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Solar-wind hybrid energy system for new engineering complex- technical university of Mombasa

Austin Wasonga, Michael Saulo, Victor Odhiambo

Department of Electrical and Electronics Engineering, Technical University of Mombasa, Mombasa, Kenya

Email address:
Austinbuger@yahoo.com (A. Wasonga), michaelsaulo@yahoo.com (M. Saulo)

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Abstract: A hybrid energy system combines multiple types of energy generation in order to meet the demand of the users effectively and efficiently. The Solar-Wind hybrid system consists of electrical energy generated from wind and solar PV systems, it is a valuable method in the transition away from fossil fuel based economies. It capitalizes on existing wind regimes and solar energy available in a particular area or region. It is in public domain that environmental degradation has greatly increased due to the adaptation of fossil fuel driven generators to produce electricity. Power system interruptions and black-outs have posed major threats to most sub-Saharan African Countries. This has negatively affected the operations of industries and universities. Resulting in major losses that cumulatively impact negatively on their economy. The objective of this paper was to analyze and design a solar-wind hybrid system for powering the New Engineering Complex at the Technical University of Mombasa (NEC-TUM). The methodology involved was first to determine the electrical loading of the building in terms of lighting and power loads. The next step was to analyze the wind speed pattern and solar intensity on the roof of the building using RET Screen software. The results obtained and specifications of the components used in the model were fed into HOMER software for simulation purposes. It was found that the optimum mix of wind and photovoltaic power with an electromechanical storage system, with or without fossil fuel generator back up, depends upon the individual sub-systems economics. Furthermore, the hybrid system was able to produce 63.36kWh/day against the 50kWh/day required by the NEC-TUM for lighting and power loads.

Keywords: Solar-Wind Hybrid Energy System, Homer, RETScreen, NEC-TUM

1. Introduction

A good quality and stable electricity supply can provide a wide variety of benefits including lighting, commercial/industrial activities and many other uses. Often this can be provided by extending the main grid electricity network to the community or consumer. However, the grid based electricity in sub-Saharan Africa (SSA) in most cases is unstable and very unreliable. Therefore, renewable sources of electricity are thus very relevant, particularly for countries in SSA, as they have potential to make connection to the electricity network affordable. While such systems are already in place, there usage is very low. Literature portrays that their capital cost is very high [1]. Although this might be true, the subsequent operational cost could be much lower as compared to the grid based electricity. In the recent times, due to the emerging technological trends, the need for energy has increased globally. Electrical energy has now become the base for almost every activity. This has made us to increase our energy production which in turn has put extra pressure on our grid based electrical supply. Therefore, there is a dire need for generating electricity by using renewable sources of energy (in other words green energy). For this paper, solar and wind energy has been used to come up with a hybrid system for generation of electricity supply. Solar photovoltaic is a system to convert light energy into electrical energy [2]. On the other hand, wind energy is utilized by converting the kinetic energy of wind in to rotational motion by using a wind turbine. This rotational motion is converted into usable electrical energy [3]. The systems with only solar or wind generation are productive but there are problems linked with both of them. The solar power is not available for 24 hours and wind is not continuous all the time. So a hybrid system containing solar and wind has been designed to overcome these shortcomings. This paper proposed design of a hybrid stand-alone solar-wind power generation system that will be used to supply power to the NEC at TUM. Variables considered in this design include the PV modules, the wind turbine parameters and size. These variables were used to find the optimal design of a hybrid power generation system, with the objective of maximizing power, while minimizing cost.

1.1. Overview of Kenya's Generation Scenario

Currently, Kenya's installed power capacity is about 1540 MW with maximum power demand of 1680MW [4]. This has been the driver of persistent power supply interruptions. Moreover, with an estimated 17% loss in electricity generated through transmission lines, against a global best practice recommendation of below 12%, this scenario does not augur well for the country's future electricity supply-demand prospects. One of the prerequisites of the realization of Kenya's Vision 2030 is reliability in electricity supply. Therefore, the country has to make concerted efforts to expand its power production in order to meet the expected increase in power demand supply for sustainable industrialization to take place [5]. Significant weather fluctuations have shown that climate change is not only a challenge to the industrialized countries, but also to developing countries like Kenya. Thus is evidenced by recent draughts in the country. Over 60% of power generation in Kenya is through hydro-electric power. This depends largely on rain water for electricity production. It is plausible to assume that, the global policy paradigm shift to green economy is informed by the negative impact of the adverse effects of these climatical changes. Against this backdrop, this paper studies the potential of generating electricity from a hybrid solar-wind system, for the New Engineering Complex at Technical University of Mombasa (NEC-TUM). The paper envisages that optimal design of the hybrid system could significantly improve technical and economic performance of power supply system in the University. The socio-economic benefits of which would be under pinned by improved stability and reliability of the power supply. Environmental degradation has greatly increased due to the use of fossil fueled generators to produce electricity [6]. The reduction of carbon dioxide and sulphur dioxide emissions are a significant advantage of solar and wind energy systems over fossil fuel power stations. The application of this renewable sources have greatly mitigated climate change problems. Consequently, the power generated in the country is not sufficient to meet the demand of the population and industries. Therefore, this paper addresses the need to come up with appropriate generating sources of electric power in order to meet the university's power demand and subsequently the country's demand.

1.2. Hybrid Systems

Researchers on non-grid-connected wind power/water electrolytic hydrogen production system showed that wind power grid connection is the only application of large-scale renewable sources in the world .

The random effects of wind affect the quality of wind power and the contribution rate of wind power on the gird is hardly beyond 10%. The wind powered generator needs to meet the requirements of power grid such as stabilization of frequency, voltage and phase, which increases complexity. As a result, the "Non-grid-connected wind power was invented [7]. Research showed that hybrid systems e.g. wind and solar complement each other effectively that is saying, "either the sun is shining or the wind is blowing, so there is always something producing power" [8].

Many rural areas, have benefited from hybrid power systems. Although wind power has been widely used in the many areas, the systems were unreliable during the summer when wind resources were low. A Solar/Wind hybrid system has been determined to be the most reliable and cost effective system for most regions where there is unreliable supply of grid based electricity.

Kolhe et al. [2003], presented a paper about analyzing the merits of hybrid wind/photovoltaic concept for stand-alone systems. A method was developed for evaluating the merits of hybrid wind/photovoltaic systems for use in stand-alone applications. It was found that the optimum mix of wind and photovoltaic power with an electromechanical storage system, with or without fossil fuel generator back, depends upon the individual subsystems economics. A computer code was developed to calculate the optimum sub-system sizes that minimize the levelized energy cost. The actual merits of a hybrid system over a pure photovoltaic or wind system depend upon these factors; load profile; wind regime; installation; costs and availability of backup power ; solar panel costs, size and efficiency; wind rotor area; array area and storage; and subsystem efficiency factors .

A feasibility study of wind and solar hybrid system for Cleveland, Ohio, USA was carried out [9]. The project was proposed with an aim of heating the individual houses in Cleveland, Ohio utilizing the wind and solar energy. Cleveland, Ohio is located at latitude 41.4822º N and longitude 81.6697ºW and the following data was collected with respect to meteorology department and solar wind hybrid system .Results from the cold winter months in Cleveland(October through March), showed that the hybrid contributed 28-36% of the required space and water service heating load.

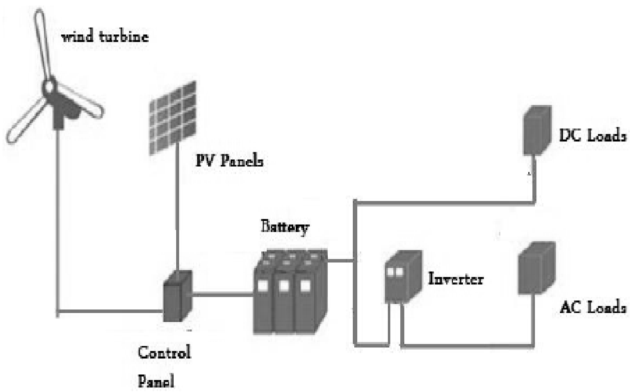

Figure 1. *Schematic for a solar-wind hybrid energy system.*

2. Model of the Hybrid System

Figure 1, shows the schematic diagram that describes a general solar wind hybrid model which comprises of the items shown.

2.1. Wind Turbine Modeling

There are several of technical models for wind turbines. The model used in this study is a generic approach, which takes into consideration the agent-based approach of the framework. As the wind turbine has to be able to be replicated (in order to create wind farms with tens or even more turbines), a simple model may be chosen to ensure fluid simulations. The basis of this model is the relation between the power outputs of the turbine, which is a function of the wind speed actuating on its rotor blades. Three different models that are commonly used, have been identified in the course of this study. The *real model* is not a mathematical model itself. It just shows the *P*(v) curve of a specific turbine-based on the manufacturers' data. In general, the curve has a shape similar to the one shown in Figure 2 [10].

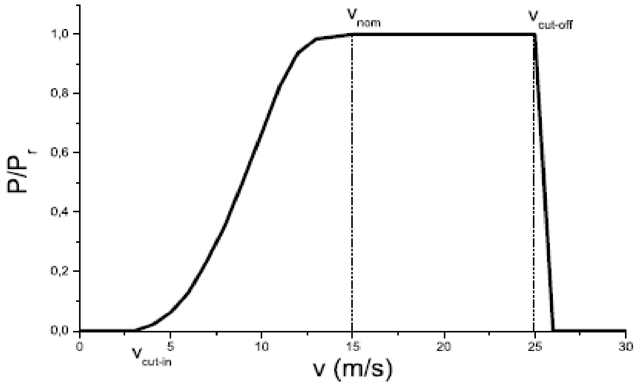

Figure 2. *A simple power curve.Pr is the rated power.*

Figure 2, shows a typical power-wind speed profile of a wind turbine. The cut in speed is the minimum wind speed at which the turbine can start working; the nominal wind speed is the point at which rated power is achieved. This power is normally almost constant up until the cut off wind speed is reached, at this point the turbine must be shut down to avoid damage caused by too strong winds. Therefore, four principle states can be defined as [9, 10];

- Stopped : for $v \le v_{cut-in}$
- Partial load : for $v_{cut-in} \le v \ge v_{norm}$
- Rated load : $v_{norm} \le v \ge v_{cut-off}$
- Cut-off : $v \ge v_{cut-off}$

The transitions between the states are smooth because of the technical characteristics of the rotor and generator in the real curve. The most interesting state to be observed is the partial loaded state, where the turbine shows a non-linear *P*(v) dependence. In this phase, the start dynamic of the turbine as well as the adoption to the fully loaded capacity at rated speed is observed. This phase can be approximated by a polynomial term shown in Figure 3

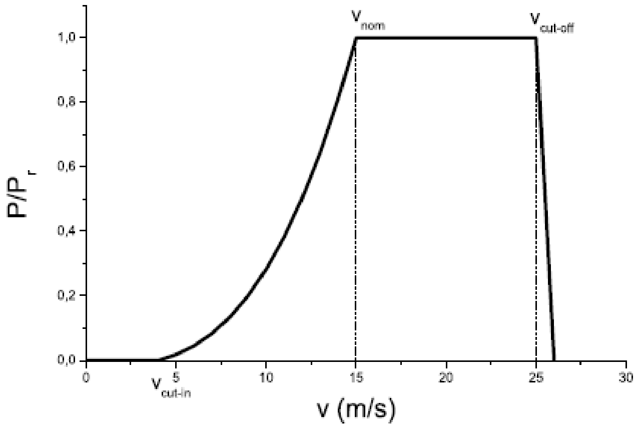

Figure 3. *Polynomial approximated power curve.*

The polynomial model generates the curved shape of the curve, but the trace just before achieving the nominal wind speed is idealised. The linear approximation of the curve which is used in more simplified models, can be defined by linear interpolation of the values for v_{cut-in} and v_{norm}. This can be observed in figure 4. The last model might be useful when only the characteristics wind speeds of the turbine (and no power curve) are available. Though, the polynomial approach can also be used as approximation by using a polynomial of degree three as described in [11].

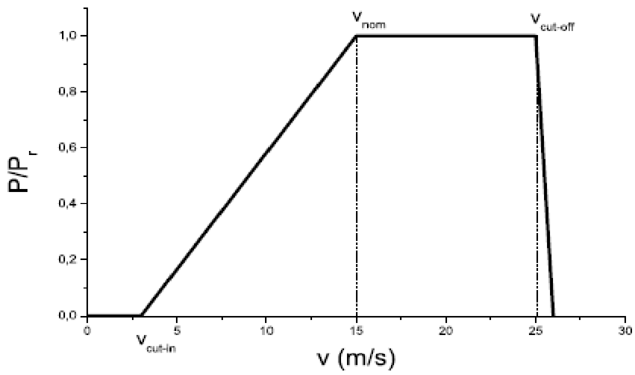

Figure 4. *Linear simplified power curve*

The cut-off state is attained when the turbine shuts-down because of exceeding $v_{cut-off}$ Further, a $v_{cut-back-in}$ parameter can be defined for the model. Its value denotes the wind speed, at which the turbine gets back to work after having entered the cut-off state. This value adds the restart behaviour of the machines after strong wind period.

2.2. Solar Pv Panel Models

Solar panel is a device which converts energy from light energy (photon) to electrical energy. These devices are inorganic or organic semi-conductors materials that absorb photons with energy greater than their band gap to promote energy carriers into their conduction band. Electron-hole pairs, or excitons for organic semiconductors, are subsequently separated and charges are collected at the electrodes for electricity generation. These panels are divided into three types which are monocrystalline, polycrystalline and amorphous silicon. They do vary with respect to the efficiency and lifespan [12]

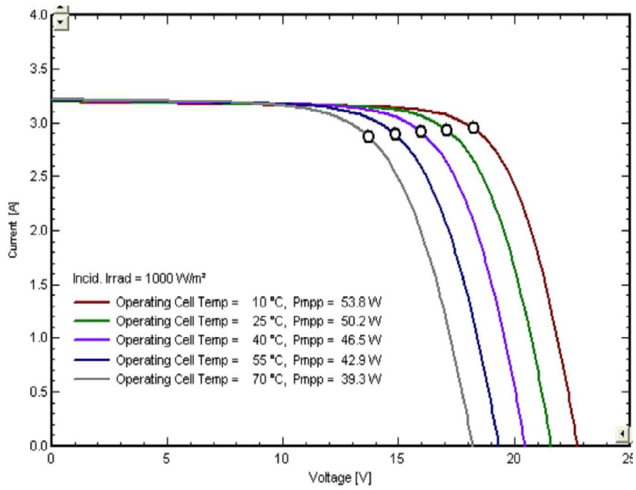

Figure 5. *Output I-V characteristics of the PV module with different temperatures*

The external parameters of solar panels are short circuit current, open circuit voltage, fill factor and conversion efficiency. Solar cells vary under temperature changes, the change in temperature will affect the power output from the cells. The voltage is highly dependent on the temperature and an increase in this specified ambient condition will decrease the voltage slightly but increase the current as shown in Figure 5 below.

2.3. Battery

This is a device that converts chemical energy into electrical energy. This background defines the variables used to characterize battery operating conditions, and describes the manufacturer specifications used to characterize battery nominal and maximum characteristics. The major battery technical specifications that should be considered are the nominal voltage, cut-off voltage, capacity, charge voltage and cycle life [13]. Battery conditions described below should be highly observed to prevent battery failure.

State of Discharge (SOC) (%). This is the expression of the present battery capacity as a percentage of maximum capacity. SOC is generally calculated using current integration to determine the change in battery capacity over time.

Depth of Discharge (DOD) (%). The percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. A discharge to at least 80% DOD is referred to as a deep discharge.

Terminal voltage, V. The voltage between the battery terminals with load applied. This voltage varies with SOC and discharge/charge current.

Open Circuit Voltage, V. The voltage between the battery terminals with no load applied this voltage depends on the battery state of charge, increasing with state of charge.

Internal Resistance. The resistance within the battery, generally different for charging and discharging, also dependent on the battery state of charge. As internal resistance increases, the battery efficiency decreases and thermal stability is reduced as more of the charging energy is converted into heat.

2.4. DC-AC Inverter

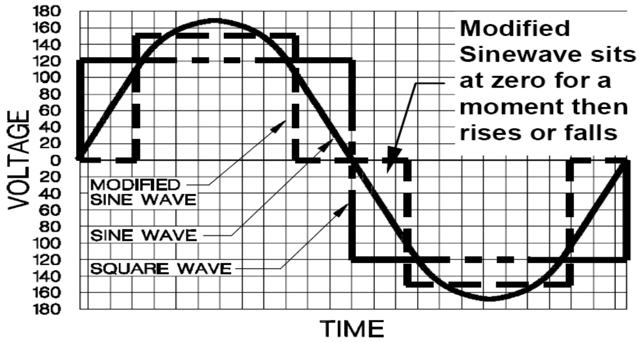

Figure 6. *Waveform of a modified and pure sine wave inverter.*

Power inverters are electronics devices that converts electrical energy of DC form into that of AC. Its purpose is to typically take DC power supplied by a battery, such as a 12V battery and transform it into 240V AC power source operating 50Hz, emulating the available power at an ordinary household electrical outlet. There are two types of inverters based on the quality of their output signal and they are modified sine wave and pure sine wave converters.

When evaluating the type of inverter to be used the following factors should be considered;

- i *Power quality* - The quality of the AC electricity generated by the inverter is very important. For most hybrid power systems, a pure sine wave inverter is used since it is the same type of power provided by the utility companies.
- ii *Power rating* - This is the amount of power that an inverter can handle, a continuous rating is frequently used and it is the amount of power it can supply continuously and can also be referred to as the inverter's capacity. The inverter chosen should have a continuous rating that is about 30% higher than the maximum power you will need to deliver to your loads.
- iii *Efficiency* - An inverter's efficiency indicates how much of the input DC power it converts into AC power. Inverters operate at maximum efficiency at a power level known as its peak efficiency point which is generally at 20-30% of its maximum power rating.

3. Methodology

3.1. Wind Speed and Solar Radiation Resource

Figure 7 and 8, shows data on wind speed (m/s) and solar radiation (kwh/m^2/d) respectively, which were collected from RETScreen renewable energy software and they were analyzed for a period of six years (2008-2013) in order to show the availability of these resources. This was done to ensure stability in power generated.

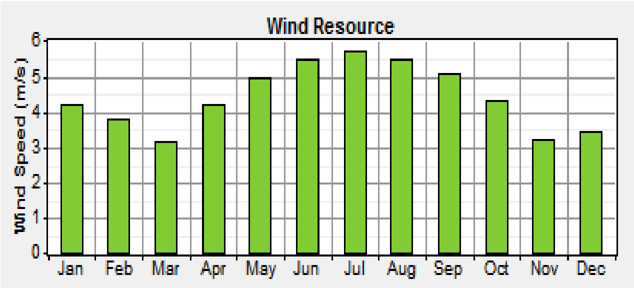

Figure 7. *Bar graph showing wind resource*

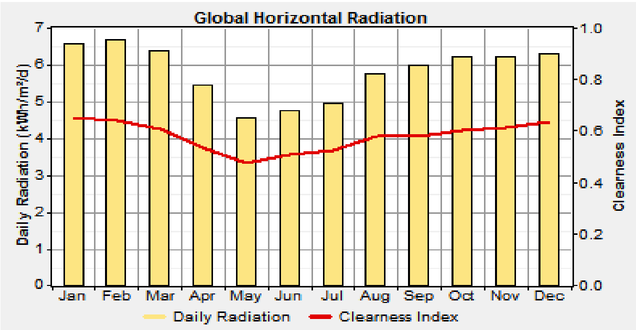

Figure 8. *Bar graph showing solar resource*

3.2. Evaluation of Load Demand of the Nec

Following a manual counting of fluorescent lamps and fans, the load demand for the building was determined to be 45.27kW with respect to the described equipment's. The bar below shows the data that was obtained with respect to the load demand and the hours of operation of the system.

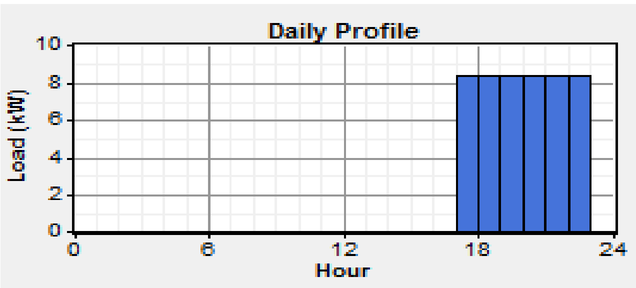

Figure 9. *Bar graph showing daily load profile for NEC-TUM*

3.3. Wind Turbine and Solar Panel Selection

This design involved the wind speed pseudo data collected from RETScreen and the wind power parameters; Beltz limit, air density, swept blade area. The selected wind turbine was SW-Whisper- 200 and its power curve is shown in Figure 10. The design also involved the solar radiation pseudo data collected from RETScreen and the solar power parameters; solar radiation data, solar panel size and rating and tilting angle of the solar panel. The selected solar panel was BP SX3190 rated at 190W manufactured by BP solar.

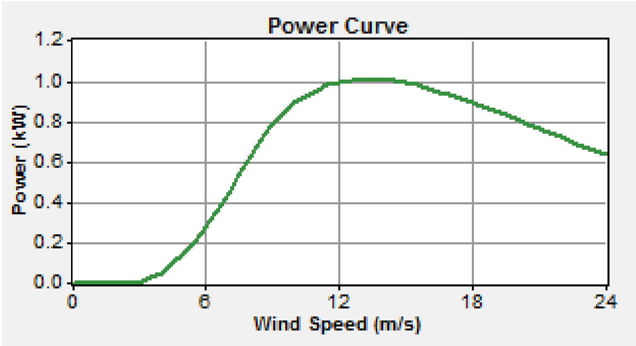

Figure 10. *Wind power curve for SW-Whisper- 500.*

3.4. Battery and Inverter Selection

Table 1, shows the selected battery was rolls surette 4-KS-25P which has the following specifications.

Table 1. *Specifications of Surette 4-KS-25P.*

Nominal Capacity	1900Ah
Nominal voltage	4V
Round trip efficiency	80%
Minimum state of charge	40%
Float life	12yrs
Maximum charge rate	1A/Ah
Maximum charge current	67.5A
Lifetime throughout	21,697kWh
Suggested value	21,697kWh

The inverter selected was FX2348ET from Outback power and its major specification are shown below.

Table 2. *Specifications of the inverter*

Electrical characteristics	FX2348ET
Nominal DC input voltage	48 V DC
Continuous Power rating at 25°C	1100kW
AC Voltage /Frequency	230VAC/50Hz
Continuous AC RMS output at 25°C	10.0 Amps AC
Typical Efficiency	93%

4. Homer Simulation Model

The Homer micro power optimization model is a computer model developed by the U.S. NREL to assist in the design of micro power systems and to facilitate the comparison of power generation technologies across a wide range of application. Homer performs three principal tasks; simulation, optimization and sensitivity analysis. The description of the structure, purpose and capabilities of HOMER was demonstrated when the model was introduced. The major components (wind turbine, solar PV panel, load, battery and converter) were added on the software interface and the data were inserted. The system model components major characteristics (sizes, costs, efficiency, lifespan, tilt angle, derating factor, ground reflectance, hub height, autocorrelation factor, batteries per string) were fed into the HOMER software inclusive of the solar and wind resource data in order to carry out simulation. Figure 11, shows the system architecture of the hybrid system.

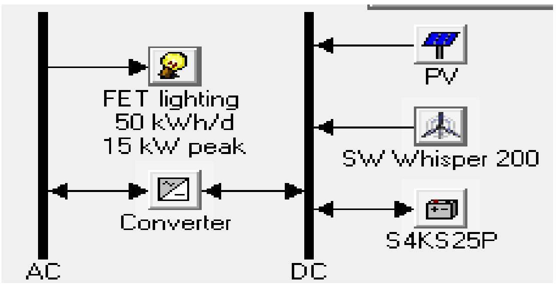

Figure 11. *The system architecture of the hybrid system.*

4.1. Electrical System

The results obtained in this section focussed on the PV and wind electricity production and the AC load consumption for a period of one year. Excess electricity, unmet electric load and capacity shortage are also indicated as shown in Table 3 and Figure 12 below.

Table 3. *Electrical concept of the system model from Homer software*

Component	Production (kWh/yr)	Fraction
PV array	12980	56%
Wind turbine	10238	44%
Total	23128	100%

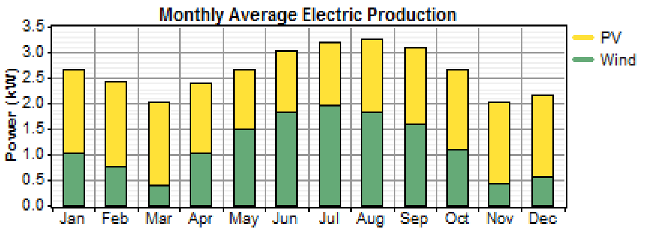

Figure 12. *Bar graph showing electricity produced by the system.*

4.2. PhotoVoltaic Sytem

The results obtained with respect to solar PV were based on the mean output related to the rated capacity of the panel. The mean output of electrical power generated per day, capacity factor and total electrical production throughout the year was shown.

The minimum output and maximum output of the solar PV, the PV penetration, hours of operation and levelized cost were also indicated in Table 4 and Figure 13 below.

Table 4. *Simulated results with respect to PV*

Quantity	Value	Units
Rated capacity	7.60	kW
Mean Output	1.47	kW
Mean output	35.3	kWh/d
Capacity factor	19.4	%
Total production	12980	Kwh/yr
Minimum Output	0.00	kW
Maximum Output	7.32	kW
PV penetration	70.8	%
Hours of operation	4,380	hr/yr
Levelized cost	0.152	$/kWh

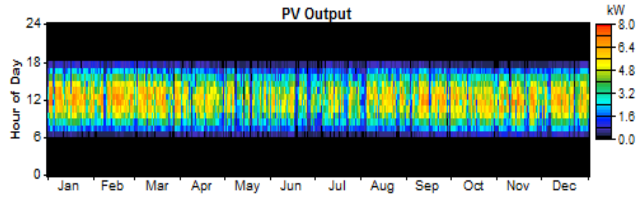

Figure 13. *DMAP for solar PV*

4.3. Wind Turbine

The results obtained from the Homer software with respect to wind was divided into two sections. The first one comprised of the total rated capacity of the wind turbine, mean output, capacity factor and annual total electrical production. The second part comprised of the minimum and maximum output of the turbine, wind penetration, hours of operation and levelized cost. Table 5; shows the simulated results with respect to Wind turbine

Table 5. *Simulated results with respect to SW Whisper 200 Wind turbine.*

Variable	Value	Units
Total rated capacity	5.00	kW
Mean output	1.17	kW
Capacity factor	23.4	%
Total production	10,238	kWh/yr
Minimum output	0.00	kW
Maximum Output	5.01	kW
Wind penetration	56.2	%
Hours of operation	6,635	Hr/yr
Levelized cost	0.100	$/Kwh

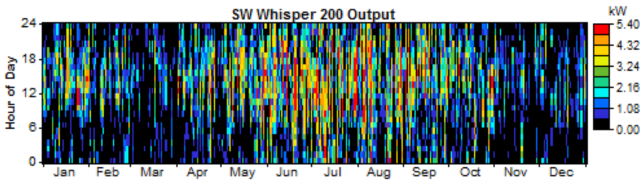

Figure 14. *DMAP for Wind turbine*

4.4. Battery

Correlating information derived from the loading conditions were simulated and results obtained as shown in Table 6 and Figure 15 below.

Table 6. *Showing the simulated results with respect to Battery*

Quantity	Value	Units
String size	6	
Strings in parallel	5	
Batteries	30	
Bus voltage (V)	24	
Nominal Capacity	228	kWh
Usable normal capacity	137	kWh
Autonomy	65.8	hr
Lifetime through put	317,058	kWh
Battery wear cost	0.026	$/kWh
Average energy cost	0.000	$/kWh

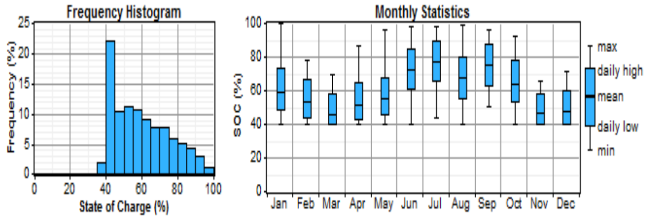

Figure 15. *Frequency histogram and state of charge.*

4.5. Converter

Table 7. *Simulated results with respect to converter.*

Quantity	Inverter	Rectifier	Units
Capacity	11.0	11.0	kW
Mean output	1.8	0.0	kW
Minimum output	0.0	0.0	kW
Maximum output	11.0	0.0	kW
Capacity factor	16.8	0.0	%
Hours of operation	2123	0.0	Hrs/yr
Energy in	17981	0.0	kWh/yr
Energy Out	16183	0.0	kWh/yr
Losses	1798	0.0	kWh/yr

Table 8, shows the simulation results from the converter. The results were obtained from the Homer software with respect to the converter.

4.6. Emissions

Table 8, shows the results obtained with respect to simulation and they include the gases produced when generating electricity.

Table 8. *Simulated results with respect to emissions*

Pollutant	Emissions (kg/yr)
Carbon dioxide	0
Carbon monoxide	0
Unburned hydrocarbon	0
Particular matter	0
Sulphur dioxide	0
Nitrogen Oxide	0

5. Analysis of the Results

5.1. Costing

Based on the simulation results, the cost of energy (C.O.E) was determined as 9.7 Ksh/Kwh that is approximately US$ 0.107/Kwh as compared to US$ 0.217/Kwh from the grid based electrical energy supply.

5.2. Emissions

Referring to Table 9, there is no emissions of gases when generating electricity using solar-wind hybrid energy system for NEC-TUM. This clearly indicates that this system is environmental friendly since it does not pollute the environment.

5.3. Electrical Demand and Supply

The total electricity generated by solar and wind is 23128 kWh/yr with solar and wind contributing 56% and 44% of the produced power respectively.

$$\text{Electricity generated per month} = \frac{\text{total electricity generated per year}}{\text{number of months in a year}}$$

$$= \frac{23128}{12} = 1927.33\text{kWh/month}$$

$$\text{Electricity generated per day} = \frac{\text{total electricity generated per year}}{\text{number of days in a year}}$$

$$= \frac{23128}{365} = 63.36\text{kWh/day}$$

The daily demand of the NEC is 50kWh/day, therefore the hybrid system can sustain the demand of the building. The excess electricity generated with the hybrid system was 11.2 kwh/yr. which is 0.0438% of the total energy produced. Table 9, shows the number of Items required for the solar wind hybrid energy system for NEC-TUM.

Table 9. *Number of system model components*

Items	Number required
Solar panels	246
Wind turbines	30
Battery	180
Inverter	6

6. Conclusion and Recommendation

The study from this simulation results show that:

- The hybrid system was able to produce 63.36kWh/day against the 50kWh/day required by the NEC-TUM for lighting and power loads.
- It was found that the optimum mix of wind and photovoltaic power with an electromechanical storage system, with or without fossil fuel generator back, depends upon the individual subsystems economics.
- The electrical active power generated was maximized since the two systems complement each other.
- The wind regime available at the proposed site matches the technical characteristics of the selected WTG – for optimum electrical power production from wind. Similarly, the solar panels selected are able to provide the required electrical power

The study makes the following recommendations:

- Socio-economic needs assessment of the project need to be carried out.

- An improvement of this system would be the adoption of a hybrid system incorporating diesel-wind-solar. The solar / hybrid systems require a lot of starting capital but looking at the long term benefits, the systems are feasible. The maintenance procedures are also not complex though proper maintenance schedules are required in order not to mismanage or inappropriately usage of the system e.g. overcharging of the battery and overloading of the system.

Acknowledgements

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