

# Hybrid Power Systems To Provide Uninterrupted Power Supply At The Federal University Of Technology, Minna, Niger State, Nigeria

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## ABSTRACT

The integration of renewables such as solar and wind energy is becoming increasingly attractive and is being widely used in substitution to fossil fuel-produced energy which also leads to great reduction in atmospheric degradation. Literature shows that commercial/residential buildings in Nigeria consume an estimated 55 – 65% of the total electric energy generated. In the present study, hourly mean wind-speed and solar radiation data for the period 2005 – 2016 recorded at the meteorological monitoring station, Minna (26° 32' N, 50° 13' E), Nigeria, were analyzed to investigate/examine the potential of utilizing hybrid (wind + solar) energy conversion systems and grid back-up to meet the load requirements of the Gidan-Kwanu campus of the University (with daily electrical energy demand currently at 8,450.5 kWh/day). The monthly average wind speeds for Minna range 4.1 to 6.4 m/s and the monthly average daily values of solar radiation for Minna ranges from 3.6 kWh/sq.m to 7.96 kWh/sq.m. The hybrid system considered in the present analysis consists of different combinations of commercial 10 kW Wind Energy Conversion System (WECS), Photovoltaic (PV) panels supplemented with battery storage unit and National grid back-up. The study shows that with thirty 10 kW WECS together with 150 sq.m PV, and three days of battery storage, the grid back-up system has to provide 17% of load demand. However, in the absence of battery storage, about 38% of the load needs to be provided for by the grid system.

**Keywords:** - Battery storage, Hybrid, Photovoltaic (PV) panels, Power Systems, Wind Energy Conversion System (WECS),

## INTRODUCTION

Electrical energy is one of the finest forms of energy that serves as an input variable to so many activities that is embarked upon by mankind. Electricity consumption in the Federal University of Technology, Minna, is mainly for lighting; comfort space cooling; water pumping; water heating, computers, teaching and general research activities. It serves as input variables to services like operation of computers, photocopiers and other social activities. Most of the electrical energy consumption basically depends on the national grid which is unstable, and an attempt to use diesel generator leads to high energy bills. To reduce this bill, the national grid can be used alongside renewable energy sources to cater for the energy need of the school. Renewable energy sources like solar energy and wind energy have been deemed clean, renewable, inexhaustible, unlimited, and environmental friendly. However, all renewable energy sources have drawbacks. Wind and solar sources are dependent on unpredictable factors such as weather and climatic conditions. Due to both sources' complementary nature, some of the weaknesses of one can be overcome with the strengths of the other. This leads us to the hybrid solar-wind power plant concept.

Hybrid power system is the combination of more than one element for the generation of electricity. Uninterrupted power supply is possible to any location by using hybrid energy system. In this energy system, electricity is generated from the combination of solar-wind energy sources. This combination is a reliable source of energy as the fluctuation that may arise as a result of the drawback of one source will not prevent the other from functioning.

It is possible to power some of the activities using this system while the rest will be powered by the national grid. In this case, the hybrid system can be designed to cater for the energy required for lighting and ventilation alone. By so doing, the energy consumed using the national grid will reduce drastically. This paper focuses on the generation of a sustainable electrical energy with affordable cost.

## SOLAR ENERGY

Solar energy is the radiant energy emitted by the Sun. It is abundantly available, renewable, inexhaustible and does not pollute the environment. In Nigeria, there is abundant sunshine all year round which makes the production of solar electricity a possibility. Below is the solar radiation map of Nigeria.

## WIND ENERGY

Wind is the movement of air masses. Wind turbines convert the kinetic energy in the wind into mechanical

power which can be converted into electricity to power homes. Below is the wind map of Nigeria.

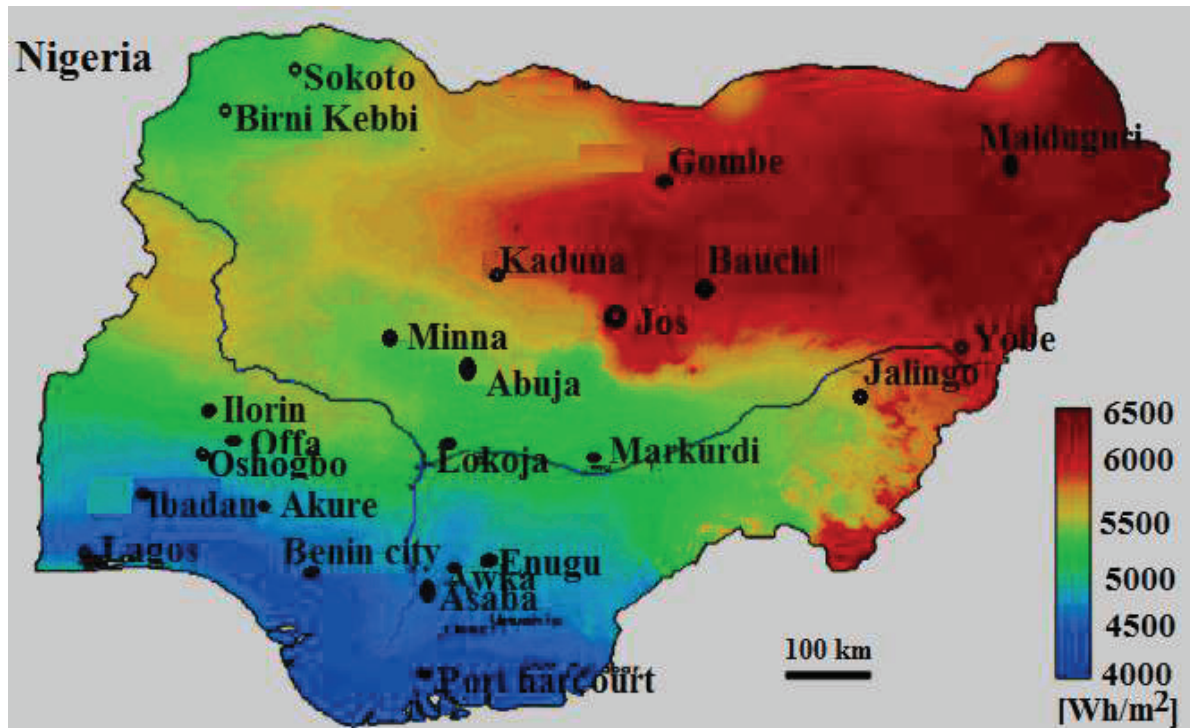


Plate 1: Solar radiation map of Nigeria.

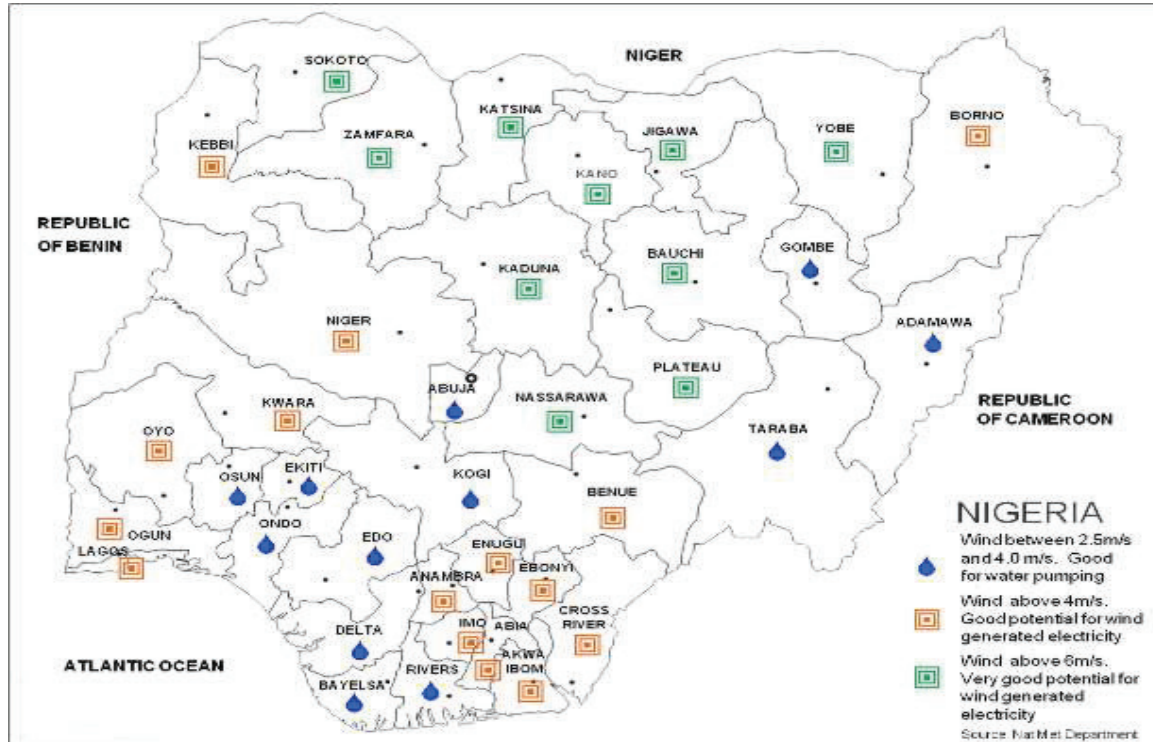


Plate 2: Wind map of Nigeria

### HYBRID SOLAR-WIND SYSTEM

Hybrid power generation system (HPGS) is a power generating system that combines two or more modes of

electricity generation together, usually using renewable technologies such as Solar Photovoltaic (PV) & Wind turbines (Hoque *et al.*, 2012). Wind and solar energy sources are the cheapest available natural resources for renewable energy and they best complement each other. The excess energy from the solar PV and Wind turbine are stored in a Battery Bank through Hybrid Controller. Energy stored in the battery is drawn by electrical loads through the inverter, which converts DC power into AC power. Solar-wind hybrid power system is the best hybrid combination of all renewable energy systems and is suitable for most of the applications. Many countries (with average wind speeds in the range of 4 m/s – 10 m/s) are pursuing the option of WECS, in an effort to minimize their dependence on fossil-based non-renewable fuels (Alim, 2001; Petersen and Habali 1990). Also, in spite of barriers and problems, presently thousands of PV deployments (with monthly average daily solar insolation level in the range of (3 kWh/sq.m – 6 kWh/Sq.m) exist worldwide, providing power to small, remote, grid-independent or stand-alone applications (Bagul *et al.* 1996; Ballarmine and Joe, 1996). Stand-alone commercial WECS (in spite of remarkable technological advancements) do not produce usable energy for considerable portion of time during the year. This is mainly due to relatively high cut-in wind speeds (speed which WECS starts producing usable energy) which range from 3.5 to 4.5 m/s. In order to overcome this downtime, use of hybrid (wind+solar) systems has been recommended in the literature. Although solar energy is environmentally benign, and available in abundance, but stand-alone PV system needs a large storage system, and is an expensive option (Bergey 1993). Stand-alone diesel generator sets, while being relatively inexpensive to purchase, are generally expensive to operate and maintain especially at low load levels (Beyer and Langer 1996). In general, the variations of solar and wind energy generation do not match the time distribution of the demand. Therefore power generation systems dictate the association of battery storage facility to smoothen the time distribution mismatch between the load and solar/wind energy generation and to account for maintenance/outages of the systems (Chadjivassiladis 1987; Dubosi *et al.* 1987). Wind and solar systems are expandable, additional capacity may be added as the need arises. In view of system costs, (wind is  $\approx$  \$1000/kW, PV is  $\approx$  \$4000/kW, battery is  $\approx$  \$170/kW), contribution of PV is small as compared to the share of wind (Elhadidy and Shaahid, 1988). The prospects of derivation of power from hybrid (wind+solar+diesel) sources of energy are proving to be very promising world-wide (Elhadidy and Shaahid 1994; 1999; 2000; El-Rafey and El-Sherbiny 1988).

#### **METEOROLOGICAL ENVIRONMENT**

Climate conditions determine the availability and magnitude of wind and solar energy at a site. Minna, the capital city of Niger state is located in the North Central Zone of Nigeria. It is about 185Km from Abuja, the Federal Capital City of Nigeria. Minna is located at a latitude  $9^{\circ}$  N and longitude  $5^{\circ}$  E. The vegetation in Minna is guinea savannah vegetation. Two distinct seasons are noticed in this region: a very hot and dry season (October to March) and a rainy season (April to September). Monthly mean temperatures reach close to  $42^{\circ}$ C for hot months and in cooler months the mean temperatures could drop to about  $20^{\circ}$ C as compared to the hot months. The relative humidity exhibits a large diurnal cycle on the order of 60% round the year. Typical annual precipitation totals are around 80mm the winds blow from  $270^{\circ}$  to  $360^{\circ}$  direction (north-westerly winds) for most of the time during the year (Nayar *et al.* 1993).

#### **INSTRUMENTATION**

The solar radiation and meteorological monitoring are currently being handled by fourteen solar radiation and six meteorological sensors and are being monitored using an IBM PC based Data Acquisition System (DAS). The instruments meet the requirements for class 1 sensors according to the classifications of the World meteorological Organization (Seeling 1997). The data are collected every minute and integrated over each hour using DAS. The hourly values are transferred, on monthly basis, to the university mainframe computer for further processing. The wind speed measurements are made using Texas cup anemometer. The global solar radiation measurements are made using Eppley (model PSP) pyranometer. The station is continuously supervised to clean the sensors and to minimize instrumental problems. The sensors are regularly calibrated against reference sensors maintained at the station.

#### **WIND/SOLAR DATA AND OPERATIONAL STRATEGY OF SYSTEM**

Wind speeds for Minna are generally higher in the dry season months (October to March) as compared to other months. This clearly reflects that a WECS would produce appreciably more energy during dry season months as compared to the other months. The overall average wind speed is 5.4 m/s. The data also shows that there is considerable variation of monthly average wind output from WECS would be subjected to considerable differences. The wind energy calculations are made by matching the power-wind speed characteristics of commercial wind machines (CWMs) with the long term hourly wind speed data. The characteristics of some CWMs are furnished in ref. ((Yvonne, et al. 2016). Today's best wind machines can achieve an overall efficiency of about 35 percent (Sunny, et al. 2014). Previous study on wind/diesel systems, in order to avoid

undersizing or oversizing of WECS or diesel systems, the data of the years 2006 – 2015 can safely be used for design purposes. However, in this study, the year 2013 has been considered as a representative year for analysis.

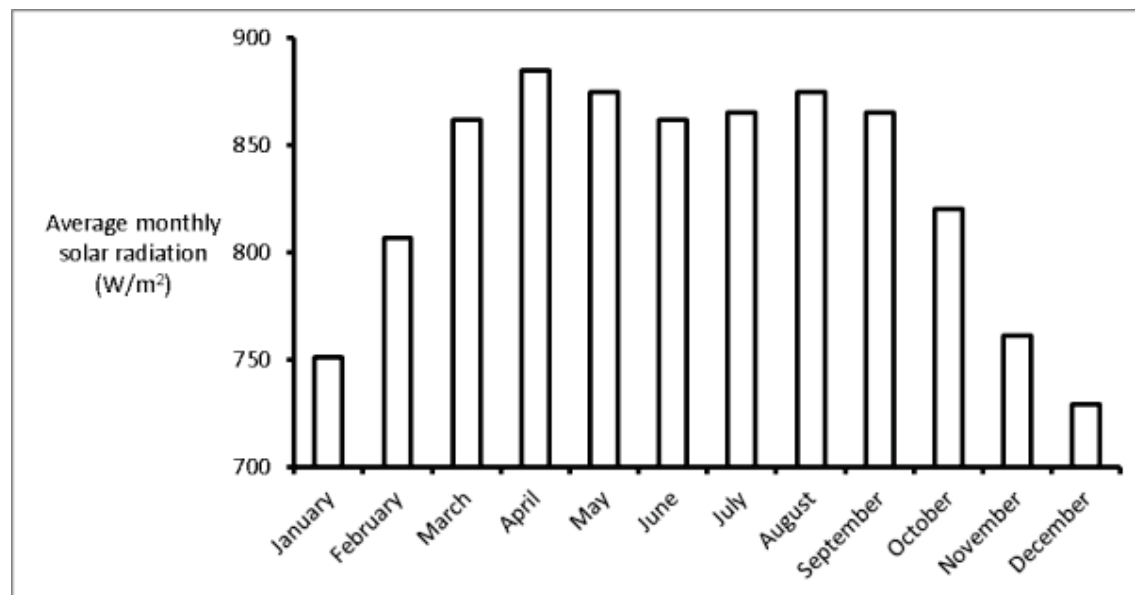


Figure 1.0: Mean monthly variation of solar radiation.

Long term monthly average daily global solar radiation for Minna are also plotted in Fig. 1. The insolation level is high during the summer months (March to September) as compared to other months. The yearly average daily value of the solar radiation is 5.84 kWh/sq.m. Previous study shows that the variation between the years is minimal (Yvonne, *et al.* 2016).

Hence, 2013 data has been used for solar energy calculations. The energy calculations are made by using the hourly solar radiation data and a given PV array area. The commercial PV modules which are composed of many solar cells are integrated to form solar array. The hourly energy generated ( $E$ , kWh) from the PV system is calculated using the equation (Shaahid and Elhadidy, 1994).

$$E = A \eta_m P_f \eta_{pc} I$$

Where  $A$  is the array area in sq.m,  $\eta_m$  is module reference efficiency (0.111),  $P_f$  is the packing factor (0.9),  $\eta_{pc}$  is the power conditioning efficiency (0.86), and  $I$  is the hourly insolation (kWh/sq.m). Today's best PV systems can achieve an overall efficiency of about 32 percent (Annual report, 2015/16, Solar Africa, 2016). These lower efficiency values may not make this alternative (PV systems) attractive at the moment. However it may be mentioned that technological breakthroughs, may change the scenario (Chadjivassiladis 1987). In general, the cut-in wind speed of most of the CWMs is 4 m/s (Mahmoud, 1990). Earlier studies at Minna indicate that the wind speeds are less than 4 m/s for about 35% of the time during the year. This implies that a stand-alone WECS installed at Minna will be diesel back-up or a large energy storage system may be needed to meet the required load. The capacity of the storage system can be minimized by using PV system alone with the WECS.

The mode of operation of the present hybrid systems (in the simulation) is as follows: in normal operation the WECS+PV feed the load demand. The excess energy (the energy above the average daily demand) from the WECS+PV is stored in the battery until full capacity of the storage system is reach (i.e. until the battery gets fully charged) the main purpose of introducing battery storage is to import/export energy depending upon the situation. In the event, that the output from WECS+PV exceeds the load demand and the battery's state of charge is maximum, then the excess energy is drained away or fed to some dump load. A diesel back-up system is operated at times when WEC+PV fail to satisfy the load and when the battery storage is depleted.

## RESULTS AND DISCUSSION

All important driving consideration of any power generating system is load which is application-dependent. As a case study and as a representation of the campus the measured annual average energy consumption (based on 5 years of data) of a typical air-conditioned lecture theatre (located in the university campus, Gidan Kwanu, Minna, floor area = 945 sq.m,) has been considered as predefined yearly load (620,000 kWh) in the present study

Traca *et al.* (1983) this load could also be a representation of remotely located commercial building which do not have access to the utility grid (even today, there are many communities living/dwelling in small pockets in remote locations of Nigeria). The projected monthly average daily load profile seems to peak during March to May.

The hybrid systems stimulated in the present investigation consist of different combinations of 10 kW WECS, PV panels supplemented with battery storage system and grid back-up. The study explores a suitable mix of inter-dependent dominant/key parameter such as: wind farm capacity, PV array area, and battery storage to match the pre-defined load while minimizing the operation of grid-back-up. In view of economic considerations and for optimum use of battery-storage/diesel, battery storage is assumed to be equivalent to three days of maximum monthly average daily demand (Nayar *et al.* 1991).

For a given rated capacity of WECS (ten 10 kW), battery storage (equivalent to about 3 days of maximum monthly average daily demand), the variation of monthly average daily hybrid energy with variation in PV array area, it is clear that a combination of ten 10 kW and even 200 sq.m. of PV, do not satisfy the load requirements. This indicates that significant amount of energy need to be supplied from the grid to meet the load. Extensive use of the diesel system may result in frequent start/stop cycles for the diesel generator (frequent starts/stops promote wear). Looking at the load requirements, one may be tempted to conclude that a very huge PV deployment (together with ten 10 kW WECS) is necessary to fulfil the load distribution for appreciable portion of the year. An increase in the PV panels' array area considerably elevates the overall cost of the hybrid system (cost of WECS is  $\approx 1000$  /kW, where as of PV is  $\approx 4000$  /kW). In view of high cost of PV, contribution of PV is generally small as compared to the share of wind (Elhadidy and Shaahid, 1988). Therefore, in-order to minimize on the contribution of PV, simulation has been made by increasing the number of wind machines. The variation of monthly average daily wind energy for different number of 10 kW wind machines is shown in Figure 3. As penetration of WECS increases, operational months/hours of diesel system (to meet the load) decrease. For given thirty 10 kW WECS, battery storage (equivalent to about 3 days of maximum monthly average daily demand), the load requirement is satisfied for about 8 to 9 months. For this scenario, invariably the diesel backup system has to be operated during August to October to match the load requirement.

The impact of variation/addition of PV array area together with WECS (for pre-defined battery storage of three days) on the ratio of diesel energy (De) generation to load (L) and on number of hours of operation of diesel system are shown in Figures 4 and 5. Examination of Fig. 4 yields some useful information. The diesel energy to be generated without PV is slightly high. Use of PV results in slight reduction of diesel energy to be generated (along with WECS+battery storage to satisfy the pre-defined load). With ten 10 kW WECS and zero-PV, about 61% of the load requirement has to be provided from diesel system. However, with addition of 150 sq.m PV to ten kW WECS, the diesel system has to provide 57% of the load demand (Fig. 4), also the number of hours of operation of the diesel system get reduced by about 4% (Fig. 5). Similarly with thirty 10 kW WECS and zero-PV, about 14% of the load requirement has to be provided from diesel system. However, with addition of 150 sq.m PV to thirty 10 kW WECS, the diesel system has to provide 11% of the load demand (Fig. 4), also the number of hours of operation of the diesel system get reduced by about 12% (Fig. 5). Decrease in diesel energy generation is not much for PV greater than 150 sq.m. However, it should be emphasized, that a trade-off has to be established/recognized between PV array area and diesel energy generation. In view of high system cost of PV, it would be judicious to minimize the penetration of PV. So, as a conservative estimate, about 150 sq.m PV has been considered in the present simulation.

As a final remark (to assess the inclusion/significance of battery storage), and for a more realistic evaluation of the decrease in diesel energy generation, the hybrid system (thirty 10 kW + 150 sq.m + three days of battery storage at the beginning of 1986 + diesel) has been simulated for the period 1986 – 1997. Similar simulation for the same period had also been made but without any battery storage (i.e. for the configuration wind+pv+diesel). The diesel energy generation for these scenarios has been plotted in Fig. 6. It is evident from Fig. 6, that the diesel energy generation is considerably less with inclusion of battery storage. It has been found that, on an average about 17% of the yearly load is supplied from the diesel system with the presence of three days of battery storage. However, with elimination of battery storage, about 38% of the yearly load needs to be provided by diesel system.

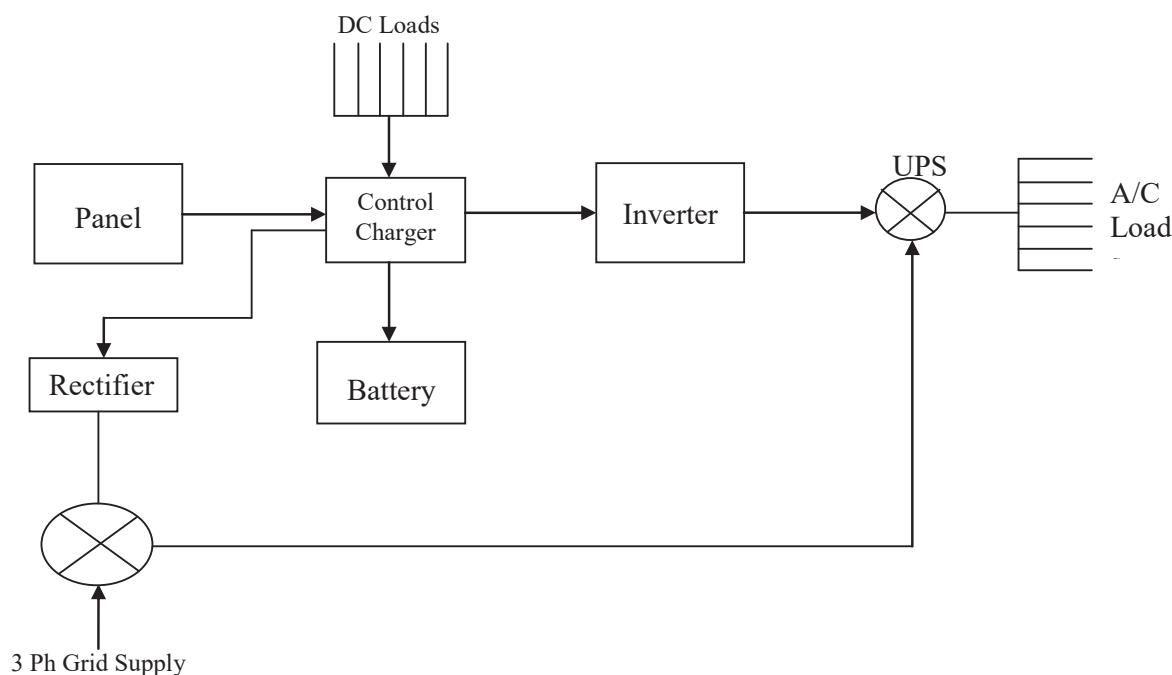


Fig.2.0 Block diagram of the Hybrid energy system.

The block diagram of the hybrid power generation system using wind, solar with grid back-up must have the following components.

1. Solar panel
2. Wind turbine
3. Charge controller
4. Battery bank
5. Inverter
6. Rectifier

### 1. Solar panel

Solar panel converts solar radiant energy to electrical energy. The physics of PV cell is very similar to that of the classical diode with a PN junction formed by semiconductor material. When the junction absorbs light, the energy of the absorbed photon is transferred to the electron-proton system of the material, creating charge carriers that are separated at the junction. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field, and flow as electric current through an external circuit. Solar array or panel is a group of a several modules electrically connected in series and parallel combination to generate the required current and voltage. Solar panels are the medium for converting solar power into the electrical power.

### 2. Wind turbine

Wind turbine is an energy conversion system extracts kinetic energy from the wind through the rotation of the blades of the wind turbine. They are basically of two types (ie vertical and horizontal types). Their power generating ability increases as the wind speed increases. The power generated from the wind is not continuous as it fluctuates. In order to obtain a continuous flow of power to the load, the turbine must be able to store power in the battery bank when its active and supply same to the load when inactive.

### 3. Charge controller

The basic function of the charge controller is to control the source which is either active or inactive. It has to simultaneously charge the battery bank and direct power to the load. The controller has over-charge protection, short-circuit protection, pole confusion protection and automatic dump load function. It also serves the role of varying the power as per the load demand. And when power is not being generated it should direct and extract power from the battery and send it to the load.

#### 4. Battery Bank

The battery bank rating/size to be chosen is dependant on the load requirements so as to be able to meet the requirements of the load it was chosen to serve. Before a given size is chosen, the information/data needed include.

1. Total daily use in watt-hour (Wh).
2. Total back up time of the battery.

The battery cells should be connected in series so that we can get bigger battery bank size.

#### 5. Inverter

The inverter to be chosen must be one with rating greater than the designed rating and in this regard the pure sine wave inverter is recommended so as to prolong the lifespan of the inverter. Inverters are needed to convert DC power into AC power. All the electrical devices in the university are AC loads and as such there is the need to convert the generated DC power. The input voltage, output voltage, the frequency, and the overall power handling depends on the design of the specific device or the circuitry. The inverter does not produce any power of itself, but only convert from one type to another. The power is provided by the DC source.

#### 6. Rectifier

Rectifiers are needed to convert AC power into DC power. Since grid power are not always available in the Network, There is the need to convert this supply when it is available to DC for store in the battery bank, so that at outage the power from the battery bank will be made to supply the load requirements for as long as the outage will last. The input voltage, output voltage, the frequency, and the overall power handling depends also on the design of the specific device or the circuitry.

#### CONCLUSION

The present analysis indicates that FUT, Minna is a viable location for the installation of WECS and PV systems (to meet the energy needs of the higher institution), but large stand-alone WECS or PV systems will be required to manage the peak load. This offset in power can be taken care by integrating WECS with PV battery storage, and grid back-up systems.

Power can be utilize close to where it is being generated so that it will reduce the transmission losses and cost. Cost reduction can also be achieved if the productions of the equipment are done in the country. Conventional energy resources are highly safe for the environment as they don't produce any emission or harmful waste product like conventional energy resources. It is cost effective solution for generation. It only need initial investment. It has also long life span. Overall it can be said to be good, reliable and affordable solution for electricity generation. The study shows that a hybrid system configuration consisting of thirty 10 kW WECS together with 150 sq.m PV deployment and three days of battery storage are what is needed to satisfy the load for all year round.

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