimal size and cost of scenario 1

Architecture						Cost		
Solar PV (kW)	Wind (kW)	Gen (kW)	Battery	Converter (kW)	Dispatch	NPC $	O & M $/Year	Initial Capital ($)
5	6	3	63	3.08	CC	208 816	15 345	69 525

Table 3. Optimal size and cost of scenario 2

Architecture						Cost		
Solar PV (kW)	Wind (kW)	Gen (kW)	Battery	Convert-er (KW)	Dispatch	NPC $	O & M $/Year	Initial Capital ($)
5	-	3	55	2.46	CC	231 577	22 104	30 938

Table 4. Optimal size and net present cost of scenario 3

Architecture						Cost		
Solar PV (kW)	Wind (kW)	Gen (kW)	Battery	Convert-er (kW)	Dispatch	NPC $	O & M $/Year	Initial Capital ($)
-	15	3	31	2.83	CC	477 149	41 401	101 350

Table 5. Optimal size and net present cost of scenario 4

Architecture						Cost		
Solar PV (kW)	Wind (kW)	Gen (KW)	Battery	Convert-er (kW)	Dispatch	NPC $	O & M $/Year	Initial Capital ($)
10	3	-	58	3.88	CC	80 667	2 105	25 000

Table 6. Optimal size and net present cost of scenario 5

Architecture	Cost

Solar PV (kW)	Wind (kW)	FC (KW)	Electrolyzer (KW)	H Tank (Kg)	Dispatch	Convert-er (KW)	NPC $	O & M $/year	Initial Capital ($)
13.8	3	3	6.5	20	CC	1.50	126 232	3 058	98 479

Table 7. Optimal size and net present cost of the base scenario

Architecture						Cost		
Solar PV (kW)	Wind (kW)	Gen (KW)	Battery	Convert-er (kW)	Dispatch	NPC $	O & M $/Year	Initial Capital ($)
-	-	3	-	-	CC	6234 456	56 520	1 200

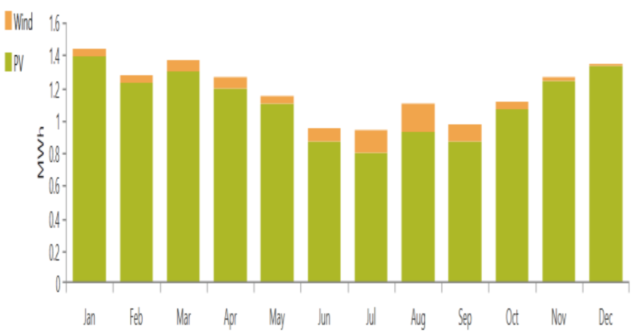


Fig. 10. Monthly electricity production from scenario 4

charging. It cost $25000 to install. Because the system is completely renewable there are no emissions from this system. The configuration meets the load requirements with an excess of 3850 KWh/yr. The excess production can be sold to the grid. The monthly electricity production is shown in Fig 10

Scenario 5:

In this scenario power is also generated solely from renewable sources. The system uses the excess renewable electricity to produce hydrogen which is stored in a tank and used by the fuel cell to produce electricity later. The result of the optimization is shown in Table 6. It consists of a 13kW solar PV array, 3kW wind turbine, 6.5kW electrolyzer, a 20Kg hydrogen tank, a 1.5kW converter and a cycle charging strategy. The initial capital for installation in US dollars is $98479 and the net present cost is $126232. The results of the simulations indicates that there was an excess production of 1654 KWh/yr. The load is met 100% by renewable resources. The monthly electric production is shown in Fig.11. The system produces a total of 277Kg of hydrogen annually. The fuel cell utilizes 267Kg of this hydrogen to produce electricity. The monthly hydrogen production from the electrolyzer is shown in Fig.12.

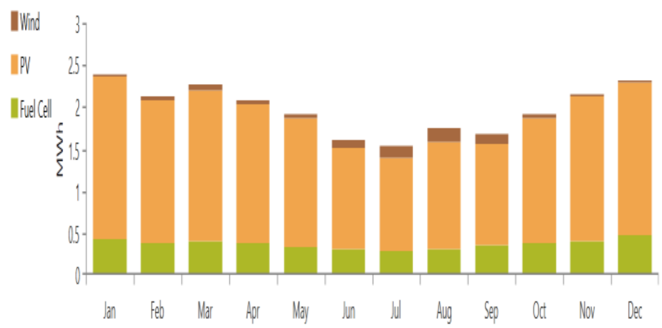


Fig.11. Monthly electricity production from scenario 5

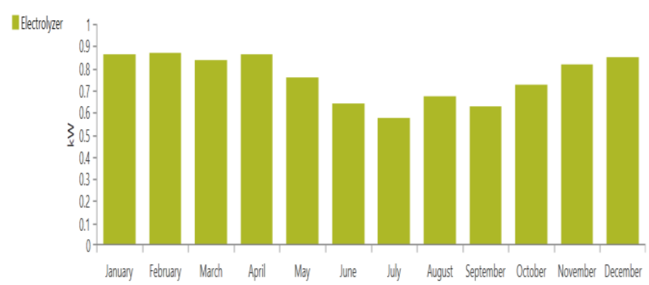


Fig.12. Monthly hydrogen production from the electrolyzer in scenario 5

Fig.13 and Fig.14 illustrates cost and emission comparison of all scenarios. Scenario 4 is the winning scenario because it has the least net present cost and produces no emission. Although the base scenario has the least installation cost the, the high net present cost and amount of emission produced makes it the least desirable. The results from scenario 3 suggest that wind turbines may not be ideal for that location. The wind speed was not sufficient to produce enough electricity to satisfy the load requirements. Although the wind capacity installed was 3 times more than the solar capacity in scenario 2, the system still relied more on the generating set.

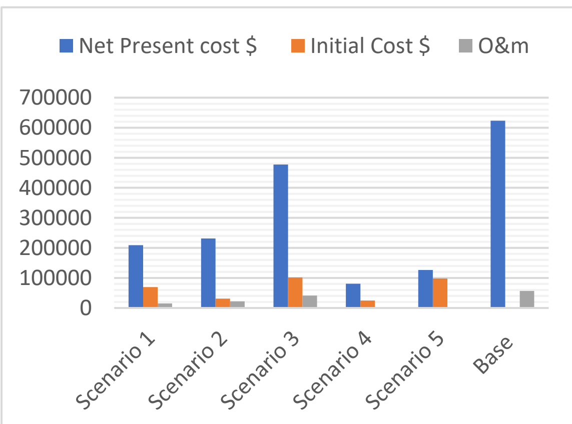


Fig. 13. Economic comparison of all scenarios

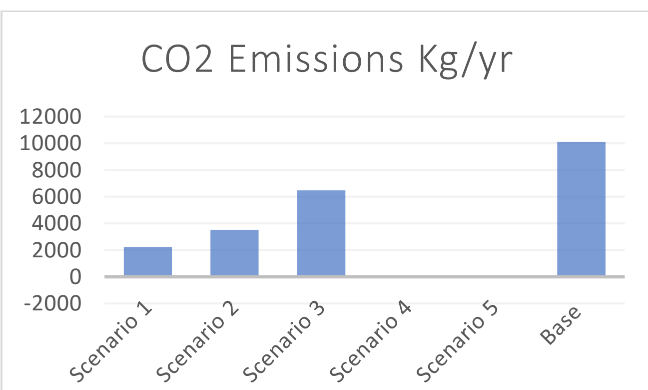


Fig. 14. Emission comparison of all scenarios

IV. Conclusion

In this study, a set of hybrid power systems for a residential building based on renewable sources and a gasoline generator were modeled and simulated. The following conclusions can be drawn based on the obtained results. The load requirements of the building can be met by all scenarios without shortages. Generating electricity from hybrid systems offer cost saving benefits. Wind installations are not ideal in the location for which the study was carried out because the installation cost is still high and the windspeed may not be sufficient to generate enough wind output to serve the load requirement. Of all studied scenarios, a hybrid power system comprising of 10kW solar and 3kW was found to be optimal. It had the least net present cost and produced no emission. Incorporating hydrogen production and storage into the power mix is very promising technology. Results from the simulation suggest that the production of hydrogen, storage, and later use to generate electricity is feasible. Asides using the produced hydrogen for electricity production, it could be used for other applications like powering hydrogen vehicles and methanol production.

V. Future work

In future work, more hybrid systems consisting of biomass and geothermal resources will be considered. The scope of coverage will be extended from one residential building to the community as well. The benefits of grid-connected hybrid power systems will be evaluated as well. Additionally, the technoeconomic benefits of including other hydrogen pathways into the power mix will be evaluated.

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