Design of an Automatic Renewable Energy Supply and Switching System

Francis E. Idachaba, Joseph O. Olowoleni, Augustus E. Ibhaze

***Abstract*—The intermittent nature of renewable energy supply systems coupled with the variation in the terminal voltage supplied by these systems either due to variation of wind speed or solar irradiation makes it necessary to have an automated means of switching between these systems when the terminal voltage supplied by any one of them falls below a rated minimum value. The public utility can thus be regarded as a standby power supply systems which is only activated when both the solar and wind supply systems fail. This system coupled with the high solar radiation and the high wind speed of the Middle East and is capable of eliminating the need for public utility as inverters and battery systems can be used to provide backup power in the event of a failure of both renewable energy sources. This system provides an opportunity for the development of standalone power supply systems in rural areas without public utility. It also provides an opportunity for the minimal reliance on public utility by users in urban areas.**

***Index Terms*—Controller Algorithm, Renewable Energy, Solar Energy, Wind Energy**

I. Introduction

THE negative impact of fossil fuel based electric power generating systems and the instabilities in the cost of these fuels are driving several governments to explore the opportunities offered by the renewable energy supply systems. Most regions explore the available natural resource with a view to developing renewable energy supply systems from them. Typical examples include, the solar based renewable energy based systems, the tidal waves renewable energy based systems, and the wind power based renewable energy supply systems [1]. The most popular source of renewable energy supply is the solar based power supply system. This is due to the fact that there is a guaranteed availability of supply for solar energy. The current technology for converting solar radiation into electrical energy has reached a mature phase and it is affordable with opportunities for low cost individual deployment possibility [2]. The wind based system is the second most popular option due to the global availability of the wind source and the modular or scalable deployment opportunity of the system. The individual gains of these systems in the area of environmental friendliness with low polluting activities and the minimal maintenance costs can be optimized by developing a hybrid system. This system comprising both solar and wind based power supply will offer a high degree of system reliability and stability in terms of utilization and performance. Although substantial fluctuations in the climatic conditions might affect the reliability of the system, the use of batteries is expected to level out abnormality in the solar irradiation and wind speed [3].

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Francis E Idachaba is currently an Associate Professor of Communication Engineering in the department of Electrical and Information Engineering in Covenant University Ota Ogun State.; e-mail: Francis.idachaba@covenantuniversity.edu.ng

Joseph Olowoleni is a PhD student and member of faculty in the Department of Electrical and Information Engineering in Covenant University Ota Ogun state in Nigeria; e-mail: Joseph.olowoleni@covenantuniversity.edu.ng

Augustus Ehiremen Ibhaze a PhD student and member of faculty in the Department of Electrical and Information Engineering in Covenant University Ota Ogun state in Nigeria; e-mail: Ehiremen.ibhaze@covenantuniversity.edu.ng

A. *Solar Based Renewable Energy System*

The relative stability of the solar radiation provides an opportunity for the development of a reliable power supply systems with a relatively stable availability. This system can be used to provide a charging source for the inverter battery systems. From the diagram in Figure 1, the Middle East among other regions has a very high amount of solar irradiation and thus a huge potential for solar energy based power supply systems. However, the presence of sandstorms and dusts limits the efficiency of these systems [4]. The lack of solar irradiation in the night also makes it difficult to develop a 24 hour fully solar based power supply systems.Figure 1 shows the geographical distribution of solar radiation covering different regions.

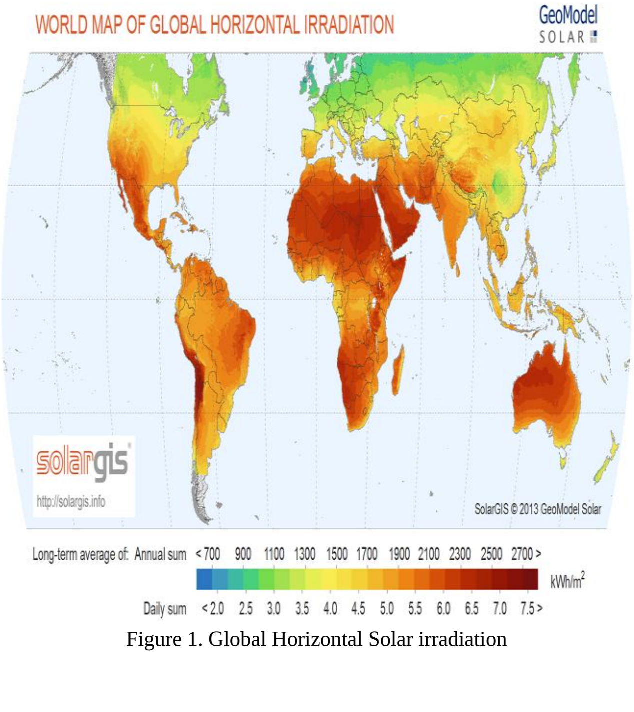

Figure 1. Global Horizontal Solar irradiation

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Solar power systems utilize the energy from the sun either directly or indirectly to generate electricity for many residential and commercial uses. Solar panels are currently available with different efficiencies and costs and they provide a cost effective means of converting solar rays to electrical energy. However, this energy source is limited by the fact that the sun is unavailable during the night time and this can be up to 12 hours in most places [4, 5]. The system is also limited by clouds and the presence of dust on the panels. These effects limit the voltage levels generated by the panels. Automated solar tracking systems are currently being used to optimize the output of the solar panels by ensuring that the panels track the sun as it rises and sets.

The power output of a photovoltaic system is given in equation (1) as

$$E= (A)\,(r)\,(H)\,(P_R) \qquad (1)$$

Where E is energy (KWh), A is the total solar panel area (m^2), r is the solar panel yield (%), H is the annual average solar radiation on tilted panel and P_R is performance Ratio coefficient for losses

At the Earth surface, quantities of isolation and net radiation undergo daily cycle of change because the planet rotates on its polar axis once every 24hours. Figures 2 and 3 show the radiation intensity over 24 hours period. It shows that the peak of the radiation occurs at noon and it also shows the impact of the presence of clouds on the amount of irradiation on the surface. Cloud cover produces a reduction in the amount of irradiation and the thicker the cloud, the lower the irradiation values under the areas with the cloud cover.

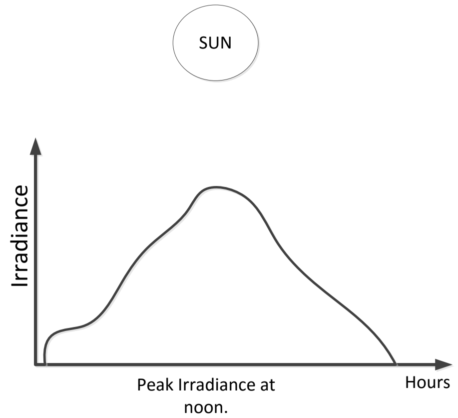

Figure 2. Solar radiation over a 24 hour period with no cloud cover

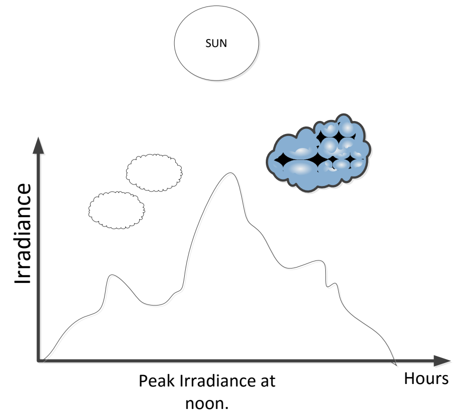

Figure 3. Solar radiation over a 24 hour period with some cloud cover

B. Wind based Renewable Energy Supply System

The Wind based system is not limited by day and night fluctuations so its availability can be established either during the day or night. However, the variation in the wind speed increases the unreliability of the wind based supply system. The wind power system captures the energy of the wind using turbines such that voltage is generated when the wind speeds are able to drive the wind turbines above the cut-in point [7]. At wind speeds below the cut-in speed, the turbine output is zero. When the wind speed gets too high, the turbines are also designed to stop operating thus returning the generated voltage to zero as shown in figure 4.

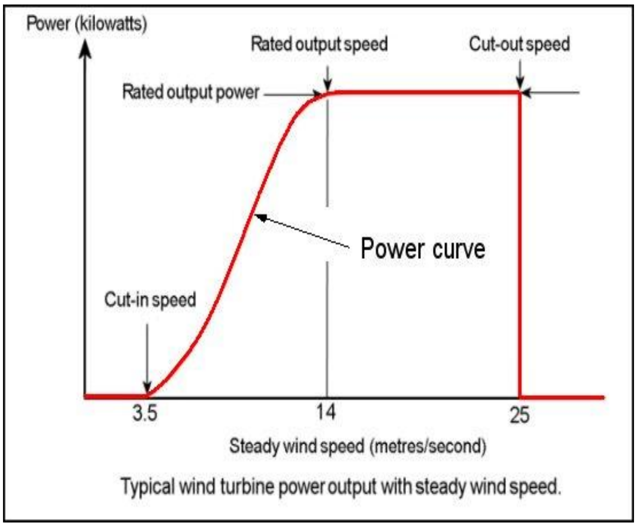

Figure 4. Wind power curve

Wind power depends on the amount of the air, the density and the speed. The power output of the turbines is expressed as

$$\text{Kinetic Energy, } KE = \frac{1}{2} m * v^2 \qquad (2)$$

Power is KE per unit time

$P = \frac{1}{2} m * v^2$, mass fluid rate is given as density * volume flux

$$\frac{dm}{dt} = \rho * A * v \text{, thus } P = \frac{1}{2}\rho * A * v^3 \qquad (3)$$

Power coefficient (C_p) is the ratio of power extracted by the turbine to the total contained in the wind resources.

$$C_p = \frac{P_T}{P_w}, \quad P_T = C_p * P_w$$

Turbine Power Output is given as

$$P_T = \frac{1}{2}\rho * A * v^3 * C_p \qquad (4)$$

From equation 4, the power output is a function of the density of the wind, the velocity of the wind, the swept area of the turbine and the betz efficiency which has a maximum of 59%.the power curve of a wind turbine is shown in figure 4 and the defination of the different parameters are listed in the following

i. Start-up Speed – This is the speed at which the rotor and blade assembly begins to rotate.

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ii. Cut-in Speed – Cut-in speed is the minimum wind speed at which the wind turbine will generate usable power. This wind speed is typically between 7 and 10 mph for most turbines.

iii. Rated Speed – The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. Rated speed for most machines is in the range of 25 to 35 mph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called “power curves,” showing how their wind turbine output varies with wind speed.

iv. Cut-out Speed – At very high wind speeds, typically between 45 and 80 mph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed, or sometimes the furling speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Figure 5 shows the impact of variable windspeed on the turbine output voltage. From the figure 5, variation in the flow stream of the wind can result in up a 100% reduction in the output power from the turbine. This reduction which is primarily observed as a reduction in the terminal voltage can be used to initiate a change over to the alternative power supply source

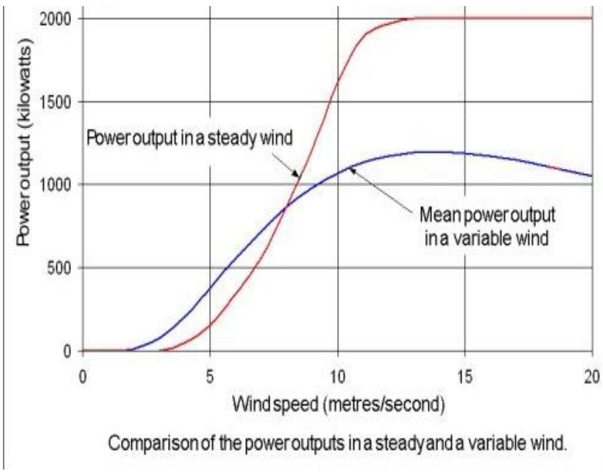

Figure 5. impact of varying windspeed on the turbine output

II. SYSTEM DESIGN

Comparing both solar and wind based systems, the solar based system has capacity to provide a stable output for over 12 hours depending on the cloud presence and the state of the panel surfaces. It is not capable of generating power during the night periods when there is no sunlight. The wind based system is capable of generating power so long as the available wind speed is above the cut-in speed and below the cut off speed of the turbine. The variation in the wind speed makes it an unreliable power supply source and as such can not be deployed alone to provide a constant power supply system[4,9]. The hybrid system presented in this paper comprises of a wind based system serving as the primary source and the solar serving as the backup. With the wind power active, the solar system charges the inverter batteries during the day and whenever the wind based system goes off during the day, the solar based system takes over. If the wind system goes off during the night, the inverter system supplies the load using the stored charge in the battery. The system diagram is shown in figure 6. For locations with public utility, the block diagram can be modified to accommodate the pubic utility source as one of the backup sources.

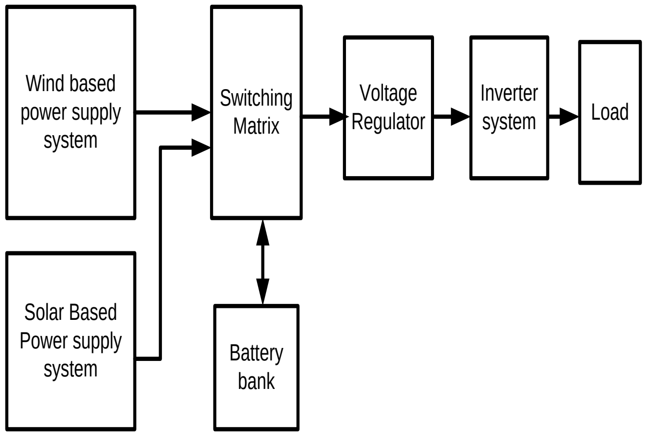

Figure 6. System block diagram

The wind based system is configured to serve as the primary source and it is fed through the switching matrix to the inverter. The output voltage of the turbine system is selected to fall within the input range of the inverter systems and voltage regulaors are used to ensure that the inverter is fed a constant DC voltage regardless of the fluctuations in the turbine output. The solar based power supply systems is configured as the back up system and when the wind based system is within acceptable limits during the day, the solar based system is automatically connected to charge the inverter batteries. Whenever the wind based system goes out of the operating envelop, the solar based system also designed to have the same terminal voltage as the inverter input system gets connected through the voltage regulator system to the inverters. During the night season, the solar system gets disconnected from the charging system and the battery is automatically connected to the inverter system.

III. CONTROLLER DESIGN

The controller design and block diagram is shown in figure 7.

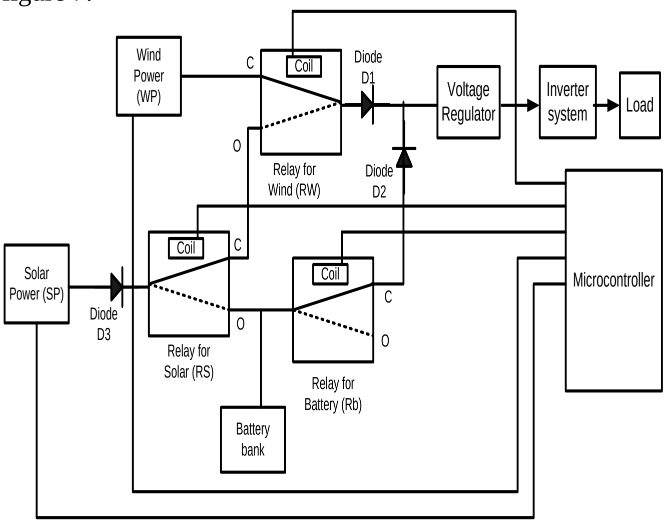

Figure 7. Controller design and block diagram

Diodes D1 , D2 and D3 are used as protective devices to prevent the reverse flow of current when the respective relays are activated. The relays have two states labeled as O for Open and C for Closed.

IV. SYSTEM ALGORITHM

The algorithm for the controller design is presented below

1. The Operating Envelop (OE) is set from the turbine datasheets to be greater than the Cut-in speed and less than the cut-off speed.
2. If Wind Power (WP) = OE
   Set RW = C
   Set RS = O
   Set Rb = O
3. If Wind Power (WP) ≠ OE
   If Solar Power = High
   Set RW = O
   Set RS = C
   Set Rb = O
4. If Wind Power (WP) ≠ OE
   If Solar Power ≠ High
   Set RW = O
   Set RS = O
   Set Rb = C

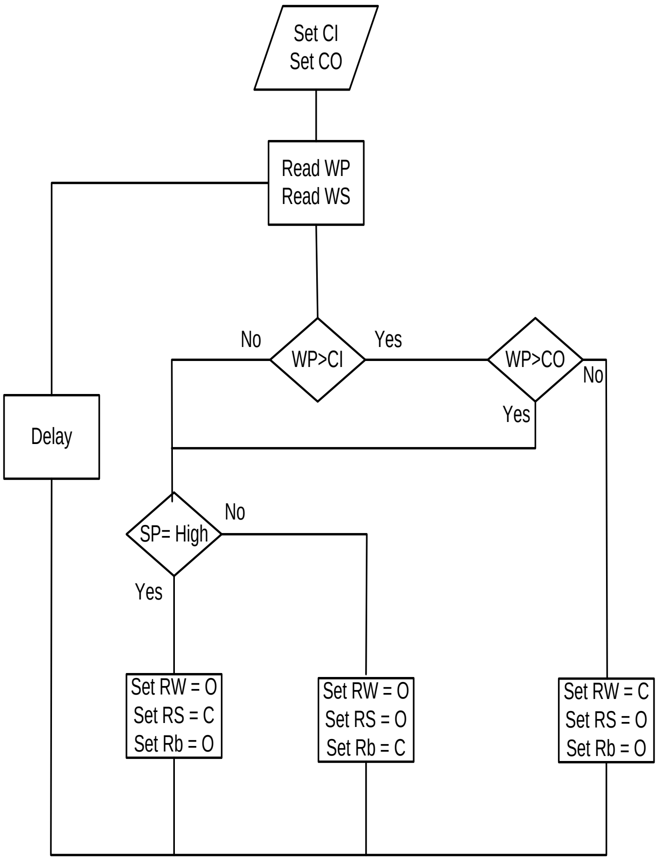

Figure 8: System Flowchart

The flowchart for implementing the system is shown in figure 8.

V. RESULTS AND DISCUSSION

The advantages of both the solar and the wind based renewable power supply system do not guarantee its reliability and availability for deployment as the only power supply source for consumers. The limitation of the solar power supply system to daytime and the possibility of outages as a result of cloud cover and sandstorms also pose a challenge to the full scale deployment of standalone solar power supply systems. Wind power on the other hand faces the challenge of unpredictable availability and variations in the wind speed as they cannot be scheduled to deliver specific amount of power at a specified time. Rather, wind and solar power plants generate electricity when their energy resources are available [10]. This is more pronounced as the presence of wind speed below the cut-in speed of the turbine will not support the generation of electricity and wind speed above the turbine cut-off point will shut down the turbine bringing power generation to zero. This work provides a cost effective approach at harnessing both the wind and the solar based renewable energy supply and automatically switching between either of the two systems to ensure constant and steady power supply regardless of the variations in the available solar radiation and the available wind speed. The integration of a battery bank ensures that power is available even when both the solar system and the wind based systems fail.

VI. CONCLUSION

This work presents an opportunity for the maximization of renewable power supply systems by residential consumers. It also provides commercial/industrial consumers with an opportunity for utilizing renewable power supply sources to power those of their equipment capable of being powered by renewable energy sources. The system is capable of limiting to the barest minimum, the reliance on fossil fuel based utility supply systems and also enabling the deployment of off-grid power supply systems in locations with no presence of public utility supply systems. It provides an opportunity for greater deployment and utilization of renewable power supply systems and the integration of these energy sources into the existing power supply network at consumer locations.

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