Global Journal of Researches in Engineering: F
Electrical and Electronics Engineering
Volume 14 Issue 4 Version 1.0 Year 2014
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals Inc. (USA)
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Integrated Solar – Wind Hybrid Power Generating System for Residential Application

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GJRE-F Classification : FOR Code: 850505, 850509, 090699

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Abstract- A hybrid power system consisting of PV-arrays and wind turbines with energy storing devices (battery bank) and power electronic device was designed and constructed in this paper. The system is aimed at the production and utilization of the electrical energy coming from more than one source, provided that at least one of them is renewable. The efficiency of the designed power electronic device is about 95% and 73% for capacitive and resistive loads respectively. The integration of the hybrid is to electrify a residential house and its surrounding in order to reduce the need for fossil fuel leading to an increase in the sustainability of the power supply. This approachis techno-economically viable for rural electrification.

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I. Introduction

The more noticeable benefits of usable electric power include: improved health care, improved education, better transportation systems, improved communication systems, a higher standard of living, and economic stability. Unfortunately, almost 33% of the world's populations live without usable electrical power (Osama & Egon, 2007). Most of the non-electrified regions are found in developing countries (Phuangpornpitak & Kumar, 2007). Nigeria is one of the developing countries that most of its population lives without usable electricity. Many of the rural areas of Nigeria have not benefited from these uses of electricity in the same proportion as the more populated urban areas of the country (Akinboro, et al 2012). These rural areas can be electrified either by extending the grids of the existing power systems or by constructing isolated new power systems, which are alternative energy sources. Electrifying these remote areas by extending grid system is difficult and costly. Some of the rural areas that were electrified Like Mubi, Adamawa State, experience unreliable power supply characterized by low voltage and incessant power cuts often without warning or even apologies to consumers (Medugu & Markus, 2011). The fluctuating power supply causes problem to electronics appliances used at homes. House occupants are forced to use fossil fuel generators. These fossil fuel generators do not only create noise but contribute to global warming.

As the current international trend in rural electrification is to utilize renewable energy resources; solar, wind, biomass, and micro hydro power systems can be seen as alternatives. Among these, combined wind and solar systems are becoming more popular for stand–alone power generation applications, due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. Research and development efforts in solar, wind, and other renewable energy technologies are required to continue improving their performance, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating sources (Oji et al, 2012).

(Prasad & Natarajan, 2006), presented a new method for optimization of a wind–PV integrated hybrid system. (Nelson et al, 2006) performed an economic evaluation of a hybrid wind/photovoltaic/fuel cell generation system for a typical home in the Pacific Northwest. (Grinspan et al, 2006) presented the development of a Savonius rotor configuration which is simple in design, fabrication and maintenance, and is suitable for small-scale rural application. (Mojola, 1985), examined the performance characteristics of the Savonius windmill rotor under field conditions.

In order to reduce the need for fossil fuel leading to an increase in the sustainability of the power supply, wind and solar energy systems in stand-alone or hybrid forms are thought to be ideal solution for residential electrification due to abundant solar radiation and significant wind distribution availability in Mubi. Thus, in this research, hybrid renewable power generation system integrating solar and wind resources is to be designed and modeled, to electrify a residential house and its surrounding.

A hybrid Photovoltaic-wind power generation system is proposed to supply electricity to a residence. The Hybrid Renewable Power Generation System (HRPGS) is a system aimed at the production and utilization of the electrical energy coming from more than one source, provided that at least one of them is renewable (Gupta, 2008). Residential generating systems harnessing wind and solar energies are seen as a potential answer to individual energy concern. The integration of renewable energies such as solar and wind are the best solution for feeding the mini-grids and isolated loads in remote areas.

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II. Hybrid Power Generating System

A hybrid power generating system is a system in which two or more supplies from different renewable energy sources are integrated to supply electricity. The hybrid used here is based on Photovoltaic (PV) modules and wind turbine.

a) Wind Turbine

Energy available in wind is basically the kinetic energy of large masses of air moving over the Earth's surface. Blades of the wind turbine receive this kinetic energy, which is then transformed to useful mechanical energy, depending on end use (Mathew, 2006)

Air of mass m (kg) moving with speed *v* (m/s) has a kinetic energy given by (Patel, 2006; Mathew, 2006):

$$KE = \frac{1}{2}mv^2 \quad (1)$$

The power P in moving air is the flow rate of KE per second. Thus the theoretical power in the moving air is giving by (Patel, 2006):

$$P = \frac{1}{2}\rho A v^3 \quad (2)$$

Where ρ is the density of the air stream, A the area of the wind captured.

The most accurate estimate for wind power density in W/m^2 is that given by eqn (3) (Getachew, 2009)

$$\frac{P}{A} = \frac{1}{2}.\frac{1}{n}.\sum_{j=1}^{n}\left(\rho_j.v_j^3\right) \quad (3)$$

Where n is the number of wind speed readings and ρ_j and v_j are the jth readings of the air density (kg/m^3) and wind speed (m/s) respectively.

The swept area, *A* depends on the dimensions of the rotor. For a horizontal axis turbine of rotor diameter d, the swept area can be given by (Patel, 2006):

$$A = \frac{\pi d^2}{4} \quad (4)$$

For a vertical axis turbine of maximum rotor width *w* and rotor height *h*, the swept area can be approximated by (Patel, 2006):

$$A = \frac{2}{3}wh \quad (5)$$

The air density ρ depends on pressure and temperature. It can be expressed as (Patel, 2006):

$$\rho = \frac{P}{RT} \quad (6)$$

Where *p* is air pressure (Pa) and *R* is the specific gas constant (287 Jkg^{-1}K^{-1}) and *T* is air temperature in K. If we know the elevation Z' (m) and temperature T at a site, then the air density can be calculated by (Mathew, 2006).

$$\rho = \frac{353.049}{T}e^{\left(-0.034\frac{Z''}{T}\right)} \quad (7)$$

If pressure and temperature data are not available, the following correlation may be used for estimating the density (Getachew, 2009)

$$\rho = 1.225 - (1.194 * 10^{-4}) * Z' \quad (8)$$

a) PV Cells

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Fig. 1.

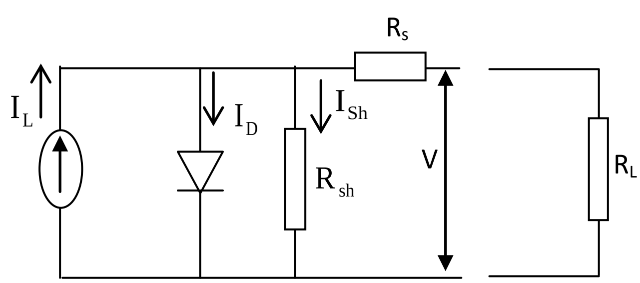

Figure 1 : A PV cell equivalent electrical circuits after (Duffie & Beckman, 2006)

The current I at the output terminals is equal to the light-generated current I_L less the diode current I_D and the shunt-leakage current I_{sh}. The series resistance R_s represents the internal resistance to the current flow, and depends on the p-n junction depth, impurities, and contact resistance. The shunt resistance R_{sh} is inversely related to the leakage current to the ground. In an ideal PV cell $R_s = 0$ and $R_{sh} = \infty$. The PV conversion efficiency is sensitive to small variations in Rs, but insensitive to variations in R_{sh} . A small increase in R_s can decrease the PV output significantly.

The open-circuit voltage V_{oc} of the cell is obtained when the load current is zero and is given by the following

$$V_{oc} = (I_L - I_D)R_{Sh} \quad (9)$$

The diode current is given by the classical diode current expression

$$I_D = I_0\left[exp\left(\frac{qV_{oc}}{AKT}\right) - 1\right] \quad (10)$$

Where *Io* is the saturation current of the diode (A), *q* is electron charge (1.6×10^{-19} C), Ais curve-fitting

constant, K is Boltzmann constant (1.38×10^{-23} J/K), T is temperature on absolute scale K.
Thus, the load current is given by the expression

$$I = I_L - I_D - I_{Sh} \quad (11)$$

$$I = I_L - I_0\left[exp\left(\frac{qV_{oc}}{AKT}\right) - 1\right] - \frac{V_{oc}}{R_{Sh}} \quad (12)$$

The last term is the leakage current to the ground. In practical cells, it is negligible compared to I_L and I_o and is generally ignored.

The maximum photo voltage is produced under the open-circuit voltage. Again by ignoring the ground leakage current, eqn 11 gives the open-circuit voltage as follows

$$V_0 = \frac{AKT}{q} ln\left[\frac{I_L}{I_0} + 1\right] \quad (13)$$

III. System Description and Design Implementation

The solar – wind with power generation system is designed as shown in Fig. 2. The generating system has a DC bus which combines the DC output of the PV module, the DC output of the wind turbine, and a battery. The AC bus combines the output of the inverter and the load. This parallel configuration requires no switching of the AC load supply while maintaining flexibility of energy source.

When solar radiation falls on the solar panel, DC electricity flows. This electricity flows through the charge controller which regulates the DC energy for efficient charging. Similarly, when wind blows over the blades of the turbine, it turns the DC generator. The electricity generated is used for battery charging. The powers from the solar panel and the wind turbine add up when the two sources are at reasonable potentials. When the wind speed is below the cut-in point, and in a sunny day, solar energy takes over the charging. If on the other hand the wind speed is reasonably high and no solar radiation, especially at night, the wind turbine takes over charging the battery. Power inverter is then connected to transform the direct current energy of the battery into alternating current energy.

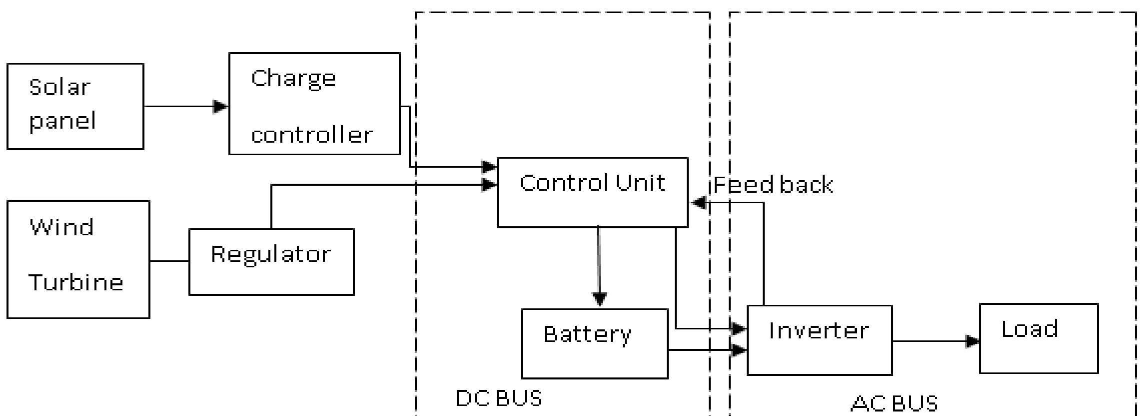

Figure 2 : Block diagram of PV- Wind Hybrid Power Generating System

a) The control unit plays two roles

- It controls the operation of the inverter. That is if it senses solar energy, it automatically switches off the inverter and allows only charging of battery. This also means that the control unit switches OFF the inverter during the day and switches ON at night.
- It controls the modulation of the inverter through the feedback loop by adjusting the modulation current. This process helps to maintain a constant 220V across the load when the voltage of a fully charged battery drops from 14V to 10V

IV. Inverter Charge Controller and Control Unit Design

The inverter is designed around the TL494 Pulse Width Modulation control Integrated Circuit which has an in-built oscillator among other features as shown in Fig.3. The picture is shown in Fig. 4.

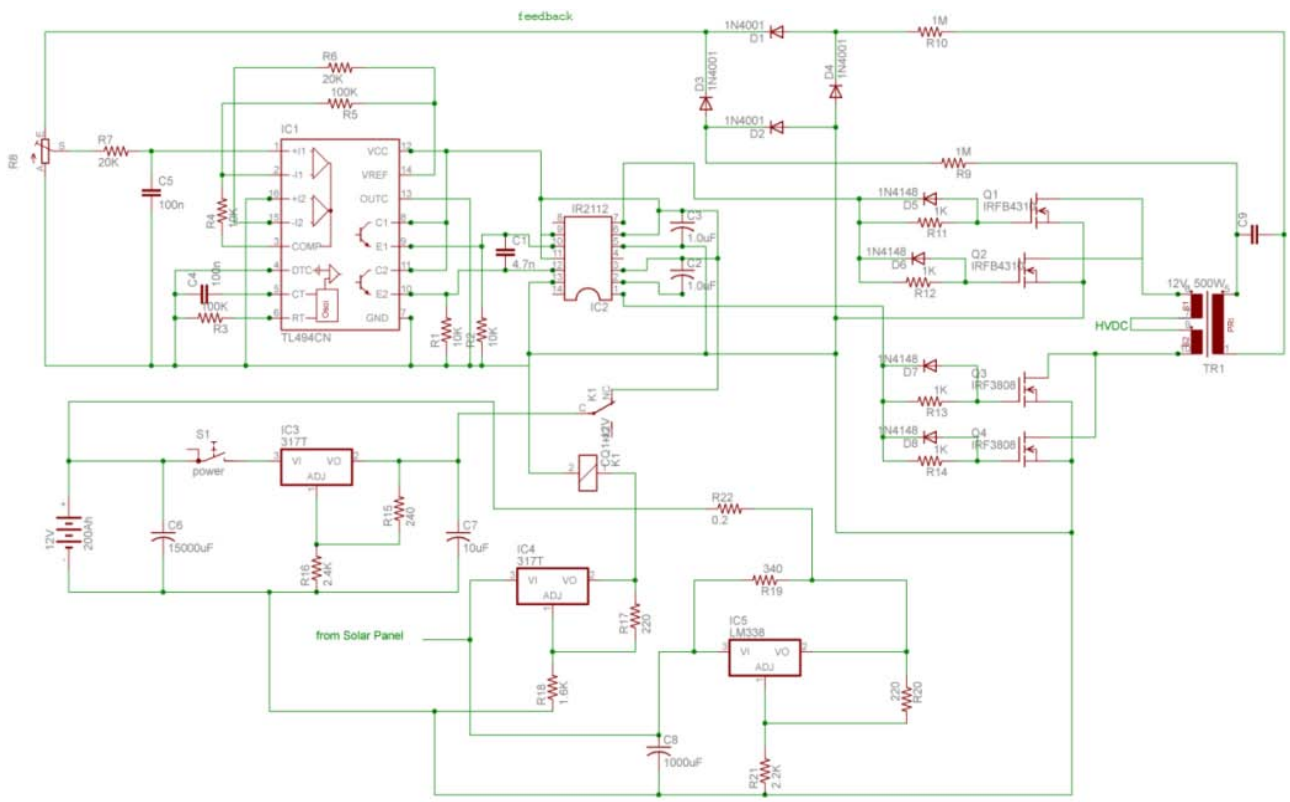

Figure 3 : Complete Circuit diagram of the Inverter Module/ Charge Controller and the Control unit.

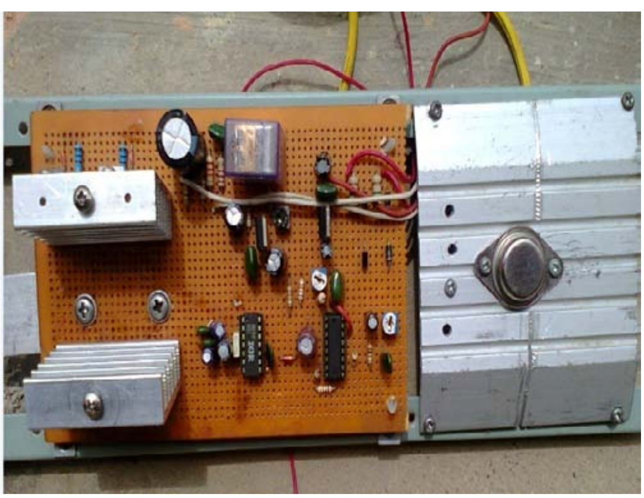

Figure 4 : Constructed Inverter and Charge controller

Connecting an external capacitor C_4 and resistor R_3 to pins 5 and 6 control the oscillation frequency of the TL494.

Choosing C_4 to be 100nF and using eqn 14, R_3 is obtained as 100$k\Omega$(Alberkrack, 2002).

$$f = \frac{1}{2R_3C_4} \tag{14}$$

The 220VAC from the inverter output is rectified and dropped to a lower value by R_9 and R_{10} allowing a current of 0.2mA and a voltage of 2.5V at pin 1. R_9 and R_{10} can be obtained using voltage divider as nearest preferred value of 1.0 $m\Omega$.

The error amplifier of the TL494 compares a sample of the internal 5V reference voltage to the voltage at pin 1 through R_4 and R_5. The two resistors also set the gain for the amplifier to 11 and using R_4 to be 10KΩ, R_5 can be calculated using eqn 15 obtaining the value of 100 $k\Omega$.

$$R_5 = (gain - 1)R_4 \tag{15}$$

R_8 and R_7 set the potential at pin 1 variable to 2.5V the error between pins 1 and 2 controls the pulse width modulation.

C_5 filters the ripple from the rectifier and R_6 serves as feedback to the second internal error amplifier of the TL494.

The output is referenced to ground through R_1 and R_2 which gives a voltage drop of 4.7V at 0.5mA.

The battery charger/controller was designed using LM338 a 5A variable voltage regulator. The output voltage is set to 14V. The power supply to the on-board components was designed using LM317 variable voltage regulator. The power unit regulates the output to 10V over battery voltage variation of 11V to 14V. Complete innovation of the inverter with the accessories discussed is displayed in Fig. 5.

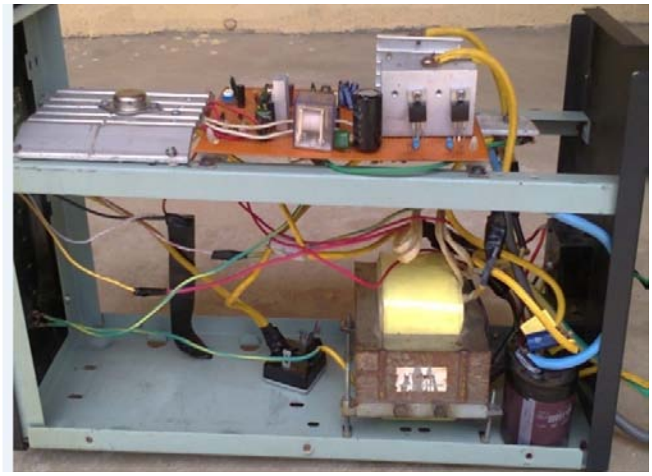

Figure 5 : The 500W Power Inverter after Casing

V. Description of the Main Parts of the Wind Turbine

A wind turbine consists of the following four main parts: the base, tower, nacelle, and blades, as shown in Fig. 6. The blades capture the wind's energy and spin a generator in the nacelle with the aid of an improvised gear box housed two gear system of ratio 1:6. The shaft with fewer gears was attached to the wind turbine rotor while the shaft with more gears was attached to the generator. The tail was cut to the shape shown in Fig.6 for turning the turbine to the direction of the wind.

The tower contains the electrical circuits, supports the nacelle, and provides access to the nacelle for maintenance while the base is made of concrete and steel and supports the whole structure.

Figure 6 : Shows the picture if the Integrated Electricity generating system in operation

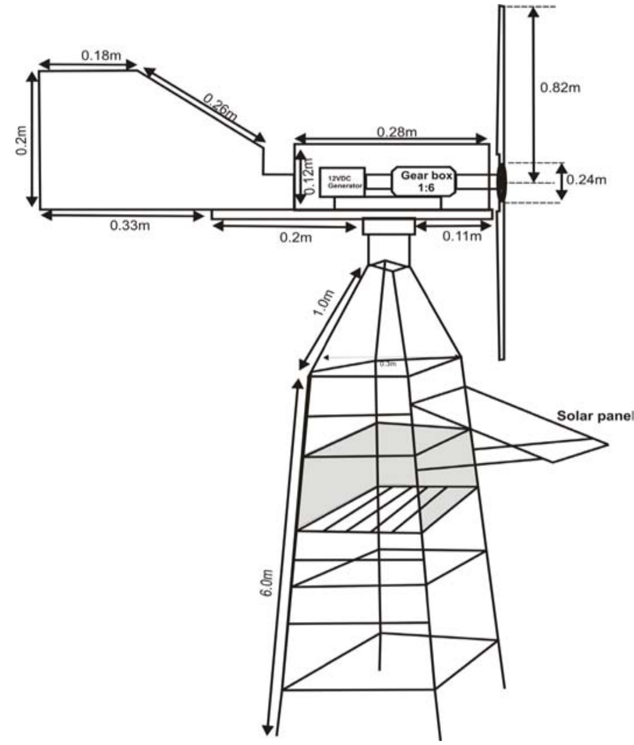

Figure 7 : structural frame of the wind turbine and solar panel

Figure 8 : The Hybrid-Power Generator Working after Sunset

VI. Results and Discussion

a) Results

Once the mechanical and electrical aspects of the system were completed the entire device was tested. The current and voltage values from the Wind Turbine, Solar Panels, Battery group and load are measured. The efficiency of the designed electricity generating machine (inverter) is about 95% and 73% for capacitive and resistive loads respectively. The efficiencies were determined from the ratio of full-load DC voltage to the no-load DC voltage. The control unit of the inverter was also tested and was in conformity with the design which was auto-switching (OFF for sun rises and ON for sunset).

The battery's state of charge was 8.7V. The charger was connected at 8:12am and the corresponding voltage across the battery was measured at an interval of thirty minutes.Fig,8 shows the graph of the voltage across battery against the corresponding time of the day indicating the three charging stages of the charge controller.

The system is able to power a 3 bedroom resident containing 16 energy saving bulbs, 1 TV set, 4 fans and 2 computer system for 12 hours without draining the battery.

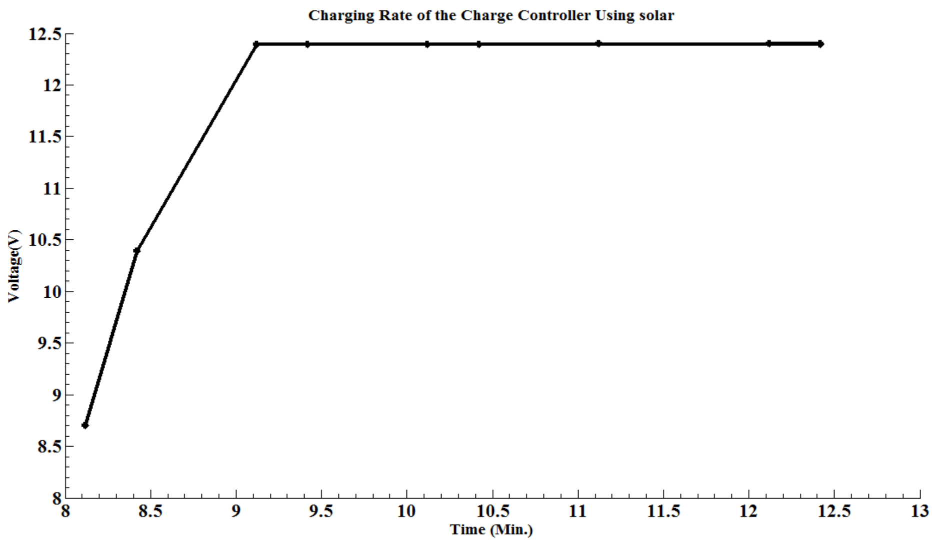

Figure 8 : Graph of voltage across the battery against time.

VII. Discussion

It was observed that wind and solar are complementary since sunny days are usually calm and strong winds are often accompanied by cloud and may occur at night. The inverter under capacitive loads draws less energy from the battery than resistive loads. This is practically indicated by a lower drain from the battery voltage.

The graph of Fig. 8 shows how the battery rapidly charged from 8.7V to 10.39V within 30minutes indicating boost stage, and from 10.39V to 12.39V for two hours thirty minutes indicating the floating stage. While the last stage showed how the charging fluctuates indicating trickle mode. The charging of the battery by the wind turbine greatly depends on the rotational speed of the blade which in turn depends on the wind speed. The readings were obtained at low wind speed. The charger was able to add 0.77V to the battery's state of charge within two hours thirty minutes.

The control unit switches ON the inverter once the solar plate could not detect any solar radiation and switches OFF once it detects it.

VIII. Conclusion

A hybrid power generating system consisting of a PV array and wind turbine with energy storage device and power electronic converter was designed and constructed to take advantage of the seasonal wind and sunshine. The design is achieved as an efficient and cost competitive system configuration so that hybrid power source can improve the life of people especially in rural areas where electricity is not stable or is absent. The efficiency of the designed electricity generating machine (inverter) is about 95% and 73% for capacitive and resistive loads respectively. The wind turbine performance showed a promising output, but there was a challenge with the generator at lower wind speed as can be seen from table 4.4 where only 0.77V was added to the battery's state of charge. This platform has been laid to harvest the wind energy and the abundant solar radiation availability in Mubi. The integrated solar-wind hybrid power generating system is environmentally friendly and maintenance free.

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