Modeling and Performance Assessment of 6mw Net-Metered Grid Tied Photovoltaic System for Owerri Metropolis

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Abstract. The Nigerian Electricity grid is highly dominated by conventional power plants with a total installed capacity of 12,522MW. Presently, 5420.30 MW of power is being transmitted to the grid which is grossly insufficient for a country that requires about 180,000 MW to stabilize her power sector. Due to this energy crisis, the manufacturing industries are folding up, while others are relocating their production plants to more friendly havens because of the high cost of doing business in Nigeria. This constitutes a serious clog in the wheel of the economic and industrial progress of the country. This paper presents an effective alternative for the energy supply problem by adopting an unconventional PV system which operates in grid-connected mode incorporated with Net-meter to take charge of energy transaction. The system also contains a battery bank to compensate for seasonal variations. The simulation was carried out using PVsol premium software. The results obtained showed that Owerri has a good solar radiation to build PV system in large quantities, with annual yield factor of 1,098 kWh/kWp and performance ratio of 76.1% respectively. The process also stands the chance of saving about 11,688 kg/year of CO₂ which would have been emitted to atmosphere by conventional power plants.

Keywords: Renewable energy, Filters, Inverter, Net meter, PVsol software.

1.0 Introduction
The energy demand of Nigeria is about 180,000 MW but this capacity is far less than available. The current peak energy transmission stands at 5420.30 MW [1]. The estimated power outages in Nigeria annually brought about a loss of 126 billion naira (US$ 984.38 million) [2]. Apart from the huge income loss, it has also resulted in health hazards due to the exposure to carbon emissions caused by constant use of ‘backyard generators’ in different households and business enterprises, unemployment, and high cost of living leading to a deterioration of living conditions. Nigeria is adequately gifted with resources and is environment friendly in nature, receives abundant solar energy with an annual average daily solar radiation of 5.25 kW h/m²/day [3]. The new paradigm of global environmental sensitivity and the reality of dwindling forest and oil reserve demand that Nigeria’s much needed energy sources must be diversified. Based on these problems, stake holders in power industry have embraced solar energy as a good choice for electric power generation in view of its apparent limitless potentials.
Grid-Tied PV system is achieved using an inverter that converts the Direct Current to Alternating Current and fed into the building loads that are connected to the utility (EEDC) grid through a service connection with surplus energy being fed into the grid and shortfall being drawn from the grid. Production of surplus energy may happen when solar energy produced exceeds the energy consumption of the building. This surplus is fed into the grid. During the night, or day, when the energy demand in the building exceeds solar energy generation, energy is drawn from the grid. Bidirectional meter (Net-meter) will be connected in between the utility and PV grid to realize the energy transaction. This policy allows customers-generators to exchange excess electricity they export onto the grid for credits to offset electricity that the independent producers import or draw from the grid [4].

2.0 Historical Overview of Owerri Sub-Station
Transmission Company of Nigeria (TCN) Owerri work Centre has installed capacity of 160MW fed via 132kV double circuit transmission line running from Alaoji to Ahoada in Rivers State. An existing generation station at Gbarain is capable of supplying up 100MW via Ahoada network, which means that Owerri can import or export from Ahoada on 132 kV level. The grid is stepped down to 33kV via 2x60MVA and 1x40MVA Transformers into 8x33kV feeders namely: - Orlu, Mbaise, Alex, New-Oguta, Oguta, Owerri 3, Owerri /Airport and Okigwe respectively. Upon all these facilities, the area is being under supplied with electricity. The total allocated supply from Alaoji GenCO to the work Centre ranges from 50- 80MW as against the installed capacity which shows that the demand is much higher than the supply. It has been estimated that about 86% of households in Imo depend on fuel wood as their source of energy. On that note, there is urgent need for the work Centre to adopt the grid connected PV technology to augment the short fall in the industry which has poised serious threat to the energy security of the state.
3.0 Methodology of the System Design
This study has employed a systematic approach to collect data, conduct of technical and financial analysis of the system, preliminary assessment of the location of Owerri cities, pre-design and simulation of PV system using PVsol software. The Simulation estimated and analyzed the system performance, including breakeven, cash flow analyses, net present value, and internal rate of return, to determine the economic features of the system.

3.1 Modeling of PV Cell
The model of the solar PV cell can be realized by an equivalent circuit that consists of a current source in parallel with a diode as shown in fig. 3.2 for ideal model $R_s$, $R_p$ and $C$ components can be neglected.

$$\text{Equation (3.1) is used to obtain the output characteristics of a solar cell. According to the following mathematical equation as}$$

$$I = I_{ph} - I_s \left( e^{\frac{q(v+IRs)}{mRT}} - 1 \right) - \left( \frac{v+IRs}{R_p} \right)$$

$$\text{Equation (3.2) is used to obtain the output characteristics of a solar cell. According to the following equation (neglecting shunt resistance):}$$

$$I = N_p I_{ph} - N_p I_s \left( e^{\frac{q(v+IRs)}{mRT}} - 1 \right)$$

Assuming $N_p$, the above equation can be rewritten as
\[ I = I_{ph} - I_s \left( e^{\frac{q(V+IR_s)}{nkT}} - 1 \right) \]  

3.3

In particular, the cell reverse saturation current, \( I_s \), varies with temperature according to the following equation as:

\[ I_s = I_s(T_1) \times \left( \frac{T}{T_1} \right)^{\frac{q}{n}} \times e^{\frac{q(V+IR_s)}{nkT}} - 1 \]  

3.4

\[ I_s(T_1) = \frac{I_{sc}(T_1)}{e^{\frac{q(V+IR_s)}{nkT_1}} - 1} \]  

3.5

The photocurrent, depends on the solar radiation (S) and the temperature (T) according to the following equation as:

\[ I_{ph} = I_{ph(T_1)} \left( 1 + K_0(T - T_1) \right) \]  

3.6

\[ I_{ph(T_1)} = S \times 1_{SC(T_1_norm)}/S_{norm} \]  

where \( K_0 = (I_{SC(T_2)} - I_{SC(T_1)}/(T_2 - T_1) \)  

3.7

The series resistance of the cell is given as

\[ R_s = \frac{dV}{dI_{ph}} - \frac{1}{X_p} \]  

3.9

where \( X_p = I_{o(T1)} + \frac{q}{nkT} \times e^{\frac{q(V+IR_s)}{nkT_1}} \)  

3.10

The PV power P is then calculated as follows: -

\[ N_p I_{ph} V - N_p I_s (e^{\frac{q(V+IR_s)}{nkT}} - 1) = VI \]  

3.11

where

\( V = \) Output voltage of PV module, \( I = \) output current of PV module, \( R_s = \) series resistance of cell (\( \Omega \)), \( R_{sh} = \) shunt resistance of cell (\( \Omega \)), \( q = \) electronic charge (1.602 *10^-19 C), \( I_{sc} = \) light-generated current, \( K = \) Boltzman constant (1.38 * 10^-23 J/k), \( T_k = \) temp (K), \( n = \) number of PV cells connected in series, \( N_p = \) number of PV cells connected in parallel, \( I_o = \) reverse saturation current which depends on the ambient temperature , \( m = \) diode factor (usually between 1 and 2); \( n_s = \) number of PV cell in series, \( n_p = \) number of PV cell in parallel.

### 3.2 Design Solar PV System

In this section, a design for grid tied photovoltaic system to provide the required electricity for the Owerri metropolis was carried out. Based on the appliances the following parameters are needed to be obtained. Size of the PV modules, Inverter sizing, Battery Bank sizing, Solar charger controller sizing, cost estimate, period based on the cost of 1kwh. The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system: Total power use per day = total appliances use power in (W/day). Total energy consumption per day = Total appliances use in watts-hour per day.

#### Table 3.1 Estimated Load for dwelling houses

| S/N | Description | Ratings in (W) | HP | Qty | Hr in use | Estimated total load(W) | Total W |
|-----|-------------|----------------|----|-----|-----------|-------------------------|---------|
| 1   | Lightening points | | | | | | |
| a. | Internal   | 6              | 20000 | 6  | 120000    | 720000                 |         |
| b. | External 1  | 8              | 1000  | 6  | 8000      | 48000                  |         |
| c. | External 2  | 9              | 500   | 6  | 4500      | 27000                  |         |
| d. | Street Light| 25             | 200   | 6  | 5000      | 30000                  |         |
| S/N | Description                        | Ratings (HP/KW) | Hr of use | Estimated Total load (W) | Total W |
|-----|------------------------------------|-----------------|-----------|--------------------------|---------|
| 1   | 30 no of Lightening points         | 6w              | 7         | 1260                     |         |
| 2   | 50 Nos Security light              | 25w             | 5         | 1250                     | 6250    |
|     | 20 Fuel Pumps                      | 1Hp             | 5         | 37300                    | 186500  |
| 3   | 2nos Electric Motor for Cassava    | 5HP             | 1         | 14920                    | 14920   |
|     | grounding                           |                 |           |                          |         |
| 4   | 2Nos Electric tools Motors         | 1.5KW           | 1         | 3000                     | 3000    |
| 5   | Sawmills Machines                  |                 |           |                          |         |
|     | a. 1 No. CDC Electric Motor        | 1.5KW           | 2         | 1500                     | 3000    |
|     | b. 1 No Circular Electric Motor    | 5HP             | 1         | 7460                     | 7460    |
|     | c. Electric Sharping Machine       | 2.5KW           | 2         | 2500                     | 5000    |
| 7   | 3 Bore Hole Electric Motor         | 1HP             | 1         | 6714                     | 6714    |
| 8   | 2.No Electric Motor for grounding  | 3KW             | 2         | 6000                     | 12000   |
|     |                                    |                 |           |                          |         |
|     | **Total**                          |                 |           | **80824**                | **246,104** |

### 3.2.1 Future Load Demand

Considering the size of the city and the above estimated loads for dwelling, Hospitals, Offices, workshops and agro allied industries, an allowance of 50% of the known load for future load demand giving us 1,146,751.2 W

The total estimated Load = 2,041,161 W

The total Energy Consumption = 4,969,252.20 W

Total Energy needed from PV module to operate the appliance $= 4,969,255.20 \times 1.3 = \frac{6460031.76 \text{wh}}{\text{day}}$ where $1.3$ = loss factor of the system, $3.41$ = panel generation factor

Total energy needed $= 6460031.76 \text{wh/day}$
Total Energy needed from PV module to operate the appliance = \frac{6460031.76}{3.41} = 1894437.5Wp

4.0 Result and Discussion

The Design, Simulation and analysis were carried out using PV_Sol premium software package. The obtained simulation results are illustrated in the following Tables and figures as discussed hereafter.

Table 4.1 Details of PV Modules

| PV Modules Details          | 1STH-350 |
|----------------------------|----------|
| Number of PV Modules       | 58       |
| PV Generator Output        | 20.3     |
| Orientation                | 180°     |
| Inclination                | 22°      |
| Installation Type          | Mounted Roof |
| Inverter Details           | TL 20000E |
| Company                    | Schneider |
| AC power                   | 20kW     |
| Nom Voltage                | 630V     |
| MPP Min Voltage            | 350V     |
| MPP Max Voltage            | 800V     |

Table 4.2 Details of Battery System

| Battery System Details     |         |
|----------------------------|---------|
| Battery Charging (PV System)| 5,301 kWh/yr |
| Battery Charging (Grid)    | 2,370 kWh/yr |
| Consumption by the Battery System | 4,864 kWh/yr |
| Cycle Load                 | 2.2 %    |
| Service Life               | 45.5 Years |
| Output                     | 20 KW    |
| 36 Battery Model           | 16OP2V2000 |
| Battery Capacity           | 6,330Ah  |

Table 4.3 Details of PV System

| PV System                  | Consumer |
|----------------------------|----------|
| PV Generator Output        | 20.3 kWp |
| Spec. Annual Yield         | 1,098 kWh/kWp |
| Performance Ratio(PR)      | 76.1 %   |
| PV Generator Power (AC grid) | 22,297 kWh/yr |
| Own Use                    | 4,259 kWh/yr |
| Annual Grid Feed-in        | 12,736 kWh/yr |
| Battery Charging           | 5,301 kWh/yr |
| Own Power Consumption      | 42.9 %   |
| CO2 Emissions avoided      | 11,688 Kg/yr |

Table 4.4 Details of the financial analysis
### System Data

| Description                        | Value       |
|------------------------------------|-------------|
| PV Generator Output               | 20.3 kWp    |
| Start Operation of the system      | 3/26/2020   |
| Assessment Period                  | 20 Years    |
| Total Investment Costs             | 30,450.00$  |
| Total Investment Costs             | 1,500.00kWp |
| Incoming Subsidies                 | 0.00$       |
| One-off payments                   | 0.00$       |
| Annual Costs                       | 0.00$       |
| Other revenue or savings           | 0.00$       |

### Remuneration or Savings

| Description                        | Value       |
|------------------------------------|-------------|
| 1st year remuneration              | 1,066.43$   |
| Specific Feed-in Remuneration      | 0.0835 $/kWh|
| 1st year savings                   | 878.60$     |
| Return on assets                   | 4.26%       |
| Accrued Cash flow (cash balance)   | 4,614.33 kWh/yr |
| Amortization Period                | 18.14 Years |

**Fig 4.1: Accrued cash flow chart**

**Fig 4.2: Electricity cost trend (Price Increase 2%)**
Fig 4.1: Shows the graph of accrued cash flow (with total sum of $4,614.33) after the investment. The breakeven time is estimated to be equal to 19 years. This change is linked to the lower cost of photovoltaic solar technology.

ii. Fig 4.2 shows the annual electricity cost trend of the system within the 21 years of the cycle. The electricity cost trend before and installation of the solar system projected from 1300 to 1950$ and 400 to 650$ within 21 years of the cycle.

iii. Fig 4.3 shows the monthly energy consumption by the PV system with the annual energy and peak consumption of 10,000kWh and peak of 2.5kW).

iv. Fig 4.4 explains the State of charge (SoC) which is the level of charge of an electric battery relative to its capacity with minimum and maximum SOC of 20 and 90 %

v. Fig 4.5: Illustrates the average performance ratio of the inverter. It explains the proportion of the energy that is actually available for export to the grid after deduction
of energy loss (e.g. due to thermal losses and conduction losses) and energy consumption for operation. The average PR was found to be 76.1%.

vi. **Fig 4.6**: Shows the line graph of the system irradiation. Irradiance shows an instantaneous measurement of solar power over some area. The values of irradiation onto the horizontal plane, irradiation onto tilted surface without shading and reflection and irradiation on tilted surface stands at 1,500.8kWh/m²/yr., 1,445.0kWh/m²/yr. and 1,378.8kWm²/yr. respectively.

### 5.0 Conclusion

Modeling and Performance Assessment of 6MW Net Metered Grid tied Photovoltaic System in Owerri Metropolis has been carried out using PVsol premium software. The results obtained showed that Owerri has a very good solar radiation to build PV system in large quantities, with annual yield factor of 1,098 kWh/kWp and performance ratio of 76.1% respectively. The process also stands the chance of saving about 11,688 kg/year of CO₂ which would have been emitted to atmosphere by conventional power plants. The integration of Photovoltaic energy generation in Owerri metropolis with the distribution network is considered satisfactory. Net-meter was incorporated in the design which allows customers-generators to exchange excess electricity they export onto the grid for credits to offset electricity that the independent producers import or draw from the grid. The preliminary results also included the technical and financial analysis for the study. The Internal rate of return of capital resources is 4.26%, while Revenue or savings 698.79 $/year with Accrued Cash flow balance of 4,614.33$ and amortization period of 18.14 years. The software also has an extensive database of meteorological data for different locations, system components and their specifications from manufacturers and simulates the performance of the PV system, taking into consideration the various possible losses.

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