# Promoting High Photovoltaic Penetration in Academic Environment: A Case Study of FUT Minna

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***Abstract*—The epileptic electricity supply from the Abuja Electricity company of Nigeria (AEDC) has resulted in extensive demand for alternative sources of electricity generation. Solar renewable energy is one area of focus among the renewable energy resources that can be harnessed to address power crisis in most institutions in Nigeria. As we all know renewable energy is the other of the day as it can complement the non-renewable sources of energy by enhancing smooth research activities in an academic environment. In this research work, an inverter thatwas solar powered was designed for some offices in Electrical and Electronics Engineering Department of Federal University of Technology (FUT) Minna. The load profile, the sizing of the photovoltaic (PV) cell, charge controller, inverter and the number of batteries expected to be used were designed. The result shows that the total load profile, total energy demand per day, the nominal rated PV module output, the total ampere-hour capacity of the batteries, the maximum short circuit current of the array and the power of the inverters were calculated respectively as 3716 watt-hours, 742watts, 1200 amp-hours, 50A and 5kVA. The performance of the system gives a stable output voltage and current that was sufficient enough to charge the batteries and power the equipment.**

***Keywords*—academics; battery; charge controller; high PV penetration; inverter; load profile**

## I. INTRODUCTION

The economic development of any nation depends on efficient electricity supply which acts as an indispensable infrastructural facility. Accessibility and efficient electricity supply will not only boost the investment of a nation, but also facilitate the creation of a viable economic environment which influences the decisions of potential investors (Galvin and Kurt, 2010). In Nigeria, the main sources of power for our domestic consumption, industrial development, Centre of learning and medical centershas beenepilepticsince decade ago (Sambo *et al.* 2012 and Sule, 2010). Various attempts to address power supply by various governments have proved abortive because holistic approach is not used to address the teaming challenges of the power sector. Hence, individuals and organizations have resorted to running diesel generators for day to day activities. Even academic environments have become unhealthy learning environment characterizedwith both noise and air pollution from generators aside the huge amount of money spent on fossil fuel (Sambo *et al.* 2012 and Sule, 2010). Businesses and learning activities are in state of comatose and not functioning at their very best due to the epileptic power supply. To address this problem, an alternative electricity power source free from environmental pollution is very vital. One of the alternative ways of providing electricity is through solar renewable energy. Solar renewable energy is totally free of pollution as compared with the generation of electricity from fossil fuel (Emodi, 2016). The design and implementation of this solar renewable energy varies in cost and wants of each individual and communities. The design and implementation of a solar powered inverter in Electrical Department of Federal University of Technology (FUT) Minna is a case study in this work.

## II. SOLAR ENERGY AN ALTERNATIVE TO ENERGY SOURCE IN NIGERIA

The location of Nigeria within the equator (i.e. latitude 4$^o$ and 14$^o$N & longitude 3$^o$ and 14$^o$ E) has made high sunshine available for the country (Aniefiok *et al*. 2013 &Vincent and Yusuf, 2014). The annual expected value of solar radiation ranges from 3.5 kWh/m$^2$/day in the coastal regions to about 7 kWh/m$^2$/day along the semi-arid areas in the Northern border region. The solar radiation received by the country on a norm per day amount to about 19.8 MJ/m$^2$/day and the expected hour of sunshine throughout the day is estimated to be 6hrs per day. Though the radiation of the sun is fairly well distributed across the country as north west region has an average of 3.55kWh/m$^2$/day in the month of January whereas the south-south region has 3.4kWh/m$^2$/day in the month of August (Sambo *et al.* 2012).

At a considerable moderate intensity of radiation of 5KWh/m$^2$/day and conversion efficiency, 1% of solar radiation energy equivalent to 192,000MW capacity of energy generated from gas power plant for 24hours, can be generated in Nigeria per day (Mshelia, 2012 and Aniefiok *et al.* 2013). This form of energy (Solar energy) can be deployed to remote villages, academic institutions and centres where the national grid does not cover or is ineffective for critical loads. For future energy mix, the solar energy can be cooperated in to the national power distribution grid by implementing a hybrid control method for network voltage regulation with high photovoltaic penetration to solve for the inadequate electricity supply in Nigeria.

The design and implementation of high photovoltaic penetration will vary based on priorities and cost considerations. However, various designs from previous work have been studied. For example, the design of PV system for residential house in Jordan was proposed by Al-Salaymeh *et al.,* 2010. The research work focused on the utilization feasibility of the project based on economy calculations and energy generated. The result indicates that the payback period for standalone PV system was high due to the cost of PV systems as compared with grid connected PV systems. Similar research work was also conducted by Oko *et al.,* 2012 and Guda, 2015, the same result was highlighted as Al-Salaymeh *et al.,* 2010except that Oko *et al.,* 2012 employed an automated MS Excel worksheet for their economy and design analysis.

The research of Li, *et al.,* 2012 collated and analysed data from grid connected PV system installed in an institutional building in Hong Kong for two years. The research revealed that high cost of electricity and feed-in tariff scheme can shorten the payback period of grid-connected PV systems to a tenable period less than the life span of the installed PV system. Moreover, a clue need to be taken from Germany, where PV system contribute about 27.6TWhr while wind produces 46TWhr in 2012 (Bayar, 2013). The Germans have successfully led the world in number of PV system installations (Tyagi *et al.,* 2013). The PV alone account for 47% of energy mix while 7.3% was from wind, 5.8% from biomass and 3.3% from hydro power(Bayar, 2013). This has greatly help Germans to achieve a sustainable energy demand. Nigeria also has a lot of this rich renewable energy across the different geographical zones which can be harnessed to create an energy mix for the country. The academic institutions need to be pace setters in making this dream a reality through researches, innovations and formation of sustainable policy for the management and operation of the energy mix production. The estimated energy profile of the country is listed in Table 1.

Table 1: Energy Reserve in Nigeria(Ekechukwu, &Akuru 2013)

| Energy | Reserves |
|---|---|
| Oil | 36.5billion barrels |
| Natural Gas | 187.44 trillion SCF |
| Bitumen & Tar sands | 30billion barrels of oil equiv. |
| Solar radiation | 3.5-7.0 KWH/m$^2$/day |
| Wind | 2-4m/s @ 10m height |
| Nuclear | Not readily available |
| Coal & Lignite | Over 4 billion tonnes |

## III. METHODOLOGY

The solar incident rays are collated by the PV array. The rays are converted to DC current. The current flows through the charge controller to the load via an inverter. The Inverter converts the DC power supplied by battery bank into AC power of 230V and 50 Hz. This power is then fed to the electrical load. The circuit breaker is designed to provide additional power supply from the national grid that would charge the battery via the inverter and also to prevent surges that occur due to fluctuation in power system. This was implemented to provide an option for charging the batteries during the wet season. There is also a provision to use grid power for the offices in case of additional heavy loads for short duration. The methodology adopted comprises of five (5) stages namely; the solar radiation and photovoltaic panel (PV), charge controller, batteries, inverter and the load. Each of these stages was chosen based on the survey and computations carried out on the PV and load sizing. Figure 1 depicts the block diagram of the solar renewable energy.

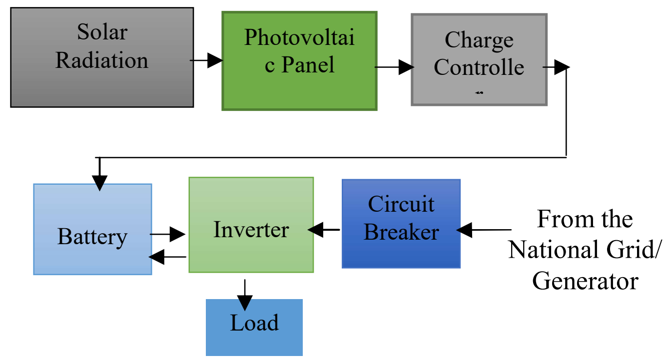


Figure 1: Block Diagram of the designed and Implemented Solar Renewable Energy Adopted

## IV. LOAD PROFILE

The load profile of two offices was surveyed and recorded on a spread sheet as indicated in Table 2. The power rating (in wattage) of all the appliances to be powered was determined along with the hours of operation per day. The loads include; two Hp desktop computer, two Laptop computers, two ceiling fans, two printers, and four energy saving bulbs whose usage are determined according to time of need in order to implement extensive voltage management and avoid energy wastage.

Table 2: Load Estimate Worksheet

| Individual Loads | Qty | Rate Wattage ( $r_w$ ) | Est. hours of usage/day($H_{est}$) |
|---|---|---|---|
| Ceiling Fan | 2 | 160 | 4 |
| Printer | 2 | 360 | 2 |
| Desktop Computer | 2 | 65 | 4 |
| Laptop Computer | 2 | 60 | 4 |
| Energy Saving Bulb | 4 | 110 | 4 |

To obtain the total energy demand per day $E_{td}$ ,The total energy demand per day $E_{td}$ was computed as the summation of energy hour per day $E_d$ as expressed in (1)

$$E_{td} = \sum_{n=1}^{N} E_{nd} \qquad (1)$$

Where $n$ is the number of computed individual energy to be powered.

where $E_d$ is obtained as the product of adjusted wattage of each of the appliances $A_{jw}$ and estimated hours of usage/day $H_{est.}$ as expressed in (2)

$$E_d = A_{jw} * H_{est.} \tag{2}$$

$A_{jw}$ is determined as the ratio of rated wattage $r_w$ with inverter efficiency $A_e$ as expressed in (3).

$$A_{jw} = \frac{r_w}{A_e} \tag{3}$$

The total ampere-hour demand per day $I_{amp-hourd}$ is obtained as the ratio of total energy demand per day $E_{td}$ by the battery bus voltage $V_b$ as expressed in (4).

$$I_{amp-hourd} = \frac{E_{td}}{V_b} \tag{4}$$

The maximum AC power requirement $P_{\max.req}$ was obtained by summing the entire appliance rated wattage $r_w$ together as expressed in (5).

$$P_{\max.req} = \sum_{n=1}^{N} r_w \tag{5}$$

The array is sized to meet the daily average electricity demand during the worst installation of the year. The required array output per day $P_{AD}$ can be calculated using (6).

$$P_{AD} = \frac{E_{td}}{B_e} \tag{6}$$

$P_{AD}$ = 4372 watts-hour

where $B_e$ is the battery efficiency.

## V. DESIGN OF BATTERY BANK SIZE

The recommended battery used for the solar PV power system is a Deep cycle battery. Deep cycle battery is specifically designed to store sufficient energy to operate loads at any given circumstance be it night, cloudy, rainy and dusty days. When the battery is discharge to lower energy level, it can still be recharge over and over again for years. The battery was kept in a location designed to minimize a fluctuation of battery temperature of 25°C.

The total amount of rated battery capacity required depends on the following factors (Jim Dunlop, 2012 and Tutorial work sheet on Stand Alone PV System Sizing Worksheet, 2015);

1. Desired Days of storage to meet system loads with no recharge from PV $D_{ds}$ (autonomy).
2. Maximum allowable depth of discharge $D_{od}$
3. Temperature and discharge rates
4. System losses and efficiencies

To determine the size of the battery bank, some vital information is necessary. The desired battery storage days $D_{ds}$ required was estimated and noted. The depth of discharge $D_{od}$ allowable limit was observed and noted as specified by the manufacturer. The required capacity of the battery $C_{req}$ was determined as the rate of the product of the total ampere-hour demand per day $I_{amp-hourd}$ and the desired days of battery storage $D_{ds}$ by the depth of discharge $D_{od}$ allowable limit as expressed in (7).

$$C_{req} = \frac{I_{amp-hourd} * D_{ds}}{D_{od}} \tag{7}$$

$C_{req}$ = 7 * 155/0.8 = 1356.25 amp-hours.

The number of batteries both in parallel and in series can be determined using (16) and (17). Thus, the number of battery in parallel $N_{bp}$ was expressed as the ratio of required battery capacity $C_{req}$ by the ampere-hour of the selected battery $I^{sb}_{amp-hr}$ as in (8).

$$N_{bp} = \frac{C_{req}}{I^{sb}_{amp-hr}} \tag{8}$$

$N_{bp}$ = 1356.25 / 200 = 6

The number of battery in series $N_{bs}$ was also expressed as the ratio of the battery bus voltage $V_b$ by the selected battery cell voltage $V_{sc}$ (as observed from the manufacturer's information sheet). Thus, the number of batteries in series is;

$$N_{bs} = \frac{V_b}{V_{sc}} \tag{9}$$

$N_{bs}$ = 24 / 12 = 2.

The total number of batteries $N_{bT}$ was calculated as the product of the number of batteries in series $N_{bs}$ and the number of batteries in parallel $N_{bp}$ as expressed in (18).

$$N_{bT} = N_{bp} * N_{bs} \tag{10}$$

$N_{bT} = 2 * 6 = 12.$

The parameters used for the design specifications of the system is presented in Table 3.

Table 3: Design Specifications

| Parameters Considered | Value |
|---|---|
| The inverter efficiency $A_e$ | 0.85 |
| The Battery bus voltage $V_b$ | 24V |
| Total energy demand per day $E_{td}$ | 3716 watt-hours |
| Total Amp-hour demand per day $I_{amp-hourd}$ | 155 amp-hrs |
| Maximum AC power requirement $P_{\max.req}$ | 850watts |
| Maximum DC power requirement $P_{\max.req}$ | 999watts |
| The battery efficiency used $B_e$ | 0.85 |
| The required array output power per day $P_{AD}$ | 4372 watt-hours |
| The Max. Power voltage of the selected PV module $V_{pvs}$ | 17.8V |
| The nominal output power $P_o$ of the selected PV module at 1000watts/m$^2$ | 53watts |
| Peak sun hour at optimum tilt in Minna at Latitude 87.7$^o$ in the month of April | 7.4hours |
| The de-rating factor (DF) for hot climate and critical applications | 0.8 |
| DF for moderate climate and non-critical applications | 0.9 |
| The battery storage room temperature. | 25$^o$C |
| The required number of days of storage desired $D_{ds}$ (autonomy) | 7days |
| The depth of discharge $D_{od}$ allowable limit | 0.8 |
| The ampere-hour of the selected battery $I_{amp-hr}^{sb}$ | 200 amp-hours |
| The short circuit current of the selected module $I_{sc}^{M}$ | 5.4A |

## VI. Result and Discussion

The result of load sizing sheet is presented here along with system test carryout before and after complete system setup. The results obtained from load sizing sheet is tabulated in Table 4 while the test result of the complete system setup is presented in Table 5. The complete system setup result was obtained from the solar charge controller as shown in Table 5 upon installation and connection to the charge controller.

Table 4: Result of Load Sizing Sheet

| Loads | **Qty** | $r_w$ | **Tt** $r_w$ | $A_{jw}$ | $H_e$ | $E_d$ |
|---|---|---|---|---|---|---|
| Ceiling Fan | 2 | 160 | 360 | 423 | 4 | 1692 |
| Printer | 2 | 60 | 120 | 141 | 2 | 282 |
| Desktop Computer | 2 | 65 | 130 | 153 | 4 | 612 |
| Laptop Computer | 2 | 60 | 120 | 141 | 4 | 565 |

Table 5:Test Result of the Complete System Setup upon Installation

| System Readings | Voltage (Volts) | Current (Ampere) |
|---|---|---|
| Solar Panel (upon installation) | 32.1 | 0.03 |
| Solar panel (in use) | 30.1 | 0.07 |
| Battery (before Charging) | 25.7 | |
| Battery (After Charging) | 26.7 | |
| Inverter (upon installation) | 226 | |
| Inverter (In use) | 216 | |
| Charge Controller | 24 | 50 |

The system was observed for any failure in either component, section, stage or the whole system setup after the connection of loads as listed on the load profile. But no system failure or fault was recorded.

## VII. Discussion of Results

The inverter efficiency is used as a power adjustment factor so as to account for the changes in current from DC to AC. The inverter's efficiency selected for this project was 0.85 in other to achieve better performance of the system. The nominal DC operating voltage of the system is 24 V which corresponds to the required DC input voltage for the inverter. The design output voltage of the inverter selected for this project was 230 V as compared to the output voltage obtained when the inverter was in use and upon installation. It should be noted that the actual power consumption of some load varies. Therefore, the rated wattage of those appliances should be considered. The adjusted wattage compensates for the inverter inefficiency and also illustrates the actual wattage consumed from the battery bank. The amount of energy each appliance requires per day was determined using (2), from which the total energy required was obtained.

The design total ampere-hour demand/day of the storage sub-system of the battery was 155 amp-hours as against the calculated value of 139.2 amp-hours when the value of the battery (in use) was computed independent of the photovoltaic array. Therefore, the tolerance in the designed and measured value of the battery capacity $C_{req}$ was obtained to be 138.43 amp-hours. This value proofs the efficiency of our system. The maximum AC power requirement of the system was obtained as 850watts excluding the surge requirement. This value represents maximum continuous AC power output requirement ofthe inverter if all the loads were to operate simultaneously. The DC maximum power requirement was obtained to determine wire sizes, fuses and disconnect requirement to eliminate the possibility of loads operating simultaneously.

The PV array (AP-PM250/3 Polycrystalline solar panels) was sized to determine the available average daily demand of electricity since the insulation striking the PV array system varies throughout the year. The insulation is a function of tilt angle and azimuth orientation of the array. The energy produced by the designed PV array is 4372 watt-hours with respect to the loads. This energy was supposed to cover for the inadequacies of the power generating company in order to support the power requirement in the academic environment. The system can provide reliable option for generating electricity for the comfort of academic activities for seven days of autonomy, for the battery bank to operate loads during any black out or shortage of generation of electricity from the power generating companies. The beauty of the system is that; it does not create any noise during its operation as compared with the fossil fuel generating set used as an alternation. The system provides a clean environment void of air pollution.

The inverter size used was 5 KVA as calculated from above. The value was chosen to provide 125% of the maximum connected loads to run PV power system simultaneously at any moment.

Figure 4 shows that there is a sharp decrease in energy demand curve as the total rated wattage of one of the appliances (ceiling fan) exceed the threshold value of required energy per day. Hence the autonomy days of battery storage will decrease as more loads are added to the system it is also important to know that the size of the PV array output power, battery capacity in kilowatt-hours, charge controller maximum short circuit current of the array size and the power of the inverter were all calculated as 4372 watt-hours, 29 KW-hours, 50A and 5KVA respectively. This in turn implies that, if the loads were implemented according to the design, there will be steady usage of energy that will last for the duration of the storage.

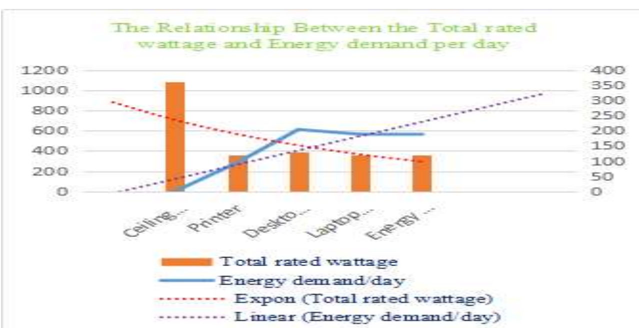


Figure 4: The relationship between the Total rated wattage and Energy demand per day

## VIII. CONCLUSION

High photovoltaic penetration in an academic environment is very vital considering the in-adequacies of electricity supply in many academic institutions in Nigeria. The design and implementation of this PV system will promote excellent academic research especially in running simulations that require uninterruptible power supply. The PV system was designed for offices with a total load of 3400 wattages. The evaluation of the performance of the system indicates that the output voltage was high enough to charge the batteries connected to it via a charge controller.

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