

Proposing Utilization of Photovoltaic (PV) Source into Power Distribution Network Using University of Port Harcourt as A Case Study

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Abstract—Relying on Power Holding Company of Nigeria (PHCN) for power distribution in University of Port Harcourt (Uniport) has not really helped in satisfying the overall power requirements, considering the fact that alternative renewable sources of power exist in its environs and tapping into it will help ameliorate these challenges. This work involves proposing utilization of photovoltaic (PV) source into power distribution using Uniport as a case study. Solar radiation profile was obtained as latitude 40°48.1' N and longitude 6°55.9' E with average clearance index of 4.37 kWh/m²/day. Solar altitude, angle of incidence, azimuth, global solar value in kW/m² were recorded as well as models for PV, battery bank and converter components formulated. Moreso, sensitivity and optimization studies including systems architecture, load and PV output for the solar network was carried out. User specified variables such as appliance peak power, total energy produced/consumed per day, total amount to be invested as well as lifespan of solar generating plant. Overall cost of solar PV amounted to about Two billion, seven hundred and forty million, six hundred thousand naira (N2, 740,600,000) for a twenty-four (24) hour power supply. Operation and maintenance cost for a projection of twenty-five (25) years (OPEX was also determined to be Ninety-six million, five hundred thousand naira (N96, 500,000:00). At 25 years, amount that must have been spent on bills to PHEDC for consuming maximum of ten (10) hours of electrical power is about Seven billion, eight hundred and sixteen million, three hundred and thirty-one thousand, one hundred naira (N 7,816,331,100:00). This implies that if Uniport decides to jettison PHEDC for the next twenty-five (25) years and want to be sure of a guaranteed 24 hours' power supply, it would have saved a total of Five billion, and seventy-five million, seven hundred and thirty-one thousand, one hundred naira (N5,075,731,100:00). Furthermore, generated power by this design is 7500MWhr but the load consumed in a year is 7100MWhr/year given an excess used power of 400MWhr/year. This excess power can be sold thereby creating extra profit for the institution.

Keywords— *phcn, phedc, photovoltaic, uniport, renewable energy*

I. INTRODUCTION

The development of solar system started in the late eighteenth century. However due to the anticipation that coal reserve will soon run dry, the need to search for alternative source became imperative [1]–[3]. This development of solar technology [4]–[6] however stagnated in the early twentieth century as a result of increase in supply, cheapness, and the utilization of coal crude oil. In recent times, as concerns for global warming and greenhouse gas effect increases, Heads

of Government as well as parastatals are now seeking alternatives and have turned their attention once more to this renewable energy source [7]–[9].

In the early 1840's it was discovered that electricity is generated when light falls on selected treated substances. This concept is based on ideas from quantum theory. Light is made up of units of whose energy depends only upon the frequency, or color of the light. The energy of visible photons will excite electrons which are bound together, up to higher energy levels where they are more free to move. An example is the photoelectric effect experiment carried out by Einstein, in which electrons escape completely from a metal through energy provided by blue or ultraviolet (UV) light. When matter receives light, electrons are excited thus resulting to photons given up their energy, which quickly relax back to ground state. These electrons are pulled out or collected away before they get to relax state and are fed to an external circuit by a (PV) device [10].

The extra energy of the excited electrons generates a potential difference, or electro-motive force (Emf) which drives the electrons through a load in the external circuit to do electrical work. Solar Power could be defined as the conversion of sun rays into electrical energy directly or indirectly through the use of PV or concentrated solar power (CSP). A CSP system is the use of lenses and tracking systems to capture vast area of the suns ray and target this light to a particular source. A PV device converts light into electric current using photoelectric effect.

The first commercial concentrated solar power plant, a 354 MW located in the United States of America was developed in the 1980s, and it is one of the largest solar power plant in the world. Other CSP plants include 150 megawatts and 100 megawatt situated in Spain. 97 megawatts solar power in Canada is the world's largest photovoltaic plant. In 1958, The Vanguard I satellite applied solar cells as a back-up power source to its mission. The back-up power enabled the satellites to transmit information for a longer period after its chemical battery was exhausted. The operational success of solar cells on this mission was later applied in many other Soviet and American satellites. PV had become the established source of power for them and went on to become an essential part in the success of early commercial satellites.



II. LITERATURE REVIEW

If 1% or 4.5×10^{13} kWhr of the 45×10^{16} kWhr per annum of the energy that is used by the earth to raise water from the oceans through the process known as evaporation is utilized, continuous yield of 5.137×10^{10} kW per annum is derived which is enough to supply 5.137kW to 10 billion people, which is the energy used by an average civilized nation.

Mathematically, Let $x = 45 \times 10^{16}$ kWhr, $y = 1\%$ of x , $a = 8760$ (24×365 days) hours, $b = y/a$, then; $y = 45 \times 10^{13}$ kWhr
 $\therefore b = 5.137 \times 10^{10}$ KW, Where $x =$ sun light (heat) used to raise the water from earth surface, $y = 1\%$ of x , $a =$ number of hours in a year, $b =$ power obtained based on yearly production of electricity in year 2018 and averaged around 155,505TWhr; this is less than the energy earth receives in one hour from the sun.

Fossil fuel accounted for about 68.4% of total energy consumption, while energy from renewable is 16.7% and nuclear power 10.9%. The major fossil fuels used for electricity generation were mainly coal and natural gas, Oil accounted for only 5% Points. Hydroelectric power accounted for about 92% points, while Wind energy produced 6% and Geothermal 2% points of the total renewable power produced. Solar was infinitesimal [11]. The unpredictable cost of conventional fossil fuel is making supply-demand of electricity product unrealistic especially in remote regions. Generators which are mostly on standby are used and run during certain hours in other to cut down on the cost of fuel and will be difficult to be applied for commercial purposes since it will increase the cost of energy per watt purchased. The uses of renewable energy resources, such as PV system and wind power have an important role to play in order to save the situation. Top Ten (10) Renewable energy sources (RES) are;

- a. Tidal Power: It is a form of hydro power, though not yet widely used in electricity generation. Tides are more predictable than wind and solar energies. This is harnessed by using tidal stream generators which make use of kinetic energy of moving water to power turbines under water, thereby tapping into the energy of the tidal waves, so as to get the rotational force necessary to generate electricity.
- b. Wave power: this involves the capture of ocean surface waves to do useful work, like electricity generation with the aid of a wave energy converter.
- c. Solar power: this involves the use of solar cells to transform the radiation from the sun or daylight into electrical energy.
- d. Wind power: this involves the harnessing of the power of wind to generate electricity, with the aid of wind turbines installed in the path of the wind.
- e. Hydroelectricity: this involves harnessing the power of a sufficient body of water to generate electricity, with the aid of turbines.
- f. Radiant energy: This is the energy of electromagnetic radiation. The quantity of radiant energy can be calculated by integrating radiant flux with respect to time. This radiation may be visible or invisible.
- g. Geothermal power: harnessing the power of natural geothermal sites to generate electricity, by channeling the steam at high pressure to turn turbines.

- h. Biomass: harnessing the energy available when human and animal wastes are burnt, to generate electricity.
- i. Compressed natural gas: this is the energy available from the use of the natural gas which accompanies crude oil naturally to generate electricity with the aid of gas turbines.
- j. Nuclear power: the use of naturally occurring nuclear fuels e.g. uranium, to generate electricity. Nuclear power is plagued by concerns about the challenges of safely managing radioactive wastes. And also managing the impact of natural disasters e.g. Fukushima nuclear plant in the wake of the tsunami of 2012 [12].

Although solar energy projects are capital intensive, it become cheaper over the years but with initial cost as high as three to five times of standard electricity pricing from conventional sources. A consumer that is connected to the grid requires considering certain environmental that will be of serious concerns, in order to make an investment decision. But if off the grid, solar is a viable economical alternative. The return on investment (ROI) can be emphasized and calculated by analyzing the startup capital of the solar energy in comparison to the price /peak watt to that of other energy sources. The lower initial investment will result to a higher pricing in regular electricity rate. Analyzing the costs into kilowatt hour pricing, gives the system investment its true economic state, which will be compared to standard electricity rates. This in return will help to calculate the period it will take to offset the initial startup capital. Also, in tropical climates where the sun rays are intense, the system will pay itself back faster. PV systems generally can be much cheaper than installing power lines and step-down transformers especially to remote areas [13].

For a solar energy system to be viable, the electricity generated must be equal to the returns on its economic investment over time with reasonable profit margin. The generated energy should be able to replace or produce more power than that supplied or produced by other energy providers or the power been provided by utility. These companies can also purchase excessive power generated from the solar energy system. This will bring down the cost of electricity through metering readings to determine the actual energy produced by the solar system, and subtracting from the energy supplied by Utility.

TABLE I. WORLD'S LARGEST PHOTOVOLTAIC POWER STATIONS [14]

PV power station	Country	DC Peak Power MW _p	Notes
Sarnia PV power plant	Canada	97	Constructed 2009-2010
Montalto di Castro PV Power Station	Italy	84.2	Constructed 2009-2010
Finstervalde Solar Park	Germany	80.7	Phase I completed 2009, phase II and III 2010
Rovigo PV Power Plant	Italy	70	Completed November 2010
Olmedilla PV Park	Spain	6	Completed September 2008
Strasskirchen Solar Park	Germany	54	
Lieberose PV Park	Germany	53	Completed in 2009

Puertollano PV Park	Spain	50	231,653 crystalline silicon modules, Suntech and Solaria, opened 2008
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The annual International Conference on Solar PV Investments, organized by EPIA notes that PV provides a secure, reliable ROI, with modules typically lasting 25 to 40 years and with a payback on investment of between 8 to 12 years. PV is a broad family of technologies displaying differing characteristics of cost and performance. The range of technologies can adapt to changing market conditions and fit with the needs of the different applications. These include the following:

- a) Mono-Crystalline: This has a higher efficiency, and it is mostly used for telecommunications and other industrial applications, where performance is the utmost goal.
- b) Poly-Crystalline: Its technological application is mainly prevalent for rooftop utilizations, due to space limitations and its efficiency, but still price sensitive.
- c) Amorphous Silicon: This is made up of a thin-film and its efficiency is lower compared to crystalline silicon, but its cost per peak watt is lower than that of crystalline silicon. Its application is mainly utilized in small technological products i.e. watches, calculators, etc.
- d) Concentrated PV: This uses a number of applicative technologies as small area collects high concentration of sunlight. This is effective in the south west desert, where the geographical location favors direct, intense and rarely interrupted sunlight.
- e) Multi-Junction Cells These are cells which have high conversion efficiency under normal or concentrated sunlight i.e. gallium arsenide or gallium indium phosphate

The working principle of solar cells applied in satellites, utilized in central power station, and its basic application on solar calculators, have the same architecture. Light passes an optical coating, or through anti reflection layer which reduces the light that will be lost by reflection, traps the light reaching the solar cell and transmits the light to the energy-conversion layers below.

This layer is made up of an oxide of silicon and tantalum, or titanium formed on the cell surface by a process referred to as spin-coating. The top junction layer, the absorber layer that constitutes the device core and the back junction layer are the three energy-conversion layers below the antireflection layer. In order to carry the electric current out to an external load and back into the cell to complete an electrical circuit two additional electrical contact layers are needed.

The electrical contact layer on the surface where light enters is generally of a grid pattern and is composed of a good metallic conductor. Since metals impair light from them, the grid lines are thin and spaced widely as is possible without limiting the collection of electric current produced by the cell. The electrical contact layer at the back has no such opposing diametric restrictions, and simply functions as an electrical contact and covers the entire back surface of the cell structure. Since it must be a very good electrical conductor, it

is produced with metal. Two or more modes of electricity generation mode can be combined together, using renewable technologies such as Solar, Wind turbines etc. Solar photovoltaic configuration is one way to provide off-grid electricity and can be employed in a tropical country like Nigeria for any kind of electrical application.

According to SK Abdul Aleem et al in 2020, reviewed various strategies required to increase photovoltaic (PV) penetration levels in smart grids [15]. From their research, it was found that application of a particular strategy depends on their location and some of these technologies are capital intensive. Their research also revealed that PV grid penetration interface has a lot of setback and impacts on the system stability, operations and flows.

Wadhah Esmael Ibraheem et al in 2014 studied the impact of PV systems on distribution networks [16]. It was found that PV fluctuation results to voltage and power quality challenges, which in turn limits its level of penetration, high power losses. This study was demonstrated using the IEEE 13 test bus system. Mohammed. I. Al-Najideen and Saad S. Alrwashdeh in 2017 designed solar photovoltaic system to cover the electricity demand for the faculty of Engineering-Mu'tah University in Jordan [17]. Their investigation considered availability of solar PV system and then proposed a design of 56.7kw grid connected solar PV power plant. Moreso, since the MWh consumed by the university is about 96 MWh annually, then installing on-grid PV system with 56.7KW capacity will produce about 97.02MWh per year. This covered the electricity demand with capital cost of \$117,000 and payback period of about 5.5years. D.W.

Almeida et al in 2019 analyzed the impacts of rooftop solar panels on distribution network [18]. Their study proposed a Monte Carlo based approach to carry out the evaluation using a case study for a typical unbalanced residential network in Sri Lanka using three phase four wire model. Validation of the model was carried out and certain parameters such as voltage unbalances, neutral currents, voltage and thermal limits. Results obtained were also analyzed and necessary recommendations were made. It was also found out that penetration of PV is effective if violation limits are maintained.

Inmaculada Guaita-Pradas et al in 2019 investigated on territory analysis for sustainable development of solar PV power system using Geographic Information System (GIS) data [19]. Their major focus was to find an optimal site location for solar farms construction while considering factors such as environmental, legal, political, technical-economic, social among others. It was recommended that new methodology for site selection and location using GIS approach while considering factors such as legal, political, environmental (solar radiation, physical terrain, climate, environment etc.) be applied.

M. M. El-Sayed et al in 2016 studied the effect of photovoltaic system on power quality in electrical distribution networks [20]. It is worthy of note that both the distribution grid (As a result of the presence of nonlinear loads) and the PV systems which consist of power converters are generating sources of harmonics. The researchers investigated further on how to solve the problem of

harmonics using single tuned passive filters that are properly located as well as determination of best location of PV for the purpose of harmonics reduction to be within acceptable limits.

S.H.Hosseini et al in 2009 did a study on PV application to distribution network and its effect on supply load and power quality [21]. Their investigation considered ways of suppressing current harmonics as well as reactive power compensation through the formulation of control systems and this was successfully achieved. Tara.M.Jackson et al in 2014 integrated PV systems into distribution networks with battery energy storage system using Grid LAB-D simulator [22]. A model of a typical South-East Queensland (SEQ) 11kV distribution feeder was designed and simulated. Various PV configurations were with emphasis on their effect was investigated and offset with battery energy storage system(BESS). The essence is to obtain the best combinations of PV and BESS for effective tackling of various mitigation issues.

F. L. Albuquerque et al in 2009 did a study on Photovoltaic solar system connected to the electric power grid operating as active power generator and reactive power compensator [23]. The researchers established that majority of contemporary inverters are current based inverters (CSI) because of it operates at unity power factor. If, however, voltage source inverters (VSI) is used instead of CSI, then reactive power can be generated equal to the remaining unused capacity at any point in time according to instantaneous power theory if the output voltage of the phases of the inverter are changed, then reactive or active power can be altered. It was further established that when the PV modules are inoperative or there is weak insolation, the reactive power compensation can be realized.

Ghiani, E., Pilo, F. in 2015 carried out a study on smart inverter operation in distribution networks with high penetration of photovoltaic systems [24]. The results showed that with better integration of PV inverter systems, there is effective management of both active and reactive power in distribution networks. Nouha Mansouri et al in 2020 carried out a review on the impact and solutions of photovoltaic power plants in electrical distribution network [25]. Some of the challenges with PV power plants centered on stability, voltage disturbances with high PV integration. Frequency regulation techniques injection of reactive power, curtailment of active power as well as storage energy, dynamic grid potentials support, operation control techniques towards ensuring smooth transition between grid-connected and islanded operation modes and synchronization between these two modes were also elaborately discussed.

K.N.Nwaigwe et al in 2019 carried out comprehensive review of modern approach to solar power (PV systems) integration into electricity grids including its benefits, characteristics ,challenges and compatibility in terms of integrating both systems(PV and the grid generation) [26]. M.Karimi et al in 2016 carried out a thorough review on photovoltaic penetration issues and impacts in distribution network [27]. The researchers reviewed various issues such as voltage fluctuation, voltage rise, voltage imbalance, harmonics, islanding issues based on different islanding

techniques which directly affects stability and the overall system integrity among others affecting PV penetration to distribution network

III. METHODOLOGY

Energy source is mainly from the 33kV line and (2) two of 1200kW diesel generators located in Abuja campus. Bulk electricity is bought from Port Harcourt Electricity Distribution Company (PHEDC) through its injection substation. There is a maximum demand meter installed which records the quantity of electricity purchased each month and fed through the four feeders; namely Abuja feeder, Choba & Delta feeder, Gambia & Ghanama and a dedicated feeder to the Senate building. This energy is further distributed to faculties, offices, hostels, residential quarters and business areas located within the campus. Although some residential houses are metered, the vast majority consuming electricity does not have meters. Due to epileptic power supply from PHEDC, the institution relies heavily on the power they generate through diesel generators. This is an enormous task as the monthly expense is a heavy financial burden on the university.

Calculation of Load Consumption for Uniport from PHEDC

The necessary load data was obtained. Table 2.0 illustrates the average load consumption rate for a seven-month period under review and falls approximately within 3MW.

TABLE II. CURRENT CONSUMPTION FOR EACH POWER STATION IN UNIVERSITY OF PORT HARCOURT

S/N	Power stations	Current consumption for 7 months average of Red-Yellow-Blue(Ampere)						
		January	February	March	April	May	June	July
1	Gambia-Ghanama	1000	950	1000	1000	900	980	1000
2	Abuja	2000	2000	2000	2000	1800	1800	1000
3	Delta and Choba Park	2000	1700	1700	1800	1800	1800	1500

The average line current for the institution is the average of the line currents for each of the power stations. The average line currents for each power station were computed as follows,

$$I_{L,delta/choba} = (2000 + 1900 + 1960 + 1970 + 1920 + 1958 + 1908)/7 = 1945.143A$$

$$I_{L,abuja} = (2000 + 2000 + 2000 + 2000 + 1800 + 1800 + 1000)/7 = 1657.143 A$$

$$I_{L,ghana/gambia} = (1000 + 950 + 1000 + 1000 + 900 + 980 + 1000)/7 = 975.714 A$$

Therefore, the average line current for the entire institution is, $I_L = (1945.143 + 1657.143 + 975.714)/3 = 1526A$

Figure 5.0 shows a section of homer where cost summary, cash flow, electrical renewable energy penetration could be

accessed. Other task that could also checked include salvage value, replacement cost, operating cost an overall capital cost.

Solar Radiation Profile:

Solar Global Horizontal Irradiance resource data for University of Port Harcourt, Nigeria was determined to be at latitude 4^o48.1N while its longitude is 6^o55.9E. Average annual clear index of 4.37 KWh/m²/day was recorded in Port Harcourt, Nigeria.

Figure 1.0 shows the data obtained for the studies. These include the date, time, global solar value in kw/m², solar altitude, azimuth, angle of incidence etc

Date	Time	Global Solar (kW/m ²)	3000W PV Solar Altitude (°)	3000W PV Solar Azimuth (°)	3000W PV Angle of Incidence (°)	3000W PV Incident Solar (kW/m ²)	3000W PV Slop (°)
Jan 1	1:00 AM	0.00	0.00	3.50	90.00	0.00	9
Jan 1	2:00 AM	0.00	0.00	-34.78	90.00	0.00	9
Jan 1	3:00 AM	0.00	0.00	-53.89	90.00	0.00	9
Jan 1	4:00 AM	0.00	0.00	-62.24	90.00	0.00	9
Jan 1	5:00 AM	0.00	0.00	-65.97	90.00	0.00	9
Jan 1	6:00 AM	0.00	0.00	-67.32	90.00	0.00	9
Jan 1	7:00 AM	0.00	0.00	-67.07	90.00	0.00	9
Jan 1	8:00 AM	0.04	10.71	-65.40	0.02	0.03	7
Jan 1	9:00 AM	0.07	24.13	-62.04	0.00	0.06	6
Jan 1	10:00 AM	0.14	36.99	-56.23	0.00	0.12	5
Jan 1	11:00 AM	0.02	48.71	-46.22	0.02	0.02	4
Jan 1	12:00 PM	0.01	57.94	-28.91	0.00	0.01	3
Jan 1	1:00 PM	0.13	62.09	-2.35	0.00	0.13	2
Jan 1	2:00 PM	0.12	59.03	25.24	0.00	0.11	3
Jan 1	3:00 PM	0.05	50.40	44.05	0.00	0.04	3
Jan 1	4:00 PM	0.02	38.96	54.97	0.00	0.02	5
Jan 1	5:00 PM	0.06	26.23	61.31	0.02	0.05	6
Jan 1	6:00 PM	0.03	12.88	64.99	0.00	0.03	7
Jan 1	7:00 PM	0.02	0.00	66.90	90.00	0.00	9
Jan 1	8:00 PM	0.00	0.00	67.37	90.00	0.00	9

Fig. 1. Solar Radiation Data

Figure 1.0b shows AC primary load daily profile for the month of May to October.

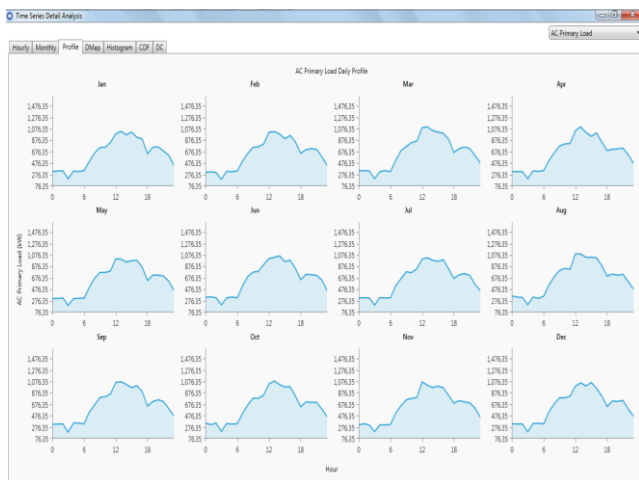


Fig. 2. AC primary load daily profile for the month of May to October.

Data Collation and Analysis

In collating data, the researchers depended majorly on the data obtained from Estate and works Department of University of Port Harcourt (Uniport) and questionnaires distributed to the residents of the institution. References were also made to data obtained from Nigerian Electricity Regulatory Commission (NERC).

HOMER (Hybrid Optimization of Multiple Energy Resources) models, originally designed at the National Renewable Energy Laboratory for village power program which simplifies the task of designing hybrid renewable

micro grids, whether it is a remote location or attached to a larger grid was applied for the analysis.

Modeling of the system

Various models for PV, generators, and converters component were applied as stated;

1. Modeling of the PV system

The PV system must operate at its maximum power point to generate optimal energy. Mathematical expressions for computing generated power and temperature of the cells are given in equations 1 to 6

$$PV_P = Na_m * G_T * N_g \tag{1}$$

$$PV_{Panels} = SA_{PV} * n_{pv} \{1 + \alpha r (T_C - T_{Cref}) * n_{pv}\} \tag{2}$$

$$I_{phmodule} = I_{scr} + \frac{K_t(T-298)*\lambda}{1000} \tag{3}$$

$$I_{rs} = \frac{I_{scr}}{[\exp(\frac{qV_{oc}}{N_s KAT}) - 1]}$$

$$I_0 = I_{rs} \left(\frac{T}{T_r}\right)^3 \exp\left(\frac{q*E_s}{eK}\right) \exp\left(\frac{T}{T_r} - \frac{1}{T}\right)$$

$$I_{pv} = N_p * I_{ph} - N_p * I_0 \left[\exp\left\{\frac{q*(V_{pv} + I_{ph}R_{st})}{N_s RGT}\right\}\right]$$

PV cells temperature result is greatly influenced by weather condition and PV cell characteristics.

Figure 3 shows one-line diagram solar based PV model in Homer.

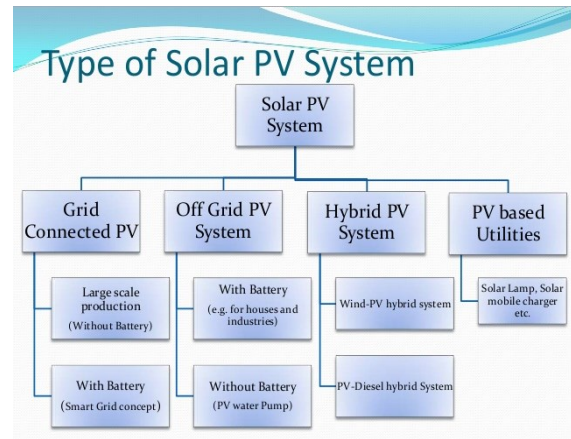


Fig. 3. One line diagram of solar based PV model in Homer.

This describes the block diagram of solar PV system. This could be grid connected, off grid connected, hybrid or PV based utility system. The grid connected could either be large scale (without batteries) or with batteries. The off-grid could also be with or without batteries while the hybrid system could be combination of one or more renewables (wind, solar, hydro, biomass etc.) and the PV based system is based on combination of solar and any other kind of renewable energy. Sensitivity studies were also carried out as shown in Figure 4. This Figure aid in the determination of the best type of solar panels, converters batteries etc. that will be most economical with optimal performance. This figure carried out various sensitivity studies through different simulation models in order to obtain the best optimum.

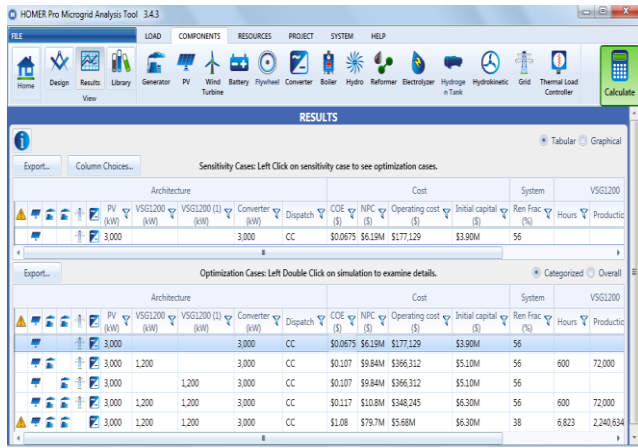


Fig. 4. Sensitivity and Optimization Studies for the Solar Network of University of Port Harcourt.

2. Modeling of the Converter

The power delivered by a converter is given by:

$$P_{in} = D_i * V_c * B_g \Delta C\alpha + R_i * E_0$$

To fully supply power;

$$\alpha = \left(13.3 * \ln \frac{c_0}{iD} + 59.8 * 100 \right)$$

Figure 5 shows a section of homer software where cost summary, cash flow electrical renewables energy penetration, PV grid system converter, determination of emissions is accessed. Other task that can be achieved include salvage value replacement, operating fuel energy source e.g. wind, solar, hydro overall capital cost etc. Figure 5 shows system architecture indicating the load while figure 6 shows system architecture indicating PV power output.

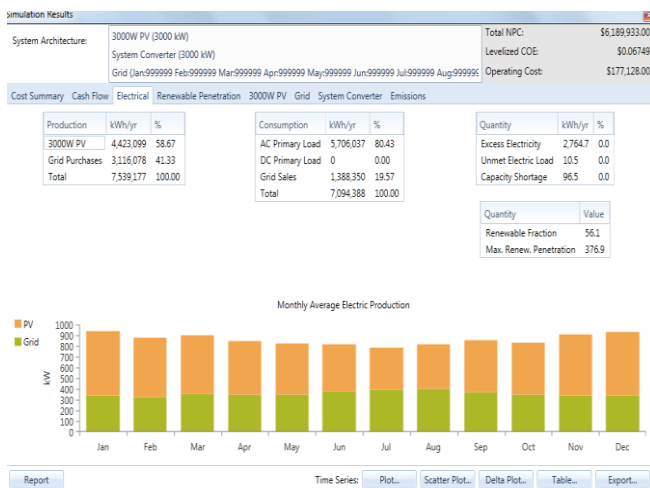


Fig. 5. System Architecture Indicating the Load.

Under this section average monthly electricity production was obtained showing the load AC load system converter rating renewable fraction as well as maximum renewable energy penetration.

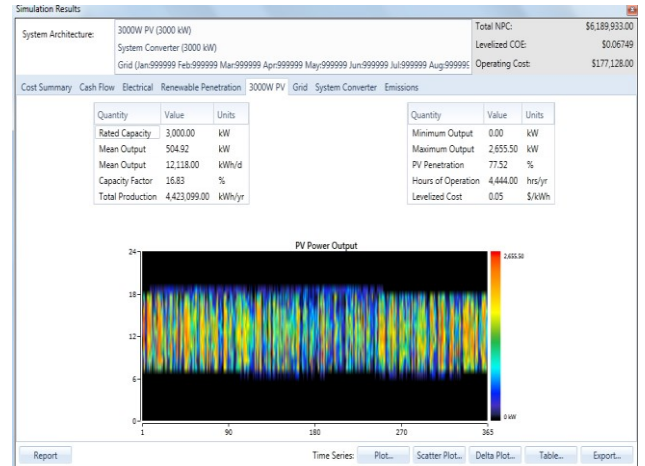


Fig. 6. System Architecture Indicating the PV output.

3. Modeling of the Battery Bank:

The battery bank is being charged by the excess power produced by the solar cells. Charge controllers limit over charging of the batteries to allow for its maximum allowable carrying capacity.

Mathematically, the charging current is given as.

$$I_c = \frac{P_+ * E_c * E_{B1}}{V_B}$$

Where;

E_c = efficiency of charge controller; E_B = converter efficiency; V_B = system Voltage.

I_c Compensates for power shortfall when energy needed exceeds the power produced from the battery and is given by:

$$I_c = \frac{P_+}{V_B * E_c * E_{B1}}$$

Also,

$$\Delta C = (I_c \times \Delta c) - C_D$$

Is change in capacity of the battery in a given time period.

Battery charge state is given by;

$$SOC_i = SOC_{(i-1)} + \Delta c$$

Figure 7 shows the modeling section in homer where the batteries are configured. It shows the battery properties such as name, make, manufacturer, nominal voltage (v) and capacities both in Ah and Kwh, round trip efficiency, float life, electrolyte replacement, interval (years), maximum charge and discharge current (A), initial state of charge as well as minimum state of charge expressed in percentages.

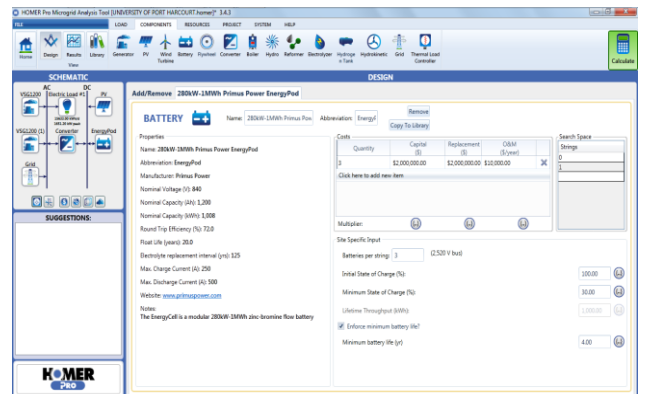


Fig. 7. Modeling the Battery for the Investigation.

Figure 8 shows the average monthly primary load from January to December for university of Port Harcourt.

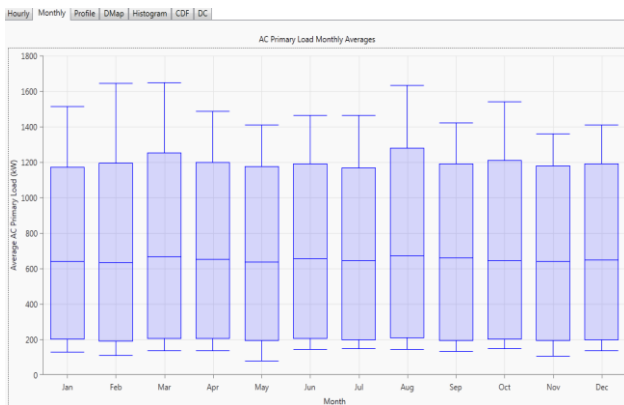


Fig. 8. Power Consumption in University of Port Harcourt.

Equation 3.13 gives power consumed by each power station.

$$P_1 = V_L I_L \cos \phi \sqrt{3}$$

Hence cumulative power consumption for the entire institution is computed as,

$$P_1 = 3 \times 415 \times 1526 \times 0.9 \times 1.732 = 2.962 \approx 3 \text{ MW}$$

From these computation, load supplied by PHEDC = 3MW
 Since this load is supplied for an average of 24 hours daily and 30 days makes a month, therefore energy supplied for a month = $3000 \times 10 \text{ hrs} \times 30 \text{ days} = 900 \text{ MWhr}$.

Recall; 1 Megawatt = 1000 Kilowatt

$$\therefore 900 \text{ MWhr} = 900 [\text{hr}] \times 1000 [\text{KW}] = 900,000 \text{ KWhr}$$

Also, 1 KWhr = ₦48.00

$$\therefore 900,000 \text{ KWhr} = 900000 \text{ KWhr} \times ₦48.00 / \text{KWhr} = ₦43,200,000.00$$

$$\text{hence, energy per day} = \frac{900000 \text{ KWhr}}{30} = 30,000 \text{ KWhr/day}$$

IV. RESULTS

In analyzing the equivalent load that could be generated using solar panels, the following steps were considered. First the cost of each major component was calculated in terms of user specified variables. The major components are:

- a) System converters
- b) Solar Panels
- c) Batteries

The user specified variables are:

- I. Peak power required to power appliances
- II. Total energy produced/consumed per day
- III. Total amount to be invested and the life span of the solar generating plant

Figure 9 shows the block diagram of a simple solar station with backup system used for the study. It consists of PV arrays, inverters, regulators, backup generators and batteries

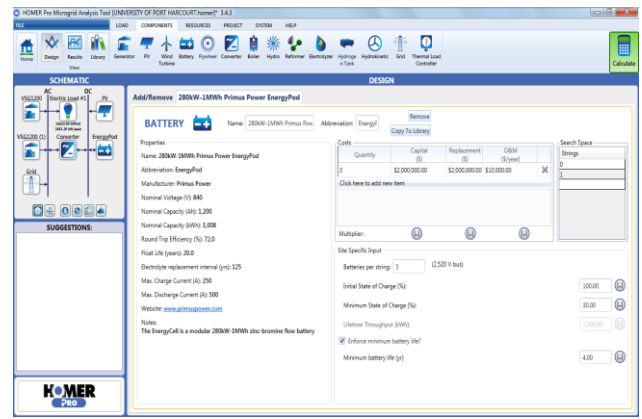


Fig. 9. Block Diagram of a Simple Solar Station with backup system.

Table 3 shows a breakdown of what the requirement as well as the cost to set the solar plant for the institution.

TABLE III. OVERALL COST OF SOLAR PV FOR UNIVERSITY OF PORT HARCOURT

Price of total Photovoltaic Module	\$3,700,000	₦1,042,200,000 @ ₦386 to a Dollar
Cost of Inverter/Regulator	\$1,500,000	₦386,000,000
Cost of Fittings	\$ 400,000	₦154,400,000
Cost of Battery	\$1,500,000	₦386,000,000
Total amount	\$7,100,000	₦2,740,600,000

This is the investment into solar smart grid generating station. After calculating the component costs, adding them up to create simple formulas which is used to compare cost with that of the conventional method currently employed to supply load to the institution from PHEDC. For such amount of load, the OPEX for maintenance purposes will amount to \$10,000/yr according to Andre Mermoud in 2011. Since the station has a life span guarantee of 25 years, OPEX (Operating Expenses) for 25 years = \$10,000 x 25 = \$250,000.00 and its naira equivalent becomes ₦96,500,000.00, Taking the current exchange rate of ₦386 to \$1; Adding the overall cost of solar PV and OPEX for the next 25 years gives

$$= \$7,100,000 + \$250,000 = \$7,350,000$$

$$\text{Taking the current exchange rate of ₦386 to } \$1; \$7,350,000 \times ₦386 = ₦2,837,100,000.00$$

This amount will be used to generate same amount of load or more for the same period of time per day for the next 25 years without major maintenance to the plant. The rate of increase of tariff increases geometrically by a common ratio factor of 1.3

$$\therefore \text{at 25 years a unit of kWhr} = ar^{n-1} = ₦48.00 \times 1.3^{25-1}$$

$$\text{From equation 3.14, monthly amount paid to PHEDC} = ₦26,054,436.96$$

$$\text{For a year} = 12 \times ₦26,054,436.96 = ₦312,653,244.00$$

V. DISCUSSION

The sub-stations used for the study are located in Gambia-Ghanama, Abuja and Delta/Choba Park. Solar radiation profile was obtained as latitude 40o48.1oN and longitude 6o55.9oE with an average clearance index of

4.37kwh/m²/day. Various data also recorded include solar altitude, angle of incidence, azimuth, global solar value in kw/m² and primary radiation data as shown both in figure 1.0a and 1.0b. the system was then modeled in homer environment (renewable energy software for hybrid optimization of multiple energy sources. Various models for PV, battery bank, generators, and converter components are designed and applied in this study. Moreso, sensitivity and optimization studies including the systems architecture, load and PV output for the solar network for the university was carried out. User specified variables include peak power required to power the appliances, total energy produced/consumed per day and the total amount to be invested as well as the lifespan of the solar generating plant. Table 3.0 shows the overall cost of solar PV for the university and it amounted to about Two billion, seven hundred and forty thousand, six hundred naira (N2,740,600,000). This cost includes cost of inverter/regulator, fittings, batteries. Operation and maintenance cost for a projection of twenty-five (25) years (OPEX was also determined to be Ninety-six million, five hundred thousand naira (N96, 500,000:00). At 25 years, amount that must have been spent on bills to PHEDC being used by the institution is about N 7,816,331,100:00. However, from the research it was found that Solar generating station will be capable of generating nominal power of 3MW at standard temperature of 37OC. Generated power is 7500MWhr but the load consumed in a year is 7100MWhr/year given an excess used power of 400MWhr/year. This excess power can be sold to nearby communities within the region where the station is situated, thereby creating extra profit for the institution. The load generated is consumed over a 24hr period.

VI. CONCLUSION

It is so obvious from the research, that for a given period of 25 years, solar generated power has not only proved to have more economic value but also very environmentally friendly. Moreso Investing in solar power, over time readily yields high profit because of the short period it uses to break even and quick realization of return on investment capital. Furthermore, utilizing solar energy as a source of renewable energy has little or no negative effect on the ecosystem. it is worthy of note that solar power is not just the energy solution of the future, but remains one of the most viable solutions for the future. This research has once more brought to light the urgent need for the replacement of conventional method of generating power through solar source. Our world is in peril; our ecosystem is dying at a massive pace daily all thanks to the pollution of the environment. According to the great Physicist Albert Einstein “the significant problems cannot be solved at the same level of thinking with which such were created”. Solar generated power if civilization is to remain is one technology that must be tapped into with all enthusiasm as the generation after us counts on us to preserve the earth the way we met it. It is one of the last resorts and a very convenient substitute to the fossil and nuclear fuel we have depended on for decades.

Furthermore, based on the findings of this research work, it was concluded that:

a) Power produced from using solar panels is far more economical compared to that obtained from Power Holding Company of Nigeria (PHEDC).

b) Power produced through renewable energy sources are environmentally friendly and would help in slowing or totally reducing the amount of greenhouse gases released to the atmosphere.

c) It was also found that the total amount that would be spent over a projected period of 25 years for power supplied by PHEDC would be far more expensive that what would be spent setting up a solar generating station.

d) A solar generating station capable of generating 3MW of power would best be operational if situated at the Faculty of Engineering in Abuja campus.

VII. RECOMMENDATION

Although from studies, it is obvious that government is yet to encourage full utilization of Renewable Energy Sources (RES). This if well encouraged would have prevented greenhouse gas emission (GHGE) into the atmosphere as well as other harmful gases released by using non-renewable energy methods of power generation. Government should enact policies that will favor full utilization of renewable energy resources. In developed countries, rebates and subsidies are given to people who venture into solar or other forms of renewable energy sources. Solar panels available today though have conversion efficiencies of about 30%, it indicates that there is prominent success in panels efficiency improvement in years to come. Research is ongoing to develop solar panels with much greater conversion efficiencies and relatively lower cost in solar research centers all over the world.

The following recommendations are suggested for further work in this field,

- i. The cost implication of the effects of using conventional methods of power generation from Power Holding Company of Nigeria (PHCN) should be studied to ascertain the extent of pollution to the environment.
- ii. The indirect and direct effects of situating the RES modules in a large area of land should be analyzed.
- iii. Load demand for future structures should be analyzed every two years to help in increasing the amount of load supplied.
- iv. A research Centre for Solar Power and Renewable Energy should be created in all higher institutions of learning.
- v. Nigeria should join the Global Energy Network Institute and other international renewable energy bodies.
- vi. A comprehensive analysis should be done to also ascertain the cost of operating the auxiliary generators situated at various locations in the institution.

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