OPTIMIZATION OF HYBRID POWER SYSTEM USING HOMER FOR URBAN ELECTRIFICATION (A CASE STUDY OF OYEMEKUN, AKURE, NIGERIA)

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ABSTRACT

With the increase in population in Nigeria, the demand for power consumption also increases with low supply from the national grid. This result in Nigeria been raked the lowest electricity per capita consumption in Africa. And there are also persistent distribution line faults which hinder the rate of power consumption. The National Electricity Regulatory Commission faces many challenges in their regulatory duties because of people who benefit from the inadequate electricity supply. The inefficiencies in the generation, distribution, and human activities in depressing natural resources make diversification into renewable energy difficult. This study aims to simulate a hybrid power generation system, with specific objectives to estimate the one year daily load demand of Oyemekun, Akure. An optimal hybrid energy system was developed using HOMER; to evaluate the solar resources available and simulate the solar capacity required using MATLAB Simulink. Finally, it also presents a review of Nigeria's renewable energy potentials to be tapped for useful and uninterrupted electric energy supply. This study provides a detailed analysis of the quantum of electricity supply to Oyemekun, Akure, and how to supplement lost hours in power supply (i.e. hours lost to a power outage) using solar energy augment for 18 hours of power unavailability in the community.

Keyword: *Hybrid, Power System, Homer, Optimization, Urban Electrification*

INTRODUCTION

Oyemekun area, Akure, Ondo State was used as a case study in this research. This development's scope is limited to determining the best techno-economic combination of renewable energy resources in a hybrid configuration for electrification of Oyemekun community, Akure, Ondo State. Oyemekun community was used as a case study because the distribution company (Benin Electricity Distribution Company) supplying electricity to the community only provides an average of seven hours of electricity daily, which is insufficient for the whole community and slow down commercial activities. The design in this study will augment for the power outage hours or the load shedding hours which is seventeen hours to provide 24 hours electricity.

Solar energy or power is the utilization of sun light for generation of electricity. The energy generation from sun can be done by a direct method using the photovoltaic (PV), or using indirect method when light or energy is focused to boil and heat water which is later used to provide power, the indirect method is called Concentrating Solar Power (CSP). Primarily solar power refers to the use of sum radiation for generation of electricity. However, beside geothermal and tidal, all other renewable energy sources get their energy from the sun (Bagen & Billinton, 2005).

The types of Solar Energy include: Solar Photovoltaic (PV) Energy: Conversion of light (photons) to electricity (voltage) using semiconductor materials that exhibit the photovoltaic effects. Photovoltaic system employs solar panels, each comprising several solar cells, which generate electrical power. Solar Thermal Energy: This collects and concentrate sunlight to produce the high temperature heat needed to generate electricity.

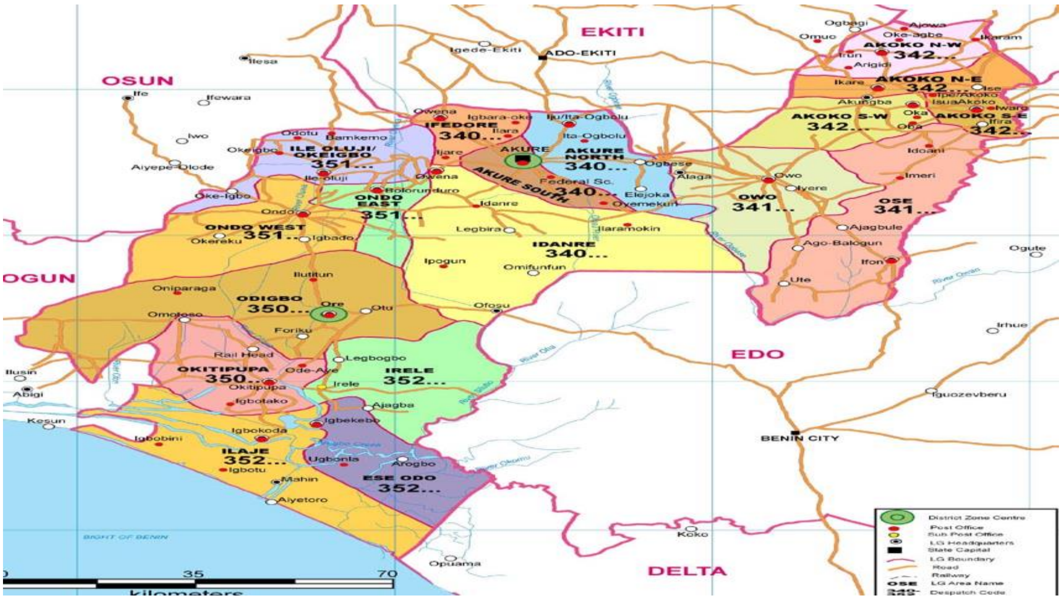

Figure 1.1: The community location on Akure map (Source:google.com/maps-streetview.com)

LITERATURE REVIEW

Renewable energy is collected from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat (Ellabban et al., 2014)Renewable energy resources and significant opportunities for energy replenished constantly. It derives directly from the sun or heat generated deep within the earth in its various forms. The use and applications of renewable energy is on the incline. As the amount of fossil fuels lessens and the environmental concerns of continuing to use fossil fuels increases, there is a heightened need to search for alternative solutions. Nigeria has a large amount of the resources needed for current renewable energy technology application; it has great potential for implementation of this kind. In addition to renewable energy techniques of energy generation being environmentally friendly, there is no necessity for fuels and therefore after initial capital investment, there are only minor operating costs associated with this. For rural environments, this is important. For non-grid electrification, different renewable energy technologies must be investigated to ascertain the most efficient and productive means of energy generation and distribution in each area to enable the area to generate, store and distribute electricity and become independent and self-sustainable.

Hybrid Renewable Energy Systems

When considering the electrification of a community it is important to design reliable systems and require little maintenance as in these areas frequent repairs and replacements might not be easy. Using a singular form of renewable energy, such as solar, to supply a community is possible, however no electricity will be generated when sunlight is not available and therefore no electricity will be supplied during that time. Suppose more than one independent source is employed for energy generation, for example a combination PV panels and wind turbines. In that case, the energy demand generation can be split between these two sources and therefore the system depends less on one intermittent energy source. To make the system further reliable, energy storage must be added to the system to store energy in times of excess generation and supply energy in times of a lack of generation. Hybrid Renewable Energy Systems, using a combination of energy sources and storage, is preferred in rural electrification. Various aspects must be taken into account when working with stand-alone hybrid systems for the generation of electricity.

Reliability and cost are two of these aspects; it is possible to confirm that hybrid stand-alone electricity generation systems are usually more reliable and less costly than systems that rely on a single energy source. In various research papers, hybrid renewable electrical systems in off grid applications are economically viable, especially in remote locations. Also, climate can make one type of hybrid system more profitable than another type. For example, wind diesel hybrid systems (wind–Diesel) are ideal in areas with warm climates. On the other hand, various mathematical models of the elements that make up these systems have been used and various design and simulation models. The complexity of the components of the hybrid systems' components mainly depends on the type of application. Renewable energy sources are widely and increasingly applied in the electrical power generation. Connecting these sources to the power network improves flexibility, reliability, security, efficiency, and releases substations from some constraints. Within this context, the power flow control strategies should be considered to assure stability of the voltage and the frequency on the power network. Before being implemented, these strategies should be validated using simulators. The balance between consumption and generation of active and reactive electrical energy is the simulator's main issue. The simulated scenario considers the variation of the power demand and the wind and solar power generation.(Garcia & Weisser, 2006)

Necessity of Hybrid System

Hybrid system is considered one of the most efficient means to access electricity from locally available renewable energy resources where access to the national grid is impossible and not economic [4](Archna et al., 2014). People of several places are out of reach of electricity because of its geographical landscape and conditions where providing electricity from a centralized power plant through some sorts of transmission lines is not possible. The people residing in such kind of place can be highly benefitted by the means of hybrid system. Also depending upon conventional energy sources is becoming harder day by day due to its rising prices and limited availability. Thus developing countries burdened by the high costs of imported fuel can benefit from small, sustainable renewable energy system that use a combination of a solar, wind and micro-hydro technologies to electrify rural, off-grids towns and villages(Ekren et al., 2009).

The increasing energy demand and environmental concerns aroused considerable interest in hybrid renewable energy systems and subsequent development [6](Zhong et al., 2013). The generation of both wind power and solar power is very dependent on the weather conditions. Thus, no single source of energy is capable of supplying cost-effective and reliable power. The combined use of multiple power resources can be a viable way to achieve trade-off solutions. With combine of the renewable systems, power fluctuations may be incurred. To mitigate or even cancel out the fluctuations, energy storage technologies, such as storage batteries (SBs) can be employed. The proper size of storage system is site specific and depends on the amount of renewable generation and the load. The needed storage capacity can be reduced to a minimum when a proper combination of wind and solar generation is used for a given site [7](Hardan et al., 1999).

There is a huge potential for utilizing renewable energy sources, for example solar energy, wind energy, or micro hydropower, to provide a quality power supply to remote areas. The abundant energy available in nature can be harnessed and sustainably converted to electricity to supply the necessary power to elevate people's living standards without access to the electricity grid. The advantages of using renewable energy sources for generating power in remote islands are obvious. The cost of transported fuel is often prohibitive fossil fuel and that there is increasing concern on the issues of climate change and global warming. The disadvantage of standalone power systems using renewable energy is that the availability of renewable energy sources has daily and seasonal patterns, resulting in difficulties in regulating the output power to cope with the load demand. Combining the renewable energy generation with conventional diesel power generation will enable the power generated from renewable energy sources to be more reliable and affordable [8](Celik, 2003). This kind of electric power generation system, which consists of renewable energy and fossil fuel generators and an energy storage system and power conditioning system, is known as a hybrid power system.

A hybrid power system can provide 24-hour grid quality electricity to the load. This system offers a better efficiency, flexibility of planning and environmental benefits than the diesel generator stand-alone system [9](De Durana & Barambones, 2009). The diesel generator's operational and maintenance costs can be decreased as a consequence of improving the efficiency of operation and reducing operational time, which also means less fuel usage. The system also allows expanding its capacity to cope with the increasing demand in the future. This can be done by increasing either the rated power of diesel generator, renewable generator or both of them. Generally Remote off-Grid areas, utilizes diesel powered generators to supply its electrical needs due to some transmission and distribution restrictions.

Overview of Homer Software

In designing power systems different decisions can be made about the system's configuration, such as; what components to include in the system, the size and the quantity of the components and the cost of each component. Incorrect power system design can lead to a shorter life of battery, increase energy production cost, and insufficient supply of electricity demand. Hybrid Optimization Model for Electric Renewable (HOMER) is a computer model developed originally by the National Renewable Energy Laboratory (NREL). It has different energy generating components in its library. The user must select the components from the library to represent the architecture considered. This modeling tool uses time step from 1 minute to several hours. HOMER simplifies or helps the designer to compare various power systems options based on technical and economic aspects [10](Rohani et al., 2010).

The software also chooses between the dispatch strategies (cycle charging) by making comparisons. Design and analysis of systems can be challenging because the large combination of design options and the inclusion of uncertainties. The design complexity and uncertainty increase when renewable sources are included in the system, because they are non-dispatch able and intermittent. HOMER developed to overcome these challenges. It does three main tasks as indicated in figure 2.1

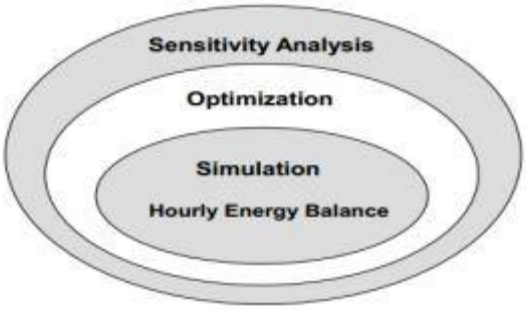

Figure 1.2: Interactions between Simulation, Optimization and Sensitivity Analysis

Simulation: It compares the system's energy supply and the load demand in 1 hour, of the 8,760 hours. During this time it decides either to use load following or dispatch strategy to operate batteries and generator. A system that contains battery and generator requires having dispatch strategy [11](Zeinab Abdallah M. Elhassan, 2012).

Optimization: This process simulates each different system configurations in search of the lowest NPC and lists each power systems that meet the load demand. The purpose of optimization is to determine the optimal system based on the designer's decision variables. Decision variable is a variable that has control by the designer. HOMERs decision variables may include like; PV array size, quantity of wind turbines, generator size, converter size, quantity of batteries, dispatch strategy, etc. Searching the optimal system includes deciding the mix of power components like size, quantity at the same time the dispatch strategy [12](Abraha et al., 2013)

Sensitivity Analysis: It examines the effect of external parameters and does optimization for each Sensitivity variables. The optimization process is repeated after specifying the sensitive parametric variables as an input in to the software. The sensitivity variables can be climatic data variations, components and fuel cost, capacity shortages, operating reserves, etc. HOMER does multiple optimizations using various sensitive inputs to see how sensitive output of the power system. The sensitivity results from HOMER are displayed in tabular and graphical forms [13](Vincent & Yusuf, 2014).

METHODOLOGY

The study will start with data collection of renewable energy resources, establish the community load profile, overview of component characteristics and costs, research on hybrid system configurations, and model and simulate the hybrid system [14](Zaghba et al., 2016).
The daily load profile of the community under review as obtained from sub-station of the existing hydroelectric energy**.** The micro grid optimization software called HOMER will be used for the model. The simulations are needed to make many hybrid system arrangements that grant several combinations of renewable energy resources [15](Badr et al., 2014). The lifetime net present cost of the hybrid systems that can supply the community load with the required level of availability would be calculated to determine the lowest energy cost hybrid configuration [16](Hassan et al., 2016). The sensitivity analysis of the anxieties regarding the

system inputs like solar radiation will be assessed to inspect the best system to supply the load at the lowest energy cost for diverse conditions.

Hybrid system design and optimization require an evaluation of the community's load profile and the renewable resources of the community. The estimation of load profile and the assessment of renewable resources, solar and hydro in the community will be discussed [18](Okedu & Uhunmwangho, 2014). The chapter discussed solar radiation calculation on a tilted photovoltaic (PV) panel using horizontal radiation data will be carefully estimated based on the average precipitation, average temperatures and topography of the region. The daily supply/load shedding hours for the community is shown in Appendix B and Appendix C.

To know the total load and consumption for the community, Power formulae will be considered.

$P = IV \cos \Theta$ (3.1)

P = Power

I = Current

V = Voltage

$\cos \Theta = 0.8$ (Power factor)

Substituting for the parameters in equation 3.1,

P = 210 x 220 x 0.8 = 36,960W/h

P = 36.9KW/h

36,960 x 24 hours = 887,040 W

36,960 x 17 hours = 628,320 W

Tolerance = 11,680W

Real Power = 640,000W

=640KW

According to the daily/hourly data obtained from Benin Electricity Distribution Company (BEDC), an average of 7 hours electricity is supplied daily to the community and 17 hours power outage. The total power load needed in the community is 887KW while the total power that we augment for the 17 load shedding hours is 640KW.

Table 3.1 shows the average power consumption for the community.

Table 3.1: Average consumption for 30 days

Days	Power Factor	Current (A)	Voltage (V) (Constant)
1	211.4286	220	0.8
2	182.5556	220	0.8
3	207.3333	220	0.8
4	182.25	220	0.8
5	238.8333	220	0.8
6	237.5714	220	0.8
7	205.375	220	0.8
8	210.75	220	0.8
9	222.625	220	0.8
10	212.5	220	0.8
11	204.4	220	0.8
12	219.1111	220	0.8
13	226.875	220	0.8
14	217.1429	220	0.8
15	199.3333	220	0.8

16	200.4286	220	0.8
17	192.8	220	0.8
18	182.3333	220	0.8
19	207.5833	220	0.8
20	238.5	220	0.8
21	218.1667	220	0.8
22	211	220	0.8
23	213.2857	220	0.8
24	226.5	220	0.8
25	200.25	220	0.8
26	200	220	0.8
27	217	220	0.8
28	198.2857	220	0.8
29	218	220	0.8
30	210.25	220	0.8
SUM	6312.468	6600	
AVERAGE	210.4156	220	

Solar Resources

In table 3.3, the solar radiation data for one year for the community is shown which is obtained from the NASA Surface Meteorology website. The location of Oyemekun is 7˚15' N to 5˚10' E. The average clearness index is estimated at 0.5825 while the average daily radiation is 4.82 KWH/m^2/Day.

Table 3.2: Solar Radiation Profile for Oyemekun Area

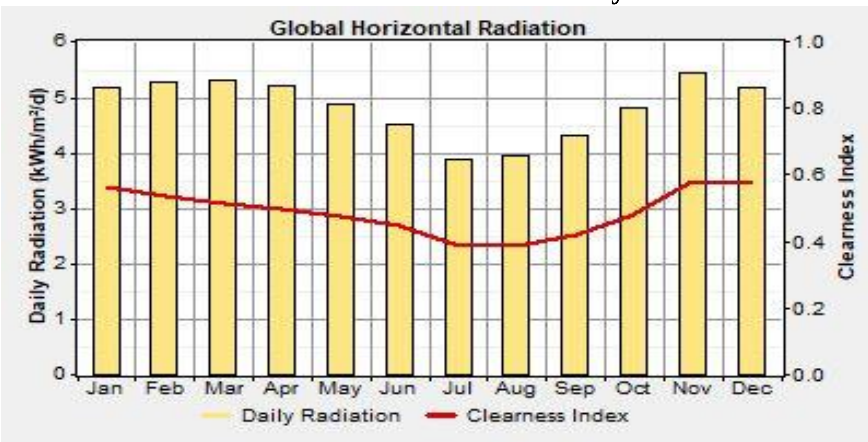

Figure 3.1: Solar Radiation Profile for Oyemekun Area.

Storage Device

To store the energy from the hybrid system compromises of Solar PV the system is modelled so that the energy can be stored in battery and used at night or during low solar radiation or cloudy days. The storage device can also provide the stored power during the night. The picked battery has a 12 V, 200 Ah limits. The battery value assessed to be #80,000/battery. Its lifetime is thought to be 917 kWh of throughput for every battery. A unique number of battery cells considered in this investigation (0, 1, 2, 3…….11) the storage input is shown in figure 3.3

Inverter (Converter)

The inverter efficiency was assumed to be 94.1% for all the size considered. The size considered is 0.25 kW. The converter input is shown in Figure 3.4.

Month	Clearness Index	Daily radiation KWH/m^2/Day
January	0.561	5.184
February	0.536	5.268
March	0.512	5.289
April	0.498	5.209
May	0.477	4.883
June	0.448	4.498
July	0.385	3.885
August	0.384	3.961
September	0.418	4.311
October	0.483	4.791
November	0.583	5.437
December	0.576	5.187
Average	0.486	4.821

Solar PV

The design consist 22 modules; each module consists of 6 panels making it 124 PV panels altogether. 300W (0.300kW) panel was used in the design and the cost of each panel is converted to Dollar. The solar PV panels' capital and replacement cost is estimated at $180/KW while the operating and maintenance cost is $10/KW. The derating factor of 80% and life span of 25 years was assumed. The panels are fixed and tilted as specified in the Figure 3.2

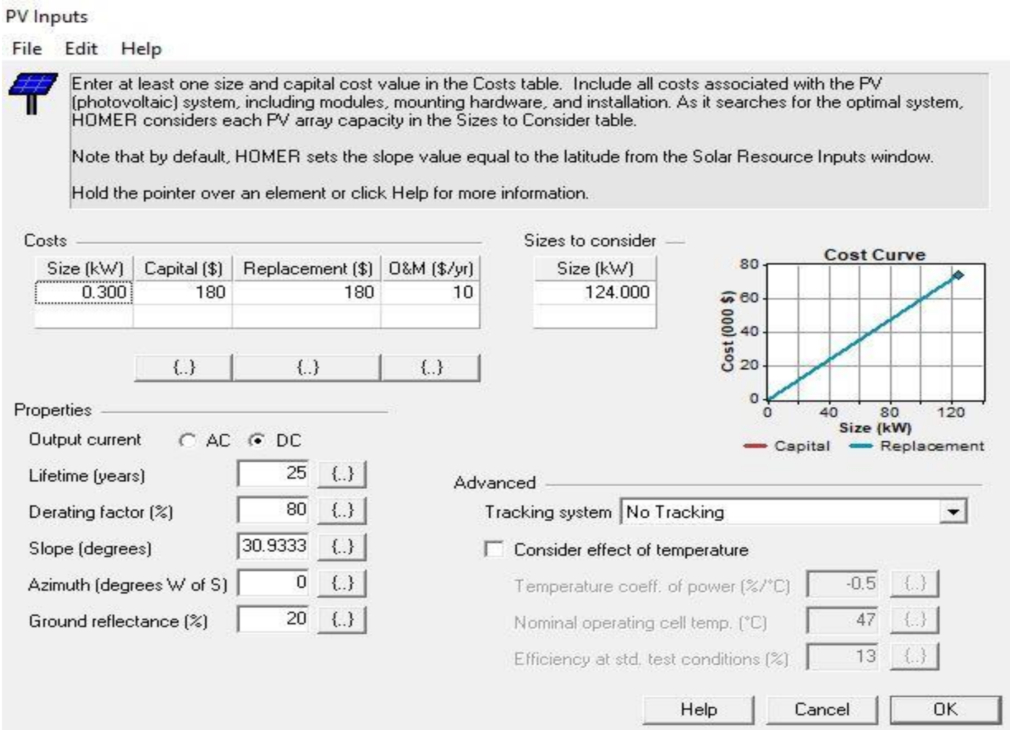

Figure 3.2: Solar PV Input

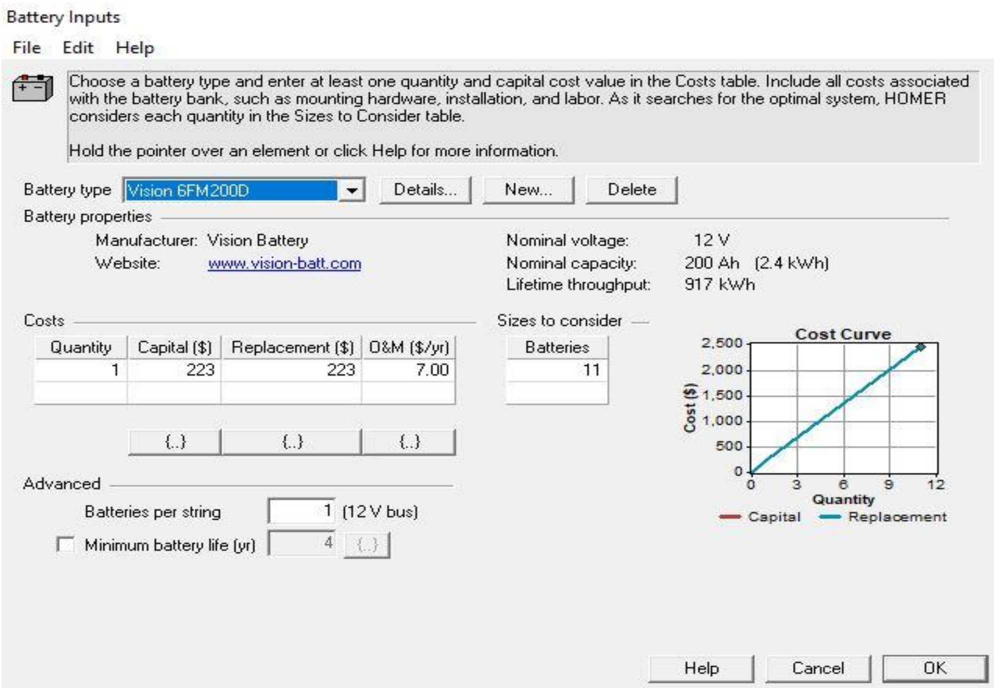

Figure 3.3: Storage Batteries Input

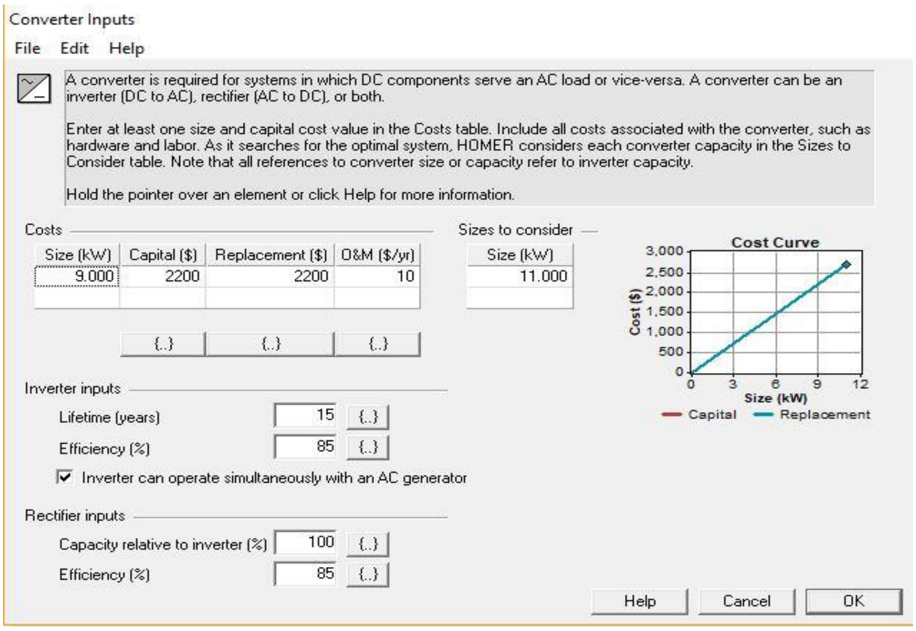

Figure 3.4: Converter input

System Modelling

The hybrid system model consists of Solar PV connected to a DC bus, a storage device connected to a DC bus and a bi-directional converter that converts the directs current from the Solar PV to AC. It's connected to the Grid and at the same time converts the current to the storage batteries shown in Figure: 3.5, the Grid Serves As A Distribution Channel.

The HOMER software is used to simulate peak demand of primary load, which is found to be 3.4kW and total energy consumption is found as 36.9kWh/day.

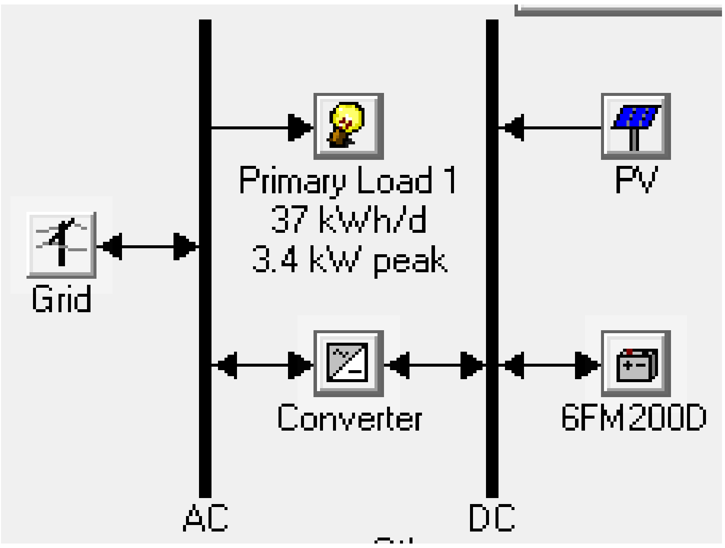

Figure 3.5: Model of Load connected to Solar PV and Grid

Evaluation of the System

Matlab Simulink was used to the model the system which shows an average model of a small PV farm (640 kW) connected to a 25-kV grid using two-stage converter. The PV farm consists of four PV arrays delivering each a maximum of 100 kW at 1000 W/m^2 sun irradiance. A single PV array block consists of 64 parallel strings where each string has 5 Sun Power SPR-315E modules connected in series.

Each PV array is connected to a DC/DC converter (average model). The boost converters' outputs are connected to a common DC bus of 700 V. Each boost is controlled by individual Maximum Power Point Trackers (MPPT). The MPPTs use the "Perturb and Observe" technique to vary the voltage across the terminals of the PV array to get the maximum possible power.

A three-phase Voltage Source Converter (VSC) converts the 700 V DC to 260 V AC and keeps unity power factor. A 260V/25kV three-phase coupling transformer is used to connect the converter to the grid. The grid model consists of typical 25-kV distribution feeders and 120-kV equivalent transmission system.

In the average model the boost and VSC converters are represented by equivalent voltage sources generating the AC voltage averaged over one switching frequency cycle. Such a model does not represent harmonics, but the dynamics resulting from control system and power system interaction is preserved. This model allows using much larger time steps (50 us), resulting in a much faster simulation.

RESULTS AND DISCUSSION

HOMER simulates system configurations with all of the combinations of components that were specified in the component input. HOMER performs hundreds or thousands of hourly simulations (to ensure best possible matching of demand and supply). It offers list feasible schemes ranked based on the NPC (net present cost). The strategy taken in this simulation is to ensure the solar PV system provide enough power to meet the demand. The renewable energy sources in collaboration with national grid were evaluated to determine the feasibility of the system. The system is also simulated to evaluate its operational characteristics, namely annual electrical energy production, annual electrical load served, electrical load served, excess electricity, renewable energy fraction, and capacity shortage.

At the end of the design, the out of the project should be able to augment for at least 17 hours electricity supply in the case study area (Oyemekun Community) with the help of HOMER in optimizing for the best option of Hybrid Renewable Energy System. Table 4.1 shows the Net Present cost of the Solar PV system.

Figure 4.1 shows the simulation result and the overall cash flow analysis of the two systems is shown in the Figure 4.2 and Figure 4.3

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	74,400	0	52,838	0	0	127,238
Grid	0	0	0	0	0	0
Vision 6FM200D	2,453	2,135	984	0	-286	5,286
Converter	2,689	1,122	156	0	-209	3,758
System	79,542	3,257	53,978	0	-495	136,282

Figure 4.1: Simulation result and Equipment used in the system

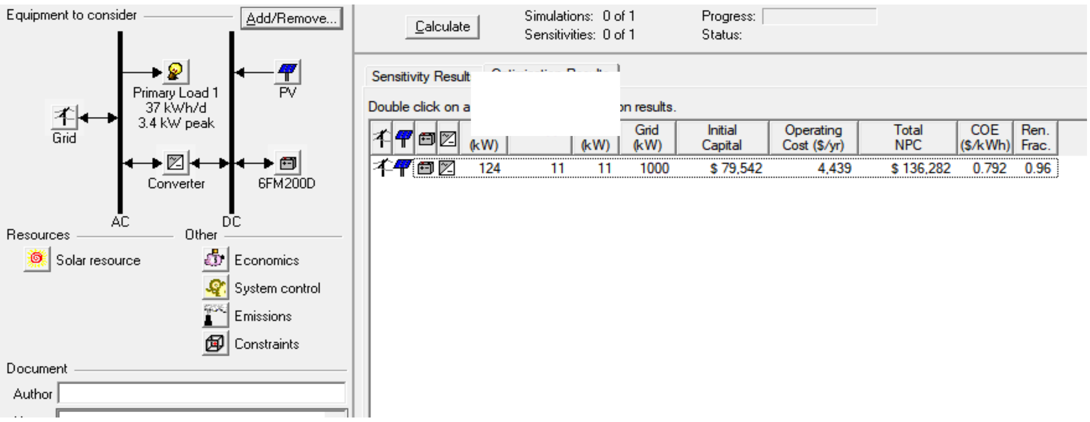

Figure 4.2: Net Present Cost of the solar PV components

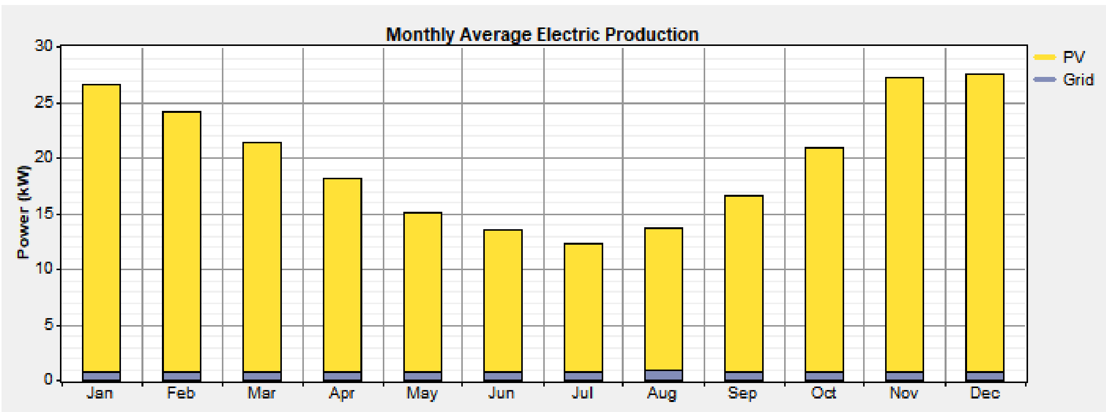

Figure 4.3: Monthly average electric production

Matlab Simulation Results Simulink is a very effective tool for modeling of complex systems. This model includes both continuous and discrete-time components. Simpower System Tool Box of Simulink was used to construct the electrical power systems (e.g. consisting of continuous states). Besides, the standard block sets (e.g. including discrete components) of Simulink are used to construct the structure solar PV model as shown in figure 4.4. In this section, the overall simulation model of the solar PV system is presented and the simulation results are examined as show in figure 4.5 – figure 4.9

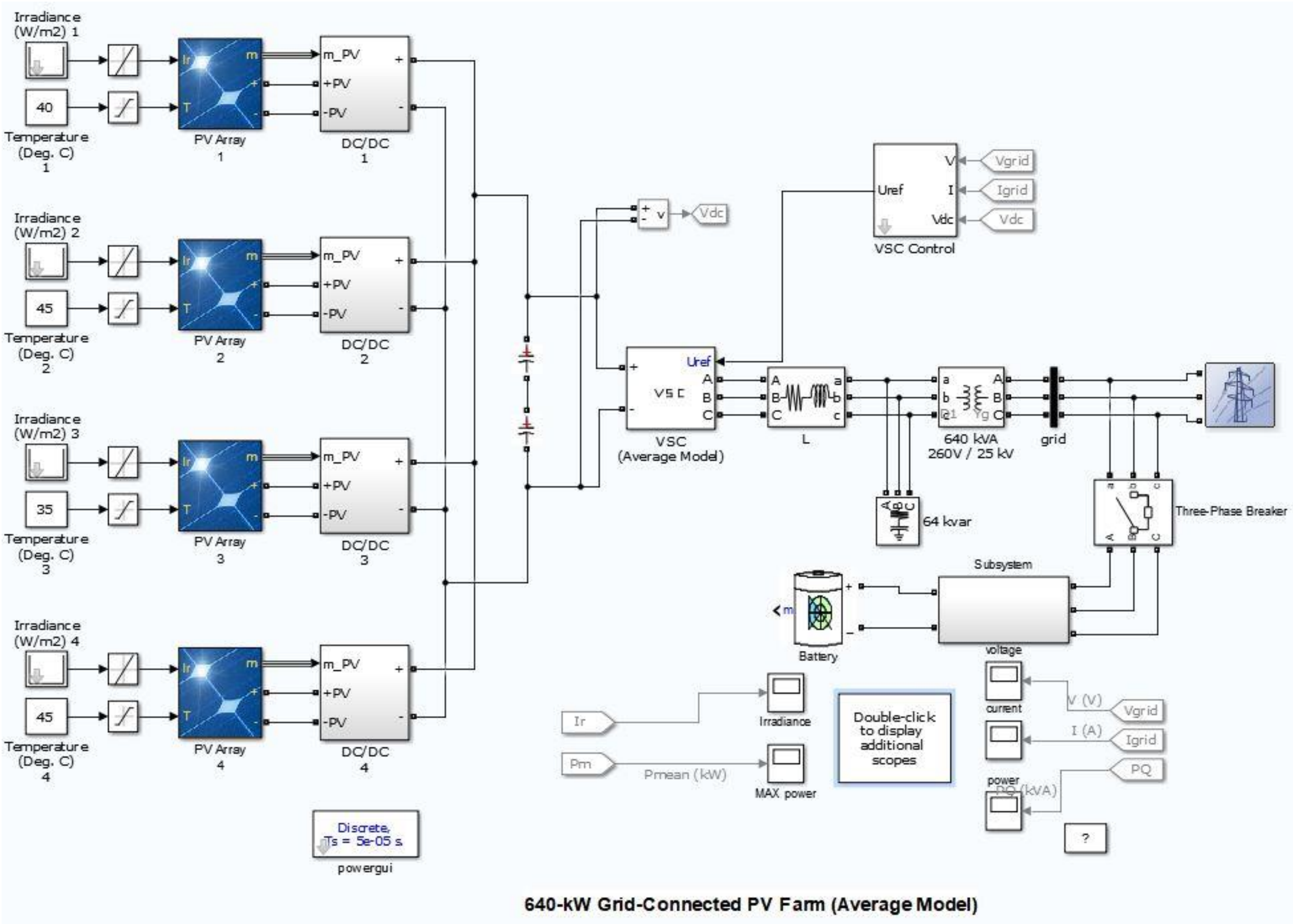

Figure 4.4: Block diagram of a Solar PV farm.

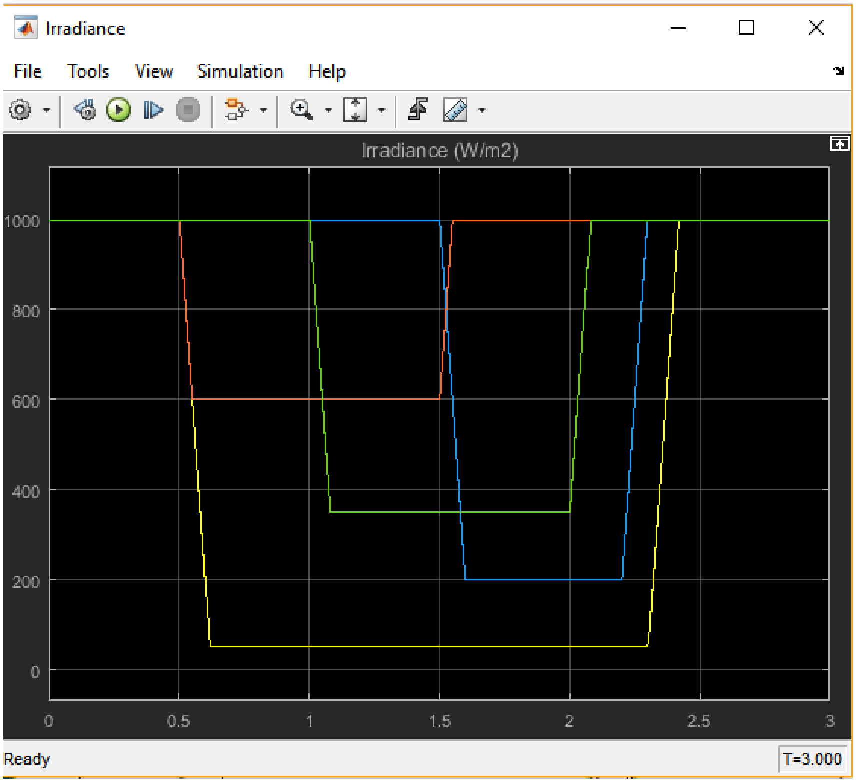

Figure 4.5: Irradiance output

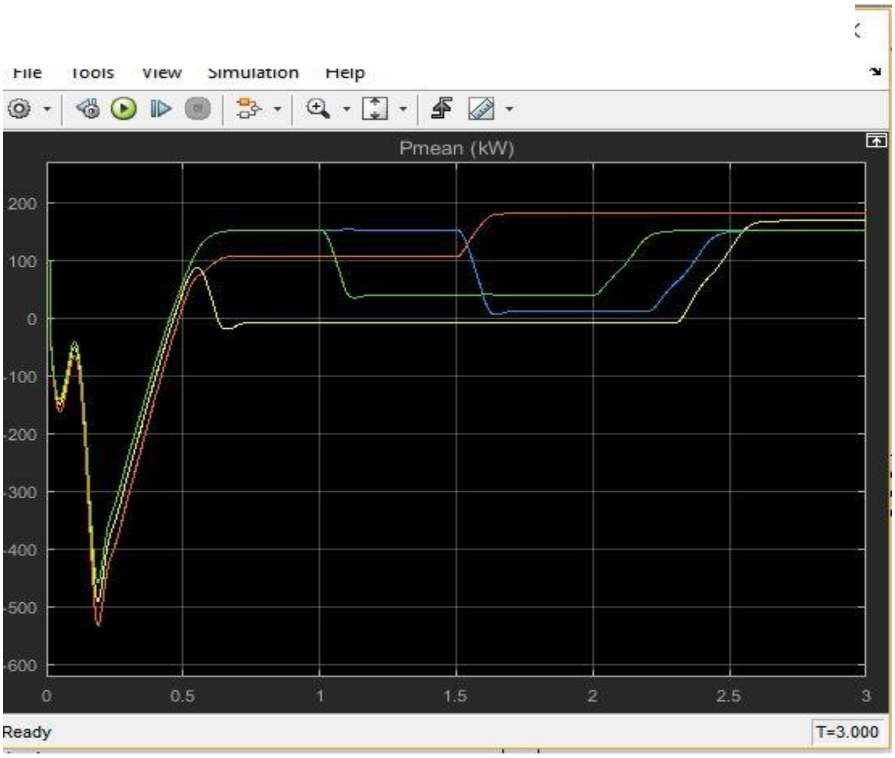

Figure 4.6: Power mean

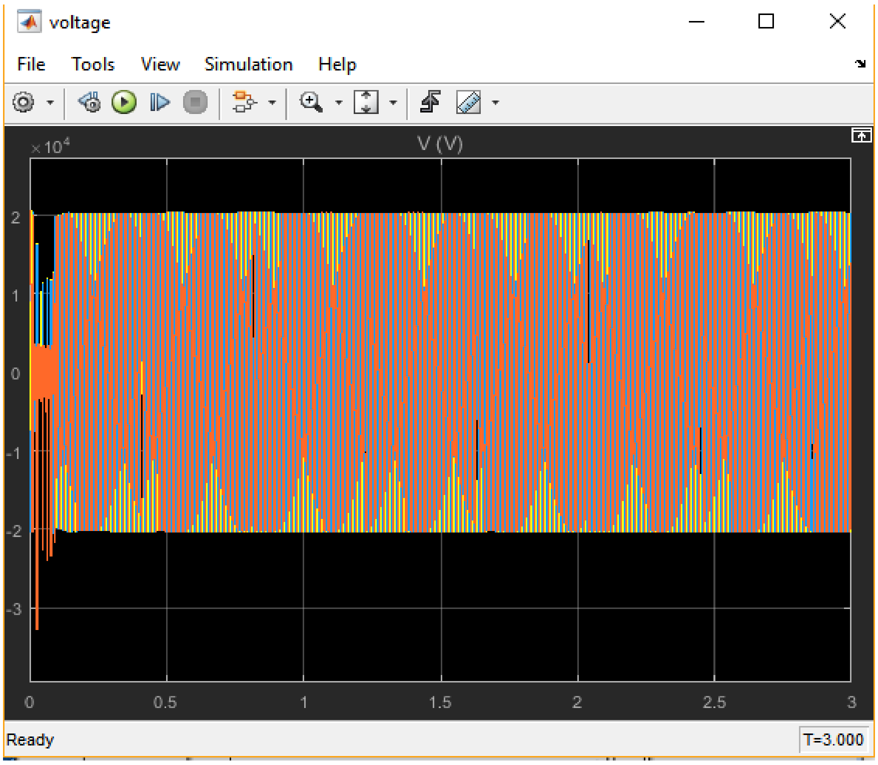

Figure 4.7: Voltage output

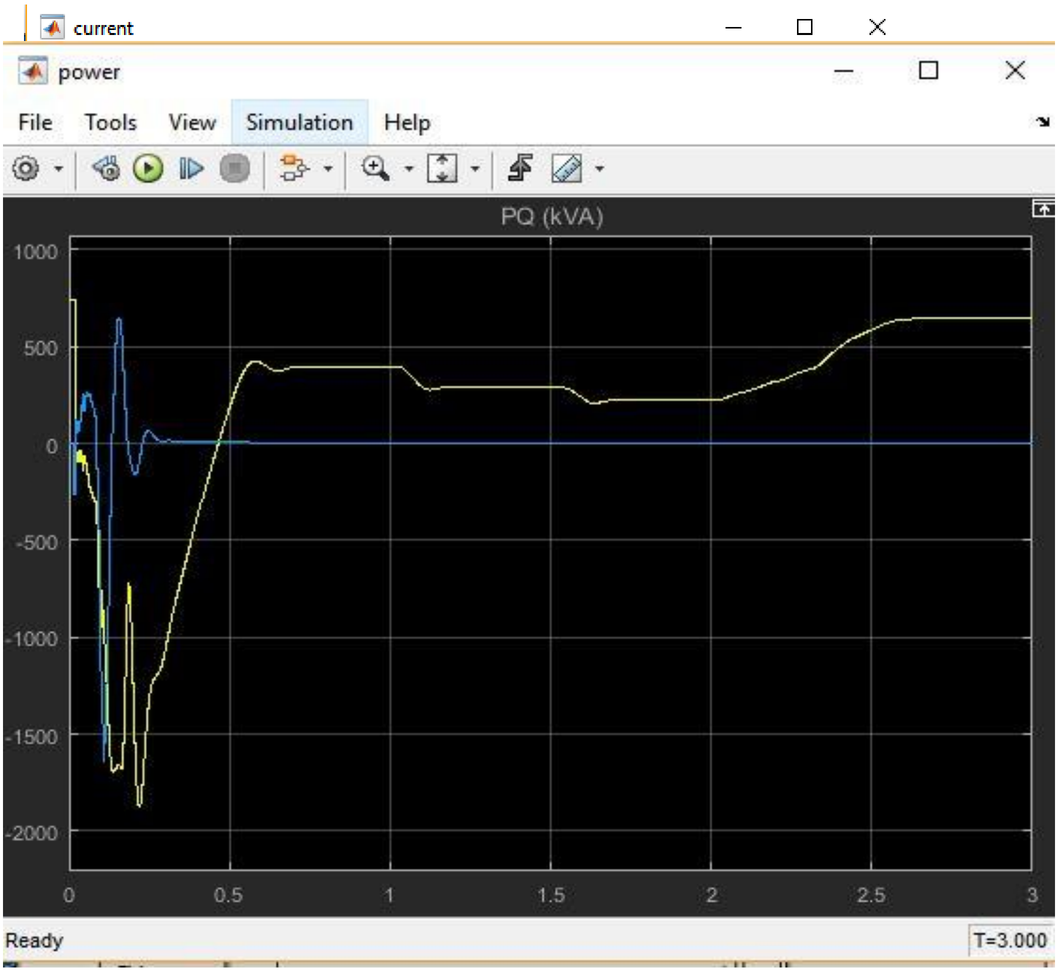

Figure 4.8: Current output

Figure 4.8 shows the total Power Generated in the model (Active and Reactive Power).

CONCLUSION

Matlab Simulation Simpower System Tool Box was used to design and identify the solar PV system and its parts to supply the augmented renewable energy. Homer software adopted to optimized classifications choice for all the system accessories depending on the net present cost. The Homer software calculates all power generated and the cost associated with providing an alternative energy to the community. The solar PV farm development was simulated to achieve a minimal cost and economically viable in the long run. The transfer capacity as the proposed system is a fixed PV panel. PV system performance depends on a range of daily radiation (kW/m^2/d) index, and clarity for each month during the year. The results showed that the Solar PV implementation is more cost-effective than the existing hydropower on a long run of 25 years. This study will assist in constructing a micro grid in the various communities using alternative energy sources.

REFERENCES

Abraha, A., Kahsay, M., & Kimambo, C. (2013). Hybrid Solar-Wind-Diesel Systems for Rural Application in North Ethiopia: Case Study for Three Rural Villages using HOMER Simulation. *Momona Ethiopian Journal of Science*, *5*(2), 62. https://doi.org/10.4314/mejs.v5i2.94227

Archna, A., Mohan, S. L., & Bhim, S. (2014). Control Strategies for DFIG Based Grid Connected Wind Energy Conversion System. *International Journal of Grid and Distributed Computing*, *7*(3), 49–60. https://doi.org/10.14257/ijgdc.2014.7.3.06

Badr, M. A., Mohib, A. N., Ibrahim, M. M., & Hamid, A. (2014). *Small Wind Turbine Hybrid System for Remote Application : Egyptian Case Study*. *8*(9), 1584–1589.

Bagen, & Billinton, R. (2005). Evaluation of different operating strategies in small stand-alone power systems. *IEEE Transactions on Energy Conversion*. https://doi.org/10.1109/TEC.2005.847996

Celik, A. N. (2003). Techno-economic analysis of autonomous PV-wind hybrid energy systems using different sizing methods. *Energy Conversion and Management*. https://doi.org/10.1016/S0196-8904(02)00223-6

De Durana, J. M. G., & Barambones, O. (2009). Object oriented simulation of hybrid renewable energy systems focused on supervisor control. *ETFA 2009 - 2009 IEEE Conference on Emerging Technologies and Factory Automation*. https://doi.org/10.1109/ETFA.2009.5347212

Ekren, O., Ekren, B. Y., & Ozerdem, B. (2009). Break-even analysis and size optimization of a PV/wind hybrid energy conversion system with battery storage - A case study. *Applied Energy*, *86*(7–8), 1043–1054. https://doi.org/10.1016/j.apenergy.2008.09.024

Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. In *Renewable and Sustainable Energy Reviews*. https://doi.org/10.1016/j.rser.2014.07.113

Garcia, R. S., & Weisser, D. (2006). A wind-diesel system with hydrogen storage: Joint optimisation of design and dispatch. *Renewable Energy*, *31*(14), 2296–2320. https://doi.org/10.1016/j.renene.2005.11.003

Hardan, F., Bleijs, J. A. M., Jones, R., Bromley, P., & Ruddell, A. J. (1999). Application of a power-controlled flywheel drive for wind power conditioning in a wind/diesel power system. *IEE Conference Publication*, *468*, 65–70. https://doi.org/10.1049/cp:19990992

Hassan, Q., Jaszczur, M., & Abdulateef, J. (2016). Optimization of PV/WIND/DIESEL Hybrid Power System in HOMER for Rural Electrification. *Journal of Physics: Conference Series*. https://doi.org/10.1088/1742-6596/745/3/032006

Okedu, K. E., & Uhunmwangho, R. (2014). Optimization of renewable energy efficiency using HOMER. *International Journal of Renewable Energy Research*. https://doi.org/10.1234/ijrer.v4i2.1231.g6294

Rohani, A., Mazlumi, K., & Kord, H. (2010). Modeling of a hybrid power system for economic analysis and environmental impact in HOMER. *Proceedings - 2010 18th Iranian Conference on Electrical Engineering, ICEE 2010*. https://doi.org/10.1109/IRANIANCEE.2010.5506962

Vincent, E. N., & Yusuf, S. D. (2014). Integrating Renewable Energy and Smart Grid Technology into the Nigerian Electricity Grid System. *Smart Grid and Renewable Energy*. https://doi.org/10.4236/sgre.2014.59021

Zaghba, L., Khennane, M., Mahamed, I. H., Oudjana, H. S., Fezzani, A., Bouchakour, A., & Terki, N. (2016). A combined simulation and experimental analysis the dynamic performance of a 2 kW photovoltaic plant installed in the desert environment. *International Journal of Energy and Environmental Engineering*. https://doi.org/10.1007/s40095-016-0216-2

Zeinab Abdallah M. Elhassan. (2012). Design and performance of photovoltaic power system as a renewable energy source for residential in Khartoum. *International Journal of the Physical Sciences*. https://doi.org/10.5897/ijps11.346

Zhong, C., Lvlong, H., Shan, G., Tingrui, L., & Haifeng, L. (2013). The research about PV/wind hybrid energy considering grid security constraints. *2013 IEEE PES Innovative Smart Grid Technologies Conference, ISGT 2013, 2011*. https://doi.org/10.1109/ISGT.2013.6497927