Improving Power Availability of the National Power System Using Solar-Based Enhanced Distributed Generation Technology

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Abstract: **In this paper, I developed a standard for connecting a solar-based enhanced distributed generation technology to the national utility grid which is expected to improve the poor state of electric power supply in Nigeria. The photovoltaic system generated 250MW solar power which was injected into the national utility grid. The 250MW will be gotten from five locations in the country as each location will generate 50MW to the national utility grid. The photovoltaic system will utilize equipment such as photovoltaic modules, boost converters, inverter, Battery Energy Storage System (BESS), step-up transformers etc. which was interconnected together to feed the 132/33kV substation. The total number of photovoltaic modules, inverters, Battery Energy Storage System (BESS), step-up transformer etc. was also depicted. The total area needed for the installation of 50MW for one location as well as for the five locations for the solar based power was put into consideration for the work. The analysis on the effect of the solar module on the varying temperature with constant irradiance and constant temperature with varying irradiance was depicted. Furthermore, the Bill of Engineering Measurement and Evaluation (BEME) of the entire work were written. The simulation carried out in this work was done with MATLAB software. Finally, It was realised that additional 250MW was integrated into the Nigeria utility grid and was generated from five locations in Nigeria.**

Keywords- **Solar, Generation, Power system, Technology, Photovoltaic system**

I. INTRODUCTION

The use of renewable energy to generate electricity has gotten the interest of researchers for many years. Renewable energy such as Hydro, Solar, and wind has gotten more development in the past decade in many countries of the world.

During the past decades, three major changes have occurred in power systems [12]; firstly, it has become more difficult for system operators to obtain public acceptance for building new overhead lines, making the overall process of grid expansion longer and more complicated. Secondly, enormous establishment of new renewable energy sources has begun happening. Thirdly, Large-scale installation of new renewable energy sources has started occurring. There have been utilities (such as electricity generation and transmission of electricity) which have been unbounded following advancement of electricity markets, thus splitting generation and transmission activities. Uninterrupted power supply is of paramount necessity for every country. In Nigeria, we can seldom boast of a day of uninterrupted power supply. The energy crisis which has been for more than twenty years in Nigeria has really been enormous and the issues have increased the occurrence of poverty by deadening industrial and commercial activities during this period. Power blackouts in the country have caused a drawdown of 126 billion naira (US$ 984.38 million) yearly [2]. Notwithstanding the huge colossal money loss, the result of the hazard brought about on the health caused by constant emission of carbon monoxide which is due to the usage of generators in different business enterprise as well as households. It has also brought about significant high living cost and lack of jobs causing the living conditions to be deteriorated.

Moreover, as indicated by the Central Bank estimate, Nigeria spent 8,771,863 tons of oil for electricity generation [1]. This is equivalent to around 180,000 barrels of oil each day. From there on out, oil utilization in Nigeria has definitely extended. The impact of this development on the economy depending entirely on income from oil is colossal. Likewise, the Department for Petroleum Resources [3] announced a measure of oil of over 78% of the complete energy utilization in Nigeria. In the current circumstance as a country, plainly depending basically upon non-environmentally friendly power source (oil) is not adequate in meeting the needs for power supply in the country. Moreover, renewable energy resources in Nigeria is abundant for power supply, for example, solar, biomass, hydroelectric, wind, and tidal, there is a need to harness these resources and put together ways to harness the power supply from these resources for a brighter future. In such manner, the public authority has a duty to make environmentally friendly power accessible and reasonable to all.

II. MATERIALS CHARACTERIZATION

A. Solar Photovoltaic Array

The solar panel used in this work is a 415W monocrystalline module with model number SPR-415E –WHT-D, it delivers an output power of 415watt under standard temperature condition. Its length and width are 2067mm and 1046mm respectively. This is utilized for the purpose of trapping of the energy from the sun, as it is set in an outdoor environment where there is sunlight. The solar photovoltaic array are organised in parallel and in series in order to get the wanted output.

The solar power needed is 250MW which was divided into five locations making each location having 50MWp of solar.

For each location the solar panel was divided into tables and blocks as each table was to produce a total of 250kWp and it is made up of 88 series string connected and 7 parallel solar panels. Each table had a total of 616 solar panels (88x7) which produced approximately 255kWp (88x7x 415) of solar.

The tables were then grouped into blocks as one block produced 12.5MWp. Therefore, one block had 49 tables. For 50MW (one location) it had 4 blocks which was equal to 196 tables and equal to 120,736 solar modules.

For the 250MW (for the 5 locations), it had 20 blocks which is equal to 980tables and also equal to 603,680 solar modules. Table 1 shows the Electrical parameters for PV module of model SunPower SPR- 415E WHT – D

Table I. Electrical parameters for PV module of model: SunPower SPR- 415E WHT – D

Peak Power(+/- 5%)	Pmax	414.801W
Cells per module	Ncell	128
Cell Efficiency	H	22.5%
Panel Efficiency	H	20.1%
Rated Voltage	Vmpp	72.9
Rated Current	Impp	5.69A
Open Circuit Voltage	Voc	85.3V
Short circuit Current	Isc	6.09A
Light Generated Current	I_L	6.0978A
Temperature coefficients	Voltage(Voc) Current(Isc)	$-0.229\%^0C$ $0.0307\%^0C$
Series Fuse Rating		20A
Diode Ideality Factor		0.8722
Diode Saturation Current	I_0	$7.1712X10^{-19}A$
Shunt Resistance	Rsh	419.78ohms
Series Resistance	Rs	0.5371ohms

B. Boost Converter

First, the converter changes over the DC Voltage created by the solar PV Array to an upgraded DC Voltage without fluctuations and keeps up with stability of the voltage. A maximum power point tracker in the converter is utilized to upgrade and direct the voltage at the output of the photovoltaic array to guarantee that the output is at its maximum power point. As seen in figure 1 the DC voltage is passed through the maximum power point tracker to enhance the voltage before being transferred to the inverter to be converted to AC voltage. The solar PV array behaves in such a way that is non-linear and its output varies persistently due to varying climate conditions. Maximum Power point device assists the PV array to convey the output of the maximum power and hence expands the system's effectiveness.

1) Maximum Power Point Tracking:

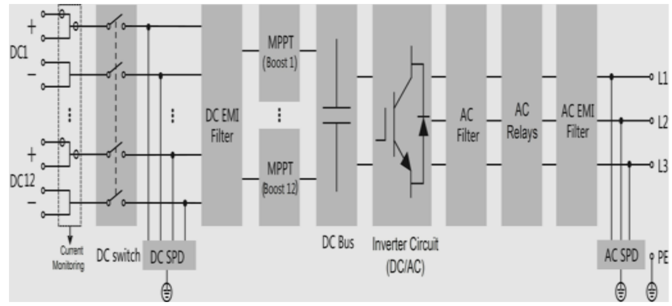


Figure 1 Converter circuit

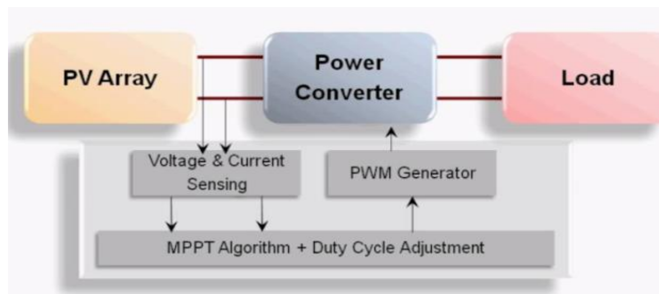


Figure 2 Maximum power point tracking from PV array to utility grid

In order to achieve maximum output at the output of the power converter there was need for a control system to maintain the balance of voltage, current, power and frequency at the output of the converter. As seen in figure 2 the voltage and current from the photovoltaic arrays (PV arrays) will be received by a voltage and current sensor in the control system, the values gotten will be transferred to Maximum Power Point Tracking (MPPT) Algorithm which will compare the output value with the maximum point of power thereby adjusting the duty cycle to meet up with the Maximum Power Point (MPP). After the adjustment the power output is transferred through the pulse width modulator generator to the converter before getting to the step-up transformer to stabilize the voltage before being transferred to the utility grid. More on the requirement and design will be described further in this paper.

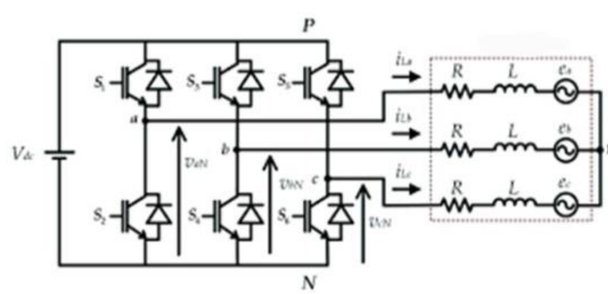


Figure 3 Three Phase Three Level Voltage Source Converter

C. Voltage Source Converter

This is utilized in changing direct current voltage to alternating current voltage as the solar panel converts the sunlight energy into direct current voltage. Three-phase three level voltage source converters have been utilized to change over direct current power into alternating current power. Circuit diagram of a three phase three level voltage source converter is displayed in figure 3. The voltage source converter gets its input from the grid into the Phase Locked Loop (PLL). A phase-locked loop (PLL) is a controller that produces a signal at the output that makes its phase in synchronism to the phase of a generated input signal from given source. The circuit comprises of a phase detector and a variable frequency oscillator in a loop for feedback purposes. The oscillator produces a signal that is periodic, and the phase detector compares the phase of the signal at the output with the phase of the periodic signal at the input, increasing or decreasing the parameters at the oscillator to keep the phases the same. Ensuring that the phases at the input and output are in lock step also implies keeping the frequencies of the input and output equal. Be that as it may, in addition to the synchronizing of input and output signals, a phase-locked loop can follow an input frequency, or it can produce a frequency that is more times greater than the input frequency. In this work, the Phase Locked Loop (PLL) is used to synchronize the frequency, voltage, current and power from the grid with the frequency, voltage, current and power from the converter.

The controller has a direct and quadratic transformation which converts the line (a,b,c) Voltages into dq0 frame domain which ensures accurate control for the signals. Figure 4 shows the Phase Locked Loop(PLL) in the voltage source converter.

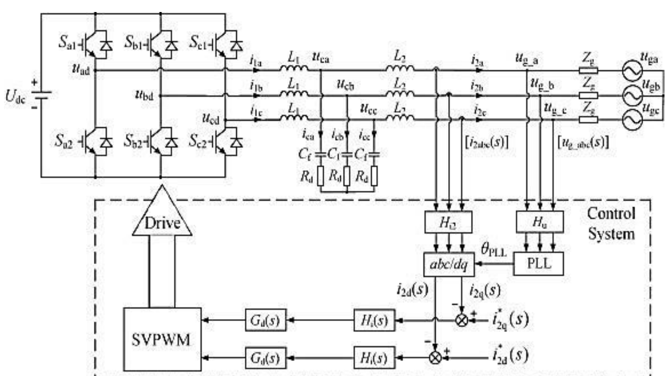


Figure 4 Phase Locked Loop (PLL) in Voltage Source Converter

The inverter controller measures the voltage, current and Power of the Grid and passes the signals through the Phase Locked Loop controller which generates the synchronization frequency, it also passes Maximum power into the Grid. Active and reactive power controllers are also embedded in the voltage source converter.

For this work each table has an inverter, since there are 196 tables so the total number of inverters is 196. Each of the inverter has a power output of 250kW.

The rating of the converters is stated in the table 2

Table II Converters Rating

Parameter	Value
Maximum PV input voltage	1500V
Minimum PV input voltage	600V
MPP voltage range	600V – 1500V
MPP voltage range for nominal power	860V – 1300V
No. of independent MPP inputs	12
Max. number of PV strings per MPPT	2
Max. PV input current	312A
Max. current for input connector	30A
Max. DC short-circuit current	600A
AC output power	250 kVA @ 30 °C / 225 kVA @40 °C/200 KVA @50°C
Max. AC output current	180.5 A
Nominal AC voltage	800 V
AC voltage range	680 – 880V
Nominal grid frequency	50 Hz
Power factor at nominal power	> 0.99
Feed-in phases / connection phases	3 / 3

D. Battery Energy Storage System (BESS)

The capacity of a storage battery is characterized by the quantity of the rated electric charge the battery stores in the form of active materials converting the chemical energy into electrical energy and vice versa.

The norminal voltage of a battery is characterized by its operating voltage like any source of electrical energy.

For the 250MW solar power which was divided into five locations with each location giving 50MWp of solar. The battery energy was needed to back up the power in the case of the night hours or when there is poor sunlight; the average sunlight for good energy for solar power generation in Nigeria is approximately eight hours.

Therefore the batteries must deliver electrical energy to supply the loads for approximately 16 hours;

$$24 - 8 = 16\text{hours}$$

In one location the battery should be able to store 50MWh of battery. The total battery size needed is

$$50\text{MW} * 16 = 800\text{MWh}$$

The required size of battery must be at least 800MWh to deliver power of 50MW for 16 hours.

There are two batteries of 250kWh that was connected to each inverter, since there are 196 inverters per location the total batteries are 392. Total battery capacity for the grid is 0.98GWh/location. All locations have a total of 1,960 batteries giving a total of approximately 4.9GWh of battery capacity.

The ratings for the Battery Energy Storage System are stated in table 3

Table III. Rating of Battery Energy Storage System

Item	Specification
Rated Energy Capacity	276kWh
Rated DC voltage	768V
Rated AC Power	250kW
Rated Grid Voltage	400 ¬ 480V
AC Rated of Current	301 – 360A
Grid Frequency	50Hz
Dimension (L/W/H)	6058/2438/2591mm
Weight	<15T
Operating Temperature	20 – 40°C
Maximum Altitude	3000m

It will also require the battery to be charged for 8hours of the day.

The charging current should be one-tenth of battery. From table 3 the rated energy capacity is 276kWh and it has a rated DC voltage of 768V; therefore the current rating of the battery is 359.38Ah. The charging current is 35.94A.

E. Cables and other accessories

The cables and accessories used are battery cables, PV cables, battery terminals, solar panel rack, MC4 connectors, strain relief adapters, ground busbar, cable clips, ground stabilizer fabric, 6 gauge bear copper, spool of stranded THHN wire, MC4 crimping tools, conduit pipes etc.

These cables and accessories will be needed for the interconnection of the photovoltaic array system.

F. Land Area Utilized

The land area utilized was dependent on some factors which include the latitude and longitude of the location, the climate of the region as well as the cost of land.

The details of the land area used for the solar installation in one location is stated below:

A location requires 120,736 solar modules

Each module has size of (2067x1046) mm^2 = 2.16m^2

Spacing between tables is: Horizontal – 0.10m

Vertical - 3.59m

Total tables in one location: 196 tables

Spaces between tables = 0.10 x 3.59 x 196 = 0.7km^2

Module land area is

$$120736 \times \frac{2.16}{10^6} = 0.26km^2$$

Inverter dimension (1051 x 363)mm = 0.38m^2

Total inverter to be used is 196 therefore, total inverter area is

$$0.38 \times 196 = 0.07km^2$$

4 numbers of Step up Transformers, High tension panel with office space, Low tension panel with office space, switch yard, gantry took approximately 0.7km^2

Total area used for the overall installation in one location is

$$0.5 + 0.07 + 0.26 + 0.7 = 1.53km^2$$

Converting the square kilometre to acres will be 378 acres of land. For all locations it utilized 7.65 km^2 which equals 1,890 acres of land.

III. METHODOLOGY

The method utilize in this paper are explained as follows:

A. Solar Power System Modelling

Figure 5(a) and (b) is solar circuit models usually utilized PV cell: It consists of a current source which is in parallel with a couple of diodes. A model consist of a single diode [15] comprises of four parts: diode parallel to source, series of resistor ***Rs***, photo-current source and shunt resistor ***Rsh***. Figure 5(b) is a model consisting of a double diode, the additional diode is for a good curve fitting.

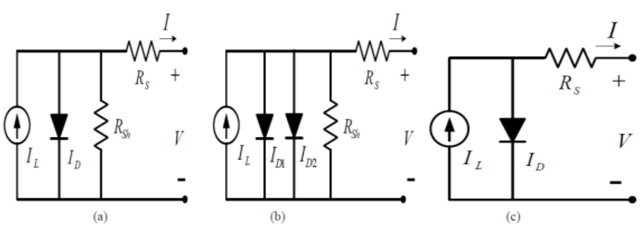


Figure 5 PV-cell equivalent circuit model a) single diode model b) two diode model c) simplified pv equivalent circuit

The shunt resistance Rsh is too high, so it usually can be [16]. Fig.5(a) is a model of four parameters and the circuit can be reduced into Figure 7c, the reduced circuit model for this work.

The output voltage *V* in relation to the load current *I* can be express as

$$I = I_L - I_D = I_L - I_0\left[exp\left[\frac{V + IR_S}{\alpha}\right] - 1\right] \text{-----1}$$

where I_L = light current (A);

I_0 = saturation current (A);

I = load current (A);

V = output voltage (V);

R_S = series resistance (Ω);

α = thermal voltage timing completion factor (V).

Four parameters (I_L, I_0, R_S, and α) need to be known to acquire the *I-V* relationship (that is why the model is known as a four-parameter model). Figure 5c equivalent circuit and Equation 1 veil the intricacy of the real model, for the four parameters are elements of temperature, load current and/or solar irradiance. Technique for determining the four parameters are given herewith.

Light Current I_L can be determined as:

$$I_L = \frac{\varnothing}{\varnothing_{ref}}\left[I_{Lref} + \mu_{I,SC}\,(T_C - T_{Cref})\right] \quad \text{----2}$$

where

$\varnothing$ = irradiance (W/m^2),

$\varnothing_{ref}$ = reference irradiance (1000 W/m^2 is used in this study),

$I_{L,ref}$ = light current at the reference condition (1000W/m^2 and 25°C),

T_c = PV cell temperature (°C),

$T_{c,ref}$ = reference temperature (25 °C for reference purpose),

$\mu_{I,SC}$ = temperature coefficient of the short-circuit current (A/°C);

Saturation Current I_0; this can be expressed in terms of its value at reference conditions:

$$I_0 = I_{0,ref}\left[\frac{T_{c,ref}+273}{q\alpha_{ref}}\right]^3 \exp \frac{e_{gap}N_s}{} \left[\frac{1 - TC_{,ref}+273}{Tc+273}\right] \quad T_c + 273$$

---------------------3

where $I_{0,ref}$ = saturation current (A) at reference conditions,

e_{gap} = band gap of the material (1.17 eV for Si materials),

N = number of cells in series of a PV module,

q = charge of an electron (1.60217733×10^{-19} C),

α_{ref} = the value of α at reference conditions.

$I_{0,ref}$ can be calculated as:

$$I_{0,ref} = I_{L,ref}\exp\left[\frac{-V_{oc,ref}}{\alpha_{ref}}\right] \quad \text{---------4}$$

where

$V_{oc,ref}$ = the reference-condition open-circuit voltage (V) of the PV module; its value is manufacturer-provided.

Therefore α_{ref} can be calculated from

$$\alpha_{ref} = \frac{2V_{mp,ref} - V_{oc,ref}}{\dfrac{I_{sc,ref}}{I_{sc,ref} - I_{mp,ref}} + \ln\left[1 - \dfrac{I_{mp,ref}}{I_{sc,ref}}\right]}$$

----------------5

where

$V_{mp,ref}$ = maximum power point voltage (V) at reference conditions,

$I_{mp,ref}$ = maximum power point current (A) at reference conditions,

$I_{sc,ref}$= short-circuit current (A) at reference conditions.

α is a function of temperature, expressed as:

$$\alpha = \frac{T_c + 273}{T_{c,ref} + 273}\,\alpha_{ref} \quad \text{----------------6}$$

Series resistance R_s is manufacturer-provided; but, if not, this equation can be used to estimate it:

$$R_s = \frac{\alpha_{ref}\ln\left[1 - \dfrac{I_{mp,ref}}{I_{sc,ref}}\right] + V_{oc,ref} - V_{mp,ref}}{I_{mp,ref}}$$

---------7

Figure 6 shows the *I-V* operating characteristics of a solar cell. A PV array comprises individual PV cells connected into a unit of suitable power rating. Its characteristics are determinable by multiplying the voltage of an individual cell by the number of cells connected in series and multiplying the current by the number of cells connected in parallel. Three important operating points are open-circuit voltage, short circuit current and Maximum Power Point (MPP).

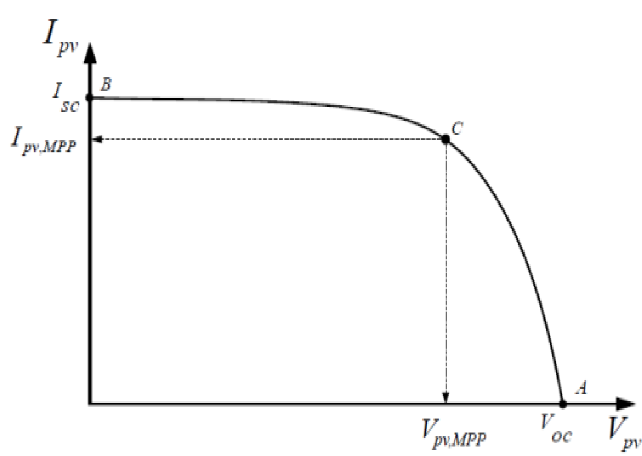


Figure 6 PV-cell operating point

In Figure 6 Voltage at operating-point-A is the open-circuit voltage; current at operating Point-B is the short circuit current and the operating-point-C is the current and voltage maximum power point of the photovoltaic cell. Figure 7 shows an open circuit with shunt current *Ish* neglected which Equations 8 and 9 represent.

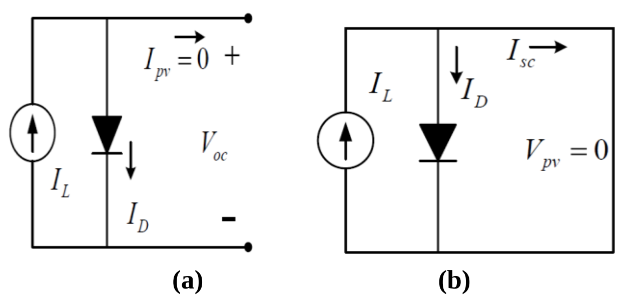


Figure 7(a): Equivalent circuit open-circuit condition

Figure 7(b): equivalent circuit short circuit condition

$$I_L - I_0 \left[\exp\left[\frac{V_{oc}}{A}\right] - 1\right] = 0 \quad \text{----------8}$$

$$V_{OC} = \alpha\left[\frac{\text{In } I_L + I_0}{I_0}\right] \quad \text{----------9}$$

Equation 10 depicts the short-circuit current. Figure 8 shows the current at operating point B, neglecting series resistance *Rs*.

$$I_{SC} = I_L \quad \text{-----------------10}$$

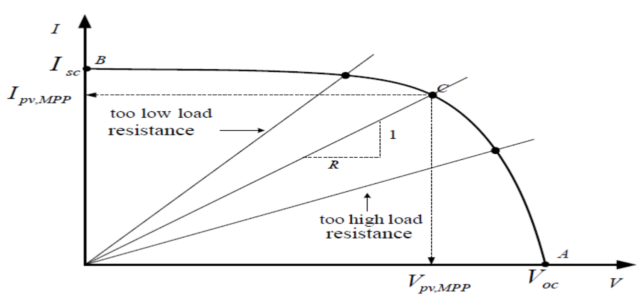


Figure 8: Intersection of the I-V characteristic and the load characteristic curve

As seen in figure 8 in the analysis of the operating point of a PV array under unchanged irradiance and temperature of a photovoltaic cell, is the intersection point of the *I-V* characteristics and the load characteristics; A straight line with slope;

$M=1/R= I_{Load}/V_{Load}$ gives the load characteristic.

The system operating point shifts along the *I-V* characteristic curve, from B to A, as load resistance adds up from zero to infinity.

The Maximum Power point is at C, where the area (same as the output power) under the *I-V* characteristic curve is maxima. If the load resistance is too high, the operating points go into the CA region. If the load resistance is too low, the operating points shifts into the CB area. MPP can, thus, be gotten by aligning load resistance to PV array characteristics.

B. Tilt Angle and Azimuth Angle Mathematical Model

To get the maximum solar radiation, it is important to plan the tilt angle and direction of a PV panel. The proper mathematical model related to the latitude of the place is a basis of calculating tilt angle (*β*) and Azimuth angle (*γ*). The climate of Nigeria differs throughout three different regions of the country. Southern Nigeria is equatorial, Central Nigeria is tropical, while the northern region of the country is dry.

The five locations in Nigeria where the solar PV systems was designed with the information of their Latitude, Longitude, Altitude and Annual average temperature is shown in table 4

Table IV. Latitude, Longitude, Altitude and Altitude and annual average temperature of some locations in Nigeria

Location	Latitude	Longitude	Altitude (m)	Annual Average Temperature(oC)
Kabi in FCT Abuja	8.73ON	7.31OE	503	25.3
Onitsha-Agu Enugu State	6.38ON	7.72OE	83	25.2
Gbalajobi in Oyo State	8.58ON	4.02OE	443	25.4
Maigarin Damo in Kano State	11.90ON	8.32OE	452	25.3
Rigwallo in Kaduna State	10.21ON	8.12OE	745	24.4

1) Solar Declination (Δ): The declination of the sun is the angle between the line joining the centres of the earth, the sun, and the equatorial plane. In Equation 11, the declination of the sun is determined by the day of the year using the following formula [10]

$$\delta = 23.45 \sin(2\pi(284 + n)/365) \text{-----11}$$

where n is the number of days that have slipped by since the first day of a year, 1 January - 31 December has n = 365, except when it has a number of 366 in a leap year.

2) Angle of Incidence (Θ): The angle of incidence of the direct solar radiation on the tilt surface, *θ*, can be calculated by equation 12 [5]:

$$\cos\theta = \sin\delta \sin\varnothing \cos\beta - \sin\delta \cos\varnothing \sin\beta \cos\gamma$$
$$+\cos\delta \cos\varnothing \cos\beta \cos\omega$$
$$+\cos\delta \sin\varnothing \sin\beta \cos\gamma \cos\omega$$
$$+\cos\delta \sin\beta \sin\gamma \sin\omega \text{ ----------------------12}$$

where Ø is the latitude of the site,

β is the tilt angle of PV panel,

γ is the azimuth angle, and

ω is the hour angle, which shifts with the sun movement.

3) Hour Angle of Sunrise and Sunset: The solar altitude angle is zero at the sunrise and sunset. To find the sunrise (or sunset) hour angle ω_r (ω_s) on a south-facing ($g = 0$) tilt surface, one can use the following formulas [13]:

$\omega_1 = \cos^{-1}(-A/(2B))$, -------------13

$\omega_2 = \cos^{-1}(-\tan \varnothing \tan \delta)$ -------------14

Furthermore, the sunrise (or sunset) hour angle ωr (ωs) for the inclined surface is given by[10]:

$\omega_r = \max(-\omega 1, -\omega 2)$ -----------------------15

$\omega s = \min(w1, w2)$, -----------------------16

with

$A = 2(\sin \delta \sin \varnothing \cos \beta + \sin \delta \cos \varnothing \sin \beta \cos \gamma) \times (\cos \delta \cos \varnothing \cos \beta + \cos \delta \sin \varnothing \sin \beta \cos \gamma)$, --------------------------17

and

$B = (\cos \delta \cos \varnothing \cos \beta + \cos \delta \sin \varnothing \sin \beta \cos \gamma)^2 \times (\cos \delta \sin \beta \cos \gamma)^2$ ----------------------18

where A and B are calculated by Equation (2), which were used to obtain the values of sunrise (or sunset) hour angle in Equations 13 –16).

C. Nigeria National Grid

Solar power integration in the national grid will be done in the 132kV substation. Power from the step up transformer which is 33kV is passed to the 33kV HT panel; it then flow through the protecting systems before being transferred to the 132kV substation.

The addition of the 50MW at five locations is presented and the total of 250MW is seen to be added to the national grid. Figure 9 shows the single line diagram of the Nigeria national grid.

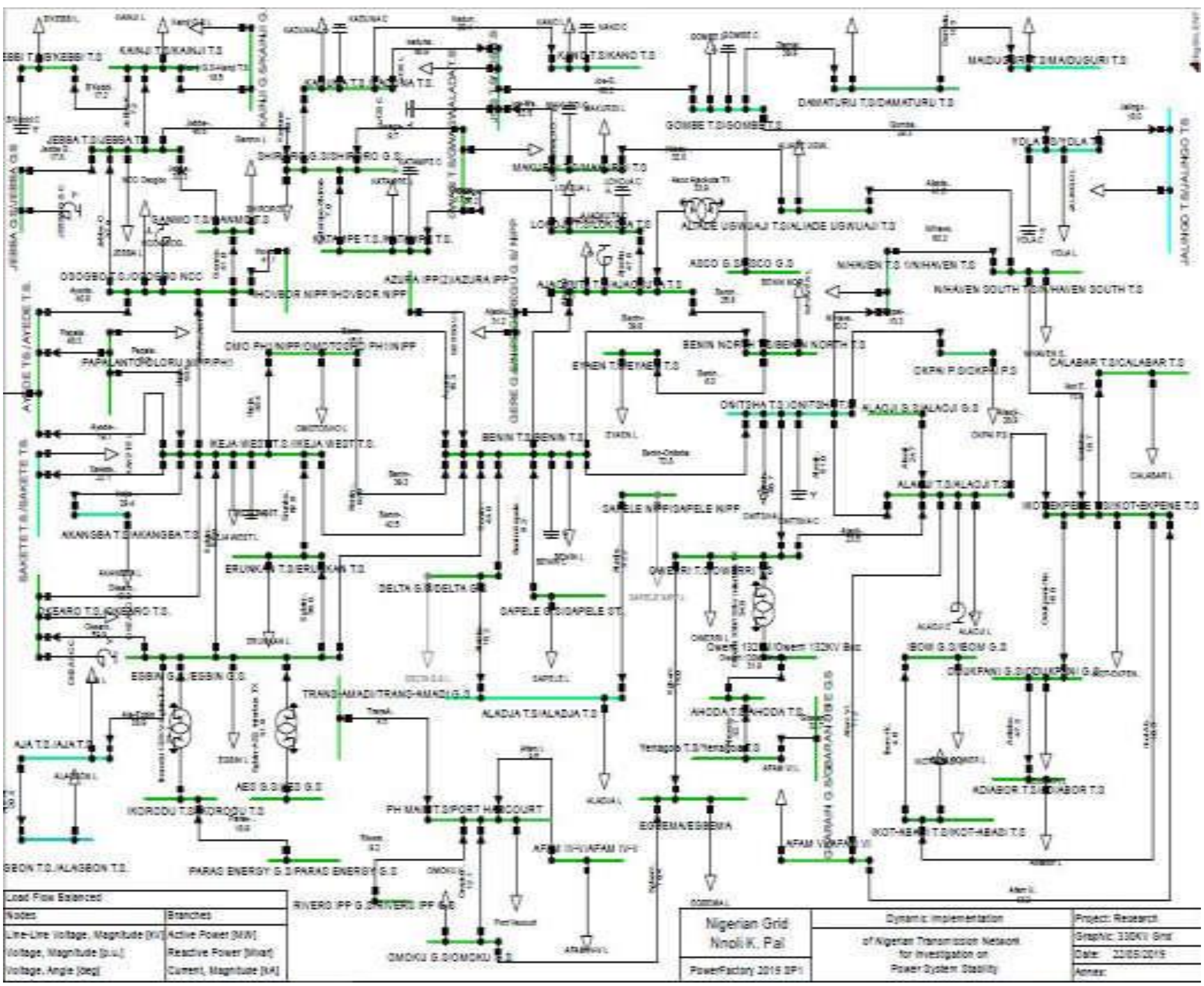


Figure 9 Single line diagram of the Nigeria national grid

IV. DATA ANALYSIS

At specific conditions there is an electro-physical rating of the output of photovoltaic modules. These conditions are known as Standard Test Conditions (STC) these conditions are put down in the table 5:

Table V. Photovoltaic Module Standard Test Condition

Parameter	Symbol	Value	Unit
Irradiance at normal incidence	G	1000	Wm^{-2}
Cell Temperature	T	25	^oC
Solar Spectrum	AM	1.5	-

The STC relates to the IEC 60904 standards, open-circuit voltage Voc, short-circuit current Isc and the maximum-point power (Pmpp) that are indicated for photovoltaic modules to ±10% tolerance. Practically, these conditions happen only occasionally; notwithstanding, assuming sun shines with the predetermined power, then, cell temperature will be higher than 25°C.

In order to analyse the system it is necessary to analyse the effect of varying temperature with constant irradiance as well as varying irradiance with constant temperature which was carried out in MATLAB Simulink software. The table 6 shows the parameters for constant temperature and varying irradiance and table 7 depicts the PV modelled parameter for module SunPower SPR- 415E WHT - D on the effect of varying temperatures and constant irradiance.

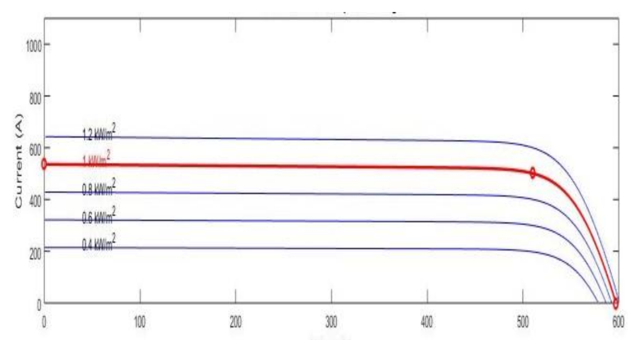
Table VI. Parameters for Constant Temperature and Varying Irradiance

Parameters	Values
Varying Solar Radiation intensities	$1200W/m^2$,$1000W/m^2$,600 W/m^2,$800W/m^2$,$400W/m^2$
Temperature of cells(T_{mod})	25+273(Constant)
Reference Temperature(T_{ref})	25^0C +273
Short Circuit Temperature Coefficient(K_i)	$0.00023mA/^0C$
Reverse Saturation Current (I_{rr})	21×10^{-10}
Boltzman's constant(k)	$1.38\times10^{-23}W/m^2$-K
Charge of Electron (q)	$1.602\times10^{-19}C$
Cell Saturation Current (I_{scr})	0.75Ma
Fil Factor (FF)	0.85
Area of the Module (A_r)	$0.40m^2$
Ideality Factor (*A*)	4
Current Temperature Coefficient(α)	$0.473mA/^0C$
Voltage Temperature Coefficient(β)	$636V/^0C$
Band Gap Energy(E_{go})	6.5eV
Number of Cells in Parallel (N_p)	88
Number of Cells connected in series (N_s)	7

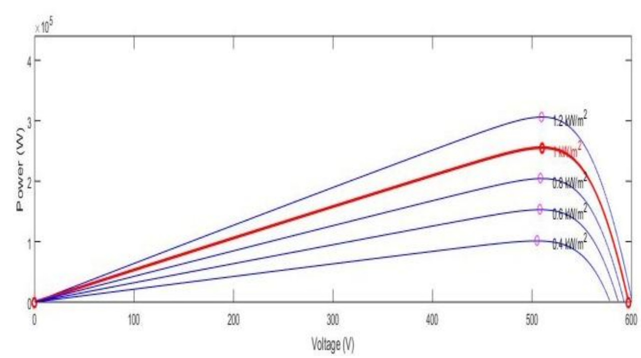
Table VII. Simulation Parameters for Constant Irradiance and Varying Temperature

Simulation Parameters	Values
Varying Solar Radiation intensities	$1000W/m^2$
Temperature of cells(T_{mod})	15^0C, 25^0C,35^0C,45^0C
Reference Temperature(T_{ref})	25^0C
Short Circuit Temperature Coefficient(K_i)	$0.00023mA/^0C$
Reverse Saturation Current (I_{rr})	21×10^{-10}
Boltzman's constant(k)	$1.38\times10^{-23}W/m^2$-K
Charge of Electron (q)	$1.602\times10^{-19}C$
Cell Saturation Current (I_{scr})	0.75Ma
Fil Factor (FF)	0.85
Area of the Module (A_r)	$0.40m^2$
Ideality Factor (*A*)	4
Current Temperature Coefficient(α)	$0.473mA/^0C$
Voltage Temperature Coefficient(β)	$636V/^0C$
Band Gap Energy(E_{go})	6.5eV
Number of Cells in Parallel (N_p)	88
Number of Cells connected in series (N_s)	7

Figure 10a and b shows I-V and P-V curve for various irradiances and constant temperatures respectively. The irradiance ranged from $400W/m^2$ to $1200W/m^2$ while temperature was maintained at 25^0C.



(a) Figure 10(a) Module I-V curves for various irradiances and constant temperature;



(b) Figure 10(b) Module P-V curves for various irradiances and constant temperature

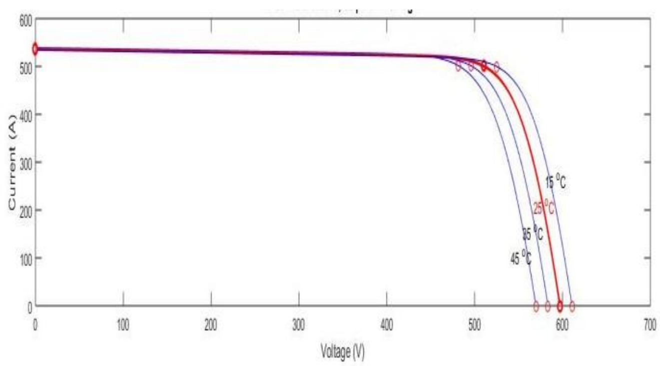
The table 8 shows the PV array maximum power point for different irradiances.

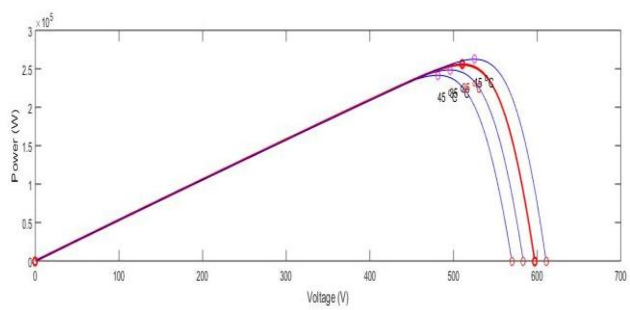
Table VIII. PV Module Maximum Power Point at Various Irradiances

Irradiances (kW/m^2)	Max. Power Point P_{mpp} (W)
0.40	102206.96
0.60	153310.44
0.80	204413.93
1.00	255517.41
1.20	306620.89

Figure 11(a) shows the module's I-V curves for various temperatures and 1000W/m^2 constant irradiance.

Fig. 11(b) shows the P-V curves for various module temperatures at 1000W/m^2 constant irradiance. Table 9 depicts PV Module Maximum Power Point(MPP) and Voltages at various temperatures





(b) Figure 11(b) Module's P-V curves for various temperatures and constant irradiance

Table IX. PV Module Maximum Power Point and Voltages at various Temperatures

Temperature (^{0}c)	Voltage (v)	Max. Power Point Power p_{mpp} (w)
15.00	525.00	236588.56
25.00	510.30	229965.67
35.00	495.66	223370.38
45.00	481.32	216905.12

A. Bill of Engineering Measurement and Evaluation (BEME)

In order to achieve the addition of 250MW into the grid the Bill of Engineering Measurement and Evaluation (BEME) needs to be analysed. This is shown in table 10.

From the Bill of Engineering Measurement and Evaluation (BEME) for 250MW power solar plant, it took One trillion, four hundred and twenty three billion, nine hundred and ten million naira only. At the point of writing this paper this is the cost of the items, as cost of the items might increase or decrease as days, weeks, months and years go by.

(a) Figure 11(a) module's I-V curves for various temperatures and constant irradiance

Table X. Bill of Engineering Measurement and Evaluation

S/No.	Description	Quantity	Unit	Rate(₦)	Amount(₦)
1.	Solar Panel Modules	603,680	W	105,000	63,386,000,000
2.	Inverters	980	W	825,000	808,500,000
3.	Rack mounting materials	603,680 panels	-	17,700	10,685,000,000
4.	LT cables	400 rolls	mm	175,000	70,000,000
5.	HT cables	300rolls	mm	105,000	31,500,000
6.	Battery Energy Storage System	1960	Ah	8,350,000	16,366,000,000
7.	Battery building	5	-	2,300,000	11,500,000
8.	Battery cables	6000pieces	mm	3000	18,000,000
9.	HT panel	-	-	8,500,000	8,500,000
10.	LT panel	-	-	9,300,000	9,300,000
11.	Combiner boxes	790	-	3,000	2,370,000
13.	Straight joint and installation	2	-	1,500,000	3,000,000
14.	Land Preparation(clearing of bushes)	1890 acres	-	30,000	56,700,000
15.	SCADA monitoring rooms	5	-	1,020,000,000	5,100,000,000
16.	Mast lighting	10nos	-	125,000	1,250,000
17.	Tele-control facilities	5	-	1,000,000	5,000,000
18.	Electric Fencing	7650m^2	m^2	900	6,885,000
19.	Thunder arrestor	40	-	17,500	700,000
20.	Earth Pit	20	-	625,000	12,500,000
21.	CCTV camera	4000	-	66,700	226,800,000
22.	Lands	1890 acres	-	700,000	1,323,000,000,000
23.	Miscellaneous	-	-	-	105,000,000
24.	Workmanship	-	-	-	4,000,000,000
	TOTAL				1,423,910,000,000

V. DISCUSSIONS OF RESULTS

From figure 10(a), it should be noted that as the irradiance increased, the current increased while voltage, on the other hand, remained relatively constant throughout the irradiance range.

The temperature ranges between 15°C and 45°C, the module performance was noted to be best at temperature 25°C and 1000W/m^2 irradiance.

From Figure 10(a) and (b), it can be seen that the lower the temperature there is higher maximum power and the larger the open circuit voltage. On the other hand, a lower temperature gave a slightly lower short circuit current.

From the above illustration it can be deduced that as light increases the maximum power output increases thereby increasing the temperature of the PV arrays which will bring about the reduction in the maximum power output. In order to control these fluctuations in power output; it is therefore the reason for converters with maximum power point trackers between the PV arrays and the national utility grid. The requirements at the national utility grid are constant voltage, specified frequency which in this case is 50Hz, and constant power. These were supplied from the PV arrays through series of converters and control systems which ensured to maintain the standard of operations.

VI. CONCLUSION

This paper was to improve the power availability of the national power system using a solar-based enhanced distributed generation technology. The materials for solar energy inclusion to the national utility grid were being analysed and utilized in the system. From the analysis, the 250MWp solar was provided from five locations with each location giving 50MWp solar to the national utility grid. The photovoltaic system for the 250MWp needed 603,680 solar modules, 980 solar inverters, 1,960 Battery Energy Storage System (BESS), 20 step-up transformers and other equipment stated in the paper. The land area used for the 250MWp solar system is 1,890 acres of land. The estimated cost from the Bill of Engineering Measurement and Evaluation (BEME) is one trillion, four hundred and twenty-three billion, nine hundred and ten million naira (₦1,423,910,000,000) only. Electrical parameters as well as standard values for the photovoltaic system were also presented. The simulation done in this paper was carried out with MATLAB Simulink. There was additional 250MW solar power gotten from five locations to the national utility grid.

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