International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1927-1938 www.ijaem.net ISSN: 2395-5252

Improving the Capacity of Power Generation in Nigeria Using Variable Renewable Energy

HarunaIjai, Dr FU Ilo, Michael Jacob
Department of Electrical and Electronics
Enugu State University of Science and Technology

Date of Submission: 20-03-2023 Date of Acceptance: 30-03-2023

ABSTRACT
This paper presents improving the capacity of power generation in Nigeria using variable renewable energy. The aim was to improve daily power generation capacity in Nigeria which has been a major challenge over the years, especially as the demand for power keeps increasing due to the increase in population. This was achieved by developing a 4MW wind turbine model, an 8.5MW photovoltaic generator model; a 12.5MW power bank model, and a converter model which serves as an inverter and rectifier based on the grid requirement. The conventional grid supplied by a 5MW gas plant was analyzed using load flow based on the Newton Raphson algorithm to determine the behavior of the grid based on NERC regulations before the variable renewable energy was integrated to maximize power generation capacity. This was implemented with Simulink and evaluated. The result showed that the generating capacity of the grid was improved with an additional 12.5MW.

Keywords: Photovoltaic, wind farm, power bank, converter, load flow, variable renewable grid.

I. INTRODUCTION

The success of Nigeria's planned socio-economic growth and its development is substantially dependent on the improvements within the power sector. Doubtless, power is the lifeblood of any country's economy and a key driver of industrialization. However, there remains a substantial energy deficit to power Africa's largest economy (Nigeria). Despite having abundant (hydro, wind, thermal, solar) natural resources to produce power, not to mention the billions if not trillions of naira which have been invested in the sector over time by the government, Nigeria's 144-kilowatt hour (kWh) per capita stillremains one of the lowest in the world [1].

In 2001, the Nigerian power sector was reformed, as a result leading to the enactment of the National Electric Power Policy (NEPP), withthe hope of changing the sad story of the power sector's state of affairs. Subsequently, the enactmentand implementation of the Electric Power Sector Reform Act (EPSRA) initiatives, resulted in the then creation of the Power Holding Company of Nigeria (PHCN) and its succeeding power companies, privatizations/licensing of Electricity Generation Companies (Gencos), and Electricity Distribution Companies (Discos) together with the attainment of other EPSRA milestones. Nevertheless, these efforts are yet to make a significant transformative impact on the quality of power supply [2] within the country to date.

It is unfortunate that over twenty years after the reformation of the power sector, Nigeria's power generation capacity is still under 7,000 megawatts (MW), serving a population of over 200 million, compared to South Africa's 51,309 MW serving a population of 56.717 million. According to [1], the crux of Nigeria's state-of-the-art power challenge is therefore the underutilization of energy resources.

Realistically, it is impossible for 6893MW to serve a population of over 200 million people. This, as a result, has overstretched the power system gird, coupling with the dilapidated operating and power system mechanisms which lack proper maintenance due to negligence by the government; all these lead to the characterization of the Nigerian power state of the art as one of the worst worldwide [3].

According to [4], this dire state of Nigeria's power sector is further complicated by transmission constraints and limitations, ranging from instabilities, system collapse, re-occurring black-out issues, voltage sags and slow expansion of transmission grid, and poor transfer capability and capacity. These have resulted in various contingencies such as shortfalls in the available power capacity and line outages.

[5] added that the current demand for electricity to sustain the population demand of Nigerians on daily basis today stands at about 88,282 MW, however, the highest daily peak generated so far prior to this research period is 6893 MW. As a result, over 60% of the country's population lacks stable electricity [6]. There is no doubt that the present power challenges and their effect on the growth of the economy will continue unless the necessary measures are taken to optimize power generation capacity and quality of service. To achieve this, there is a need for the diversification of energy sources in the domestic, commercial, and industrial sectors, adopting modern state of arts like renewable energy to save cost and optimize the production of power supply.

Renewable energy is a form of energy generated from natural sources like sun, water, fossil fuel, wind, and biomass among others. Among these various sources of renewable energy, all have their advantages and disadvantages. Hydro is sustainable, as the water can be recycled, but the implementation cost is very expensive. Biomass and thermal energy required huge space and initial capital for implementation. Wind and solar provide vital features such as efficiency, sustainability, space, and low cost of implementation but are based on weather and climate change. However, considering the demography of the case study area (Nigeria), the environment is best suited for wind and solar renewable energy as the resources are available in abundance on daily bases.Already other countries in [7] [8] and [9], have adopted this approach (wind and solar turbines) to improve their power generation capacities, and today they are reaping the benefits with sustainable power and economic growth.

Therefore this paper proposed to improve power generation in Nigeria using 12.5MW variable renewable energy. The aim is to improve daily power supply quality which as of today is unable to satisfy the consumer's demand. This will be achieved by designing wind farms, and solar farms and integratingthem into a conventional 15MW gas plant as a hybrid renewable grid to improve the generation capacity. This will improve economic growth and sustainability, increase gross domestic product, attract foreign investors, and provide employment opportunities, provide a stable power supply among other benefits.

II. METHODOLOGY

The methodology used for the design was based on the international electro-technical commission (IEC) 1547 standard regulations for the design, implementation, and testing of variable renewable hybrid integrated grids. From this standard, the methodology for the design of the wind turbine was based on the IEC 61400 guide while for the design of the photo voltaic system was based on the Institute of Electrical Electronics Engineering (IEEE) 197 standard. The storage of the grid which is the power bank was developed based on IEEE 1661 standards. These standards are the international regulatory guide for the design and integration of variable renewable grids and are recommended by the Nigerian electricity regulatory commission (NERC) for the optimization of power generation in Nigeria. The hybrid grid was developed using the following wind turbine [10][12], photovoltaic system [12][13], converter, DC Bus, [13][14]. AC Bus, power bankload flow analysis,and variable integrated grid [15][16][17].The methodology for the integration is the centralized method. The system block diagram is presented as shown below;

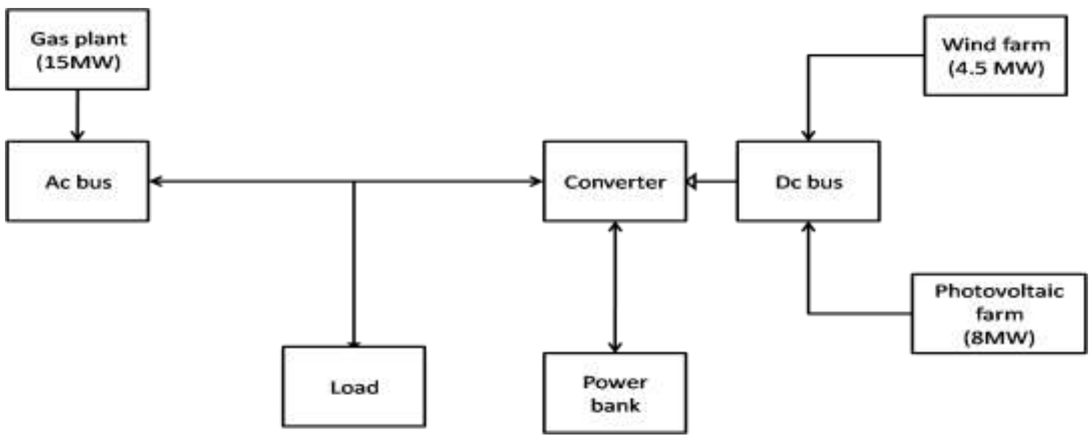

Figure 1: the proposed system

In the block diagram above, the 15MW gas plant is improved using variable renewable grid consisting of 8MW photovoltaic and 4.5MW wind farm. The overall power generated by the variable renewable gridis integrated into the Nigerian national grid (NNG) using the centralized method [12] as a hybrid grid after load flow analysis was performed to determine the NNGcharacteristics based on NERC standard for renewable grid integration. The power bank was used to storeexcess power generated. This power is rectified as the direct current (DC) and used to charge the power bank. However, when power is required by the NNG, the DC is rectified to alternating current (AC) and supplied.

III. SYSTEM DESIGN

The system was designed using universal mathematical models and universal modeling diagrams as shown beginning with the design of the wind farm.

Model of the wind farm

The model of the wind turbine was developed using the relationship between the wind characteristics such as performance coefficient, motor characteristics, pitch angle, air density, and output power characteristics. The model was presented as shown below;

$P_m = c_p(Л, ß)\frac{\rho A}{2}v^3{}_{wind}$ 1

Where Pm is the mechanical output of the wind turbine in watts, c_p is the performance coefficient of the turbine, Л is the rotor blade speed ratio, ß is the pitch angle, A is the swept area of the turbine, ρ is the air density and v is the wind speed. From the model in 1 the $c_p(Л, ß)$ presented the performance coefficient of the turbine with relation to the motor characteristics like the blade pitch and speed ratio. There are related using the model in equation 2 as;

$c_p(Л, ß) = C_1\left(\frac{C_2}{Л} - C_1ß - C_4\right)e^{\left(\frac{-C_1}{Л_1}\right)} + C_6Л$2

Where the constants C_1 to C_6 are the motor characteristics of such as the rotor behavior and blade size, where $Л_1$ is specified as $\frac{1}{Л_1} = \frac{1}{Л+0.08\beta} - \frac{0.035}{\beta^3+1}$; the equation 1 which is the wind energy was controlled using the relationship between the power gain, wind speed, performance coefficient, and nominal power as shown in equation 3;

$P_{m-pu} = K_p C_{p-pu} V^3_{wind\ -pu}$ 3

Where P_{m-pu} presented the nominal power for the turbine swept area and wind density; C_{p-pu} presented the performance coefficient, $V_{wind\ -pu}$ is the wind speed and K_p is the controlled power gain.

Design of the solar plant

To develop the model of the solar plant the characteristics of the solar cell such as rectified current, solar generated current, shunt leakage current, and shunt resistance current interconnected in series and parallel configuration with an internal resistance developed within the circuit during the system operation as shown in the equivalent solar PV cell below;

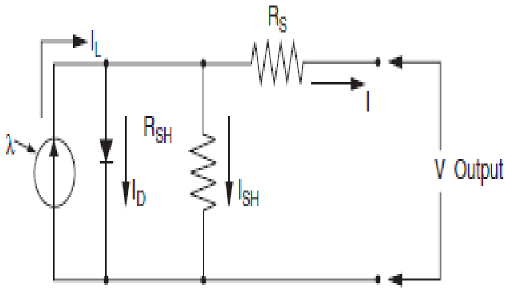

Figure 2: Solar PV cell circuit

From the circuit in figure 2, the relationships between each variable are used to develop the PV output current as shown in equation 4 below;

$I = I_L - I_D - I_{SH}$ 4

Where I is the PV output current, I_L is the solar-generated current, I_D is the rectified current from the diode and I_{SH} is the shunt leakage current. This model in equation 4 presented the output current produced by the arrays of PV cells, however, the efficiency can be minimized using the internal resistance in the cell, but the change in the shunt resistance doesn't affect the output voltageproduced. Equation 3.4 can be remodeled as below;

$I = D_l - I_0\left[e^{\frac{QV_D}{KT}} - 1\right] - \frac{V_{OC}}{R_{SH}}$5

Where D_L is the rectified current from the diode, Voc is the open circuit voltage, R_{SH} the shunt leakage voltage, K is Boltzmann constant, V_D is the voltage of the diode, Q is the electron charge, and T the cell junction point temperature. The equation 5 and the overall output voltage and shunt leakage voltage are used to model the open circuit voltage and diode current as;

$V_{oc} = V + (I * R_{SH})$ 6

Equation6 defined the open circuit voltage of the PV cell, while the diode current was modeled considering the reverse saturation current of the diode, electron charge, the voltage of the diode, and K and T parameters respectively (they are already defined). The model is presented as;

$I_D = I_0\left[e^{\frac{QV_D}{KT}} - 1\right]$7

In the same vein, the circuit current of the cell can be achieved at zero open circuit voltage while the short circuit and solar current generated maintain similar magnitudes [18]. When the temperature generated from the sunny weather is the same for a particular day or at a given time the diode saturation current is the same as shown in the model below;

$$I_O = \frac{I_{SC}}{e^{Q.Voc} - 1} \quad 8$$

According to [17] if the short circuit current of the module is known from the data sheet of the cell therefore at any solar irradiance, the cell current is given as follows;

$$I_{SC} = \left(\frac{G}{G_O}\right) I_{SC} G_O \quad 9$$

Where Isc is the short circuit current, G s the solar irradiance, IscGo is the short circuit current at standard test condition and Go is the solar irradiance at standard test condition which is $1000W/m^2$.

The open circuit voltage can also be achieved with zero output current as shown in the model below;

$$Voc = \frac{AKT}{Q} \log\left(\frac{I_L}{I_o} + 1\right) \quad 10$$

To measure the quality of these PV cells the fill factor parameter is employed. This fill factor is used to determine the total output power the solar arrays can produce and is presented using the relationship between the maximum potential voltage, short circuit current, and a maximum current flowing from the arrays of the solar cells or panels.

$$F_F = \frac{V_{mp} * I_{SC}}{P_{mp}} \quad 11$$

Where V_{mp} the potential voltage of the PV, Isc already is defined in equation 8; P_{mp} the maximum power of the cell which is determined using the model below;

$$P_{mp} = I_{mp} * V_{mp} \quad 12$$

The models developed so far in this section have presented the interrelationships between the various characteristics of the solar cell and how these parameters were used to convert the irradiance collected from the sun to electrical-related parameters such as current, voltage, and power. The models also considered the quality of the cell using the fill factor and determined the output per given time. However to determine the maximum output of the solar cell the relationship between the power of the cell in equation 12, the efficiency, the area of a single model, irradiance and the number of solar cells in the system and presented below as;

$$P_{ot} = \varkappa N A_m G_t \quad 13$$

Where P_{ot} is the optimal power output from the solar cell (Watt), $\varkappa$ *is the efficincey* (%), A_m *is* area of a single module, G the overall radiation collected and N number of solar cells used.

Model of the Power Bank

Renewable energies are abundant in nature, however, some like solar and wind is time dependent and in some particular time of the day is not available to be extracted for direct power supply. To address this issues a power bank was used to store the power generated temporarily and then supply it to the grid after conversion to alternating current. To design the model of the power bank, the model was used as shown in equation 14;

$$C_B = \frac{E_L A_D}{V_B DD_M T_{FC} \varkappa_B} \quad 14$$

Where C_B is the power capacity of the power bank, $E_L$is the electrical load, A_s is the power bank autonomy measured in days, DD_m maximum discharge depth of the power bank, V_B is the size of voltage the power bank can store, T_{FC} is the temperature correction factor and $\varkappa_B$ is the power bank efficiency (%). This model presented the power capacity the bank can store for the grid supply. However, not all the power stored will be supplied to load due to certain attributes of a power bank like charge and discharge rates respectively. Hence to determine these parameters the equation 15 was used to present the charging state for the power bank, while equation 16 discharge as shown below;

$$B_c\ (t) = B_c\ (t-1)(1-x) + [E_{GEN}(t) - \frac{E_L(t)}{\varkappa_{IN}}]\varkappa B \quad 15$$

$$B_c\ (t) = B_c\ (t-1)(1-x) + [\frac{E_{l(t)}}{\varkappa IN} - E_{GEN}(t)] \quad 16$$

Where equation 15 and 16 were used to present the charging and discharge rate of the power bank, however, to compute the overall energy storage capacity for the renewable grid (i.e power generated from the solar and wind turbine systems) the model in equation 1 was used as shown below;

$$E_{GEN}(t) = E_{PV}(t) + E_{WG}(t) \quad 17$$

Where B_c (t) is the total power storage capacity of the power bank, $B_c(t-1)$ is the storage capacity at the hour (t – 1), x is the hourly discharge rate, $E_{l(t)}$ is the load requirement time, $\varkappa IN$ is the efficiency of the inverter which is dependent on the charging current, E_{GEN}(t) is overall energy generated from the renewable systems, E_{PV} is the photovoltaic energy and E_{WG} is the wind energy generated respectively. Since the power bank has been modeled, the runtime is defined as equation 18;

$$B_{RT} = \frac{N_p V_n Q_n \left(1 - \frac{q_{min}}{wh}\right)\left(\frac{24hr}{day}\right)}{I_{ap}\left(1000 \frac{Wh}{kWh}\right)} \quad 18$$

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1927-1938 www.ijaem.net ISSN: 2395-5252

Where B_{RT} is the power bank system operation time, N_p presents the number of the power banks used, where each storage capacity is presented byQ_n, q_{min} is the lowest charging state, I_{ap} isthe mean average primary load per day.

Modeling of the Converter

The essence of the power bank is to store the excess power generated and then supply on demand. However the power stored by this bank is in a DC form and requires a conversion process into AC before flow to the AC bus. The conversion process is also required when excess AC is available for supply to the NNG, hence it was recycled back to DC for the charging of the power bank. Hence a multipurpose converter was designed which has the capacity to convert AC to DC and vice versa. The modeling was presented starting with the DC to AC part of the system which is an inverter model for the variable renewable energy generated and the power bank as shown in equation 19;

$$E_{vr-IN(t)} = E_{vrv-IN(t)} * \varkappa_{IN} \quad 19$$

$$E_{ps-o(t)} = \left[\frac{E_{PW\,(t-1)} - E_{load\,(t)}}{\varkappa_{IN} * \varkappa_{DCG}}\right] \quad 20$$

Where $E_{vr-IN(t)}$the energy output when inverted in (KWh) is, $E_{PV(t)}$ is the energy from the variable renewable systems, $\varkappa_{IN}$is the system efficiency, $E_{ps-o(t)}$ is the output energy from the power bank, $E_{load\,(t)}$ is the energy used by the load, $\varkappa_{DCG}$ is the efficiency of the battery discharge and $E_{PW(t-1)}$ is the total energy which the battery can store at (t-1).

These models were used to convert the power stored in the power bank into AC and then supply it to the line bus. However in a case where the AC is excess as shown in equation 21,

$$E_{S-AC(t)} = E_{vrv(t)} - E_{load\,(t)} \quad 21$$

Equation21 presented the excess AC power supply by the power bank. This reserve is converted back to DC for charging the power bank. To achieve this the converter acts as a rectifier taking the total energy input as in equation 22 and convert to charging current (DC) in equation 23.

$$E_{r-o(t)} = E_{r-IN(t)} * \varkappa_r \quad 22$$

$$E_{r-o(t)} = E_{S-AC(t)} \quad 23$$

Where $E_{S-AC(t)}$ presented excess AC power from the renewable sources, $E_{r-o(t)}$ is the rectified output energy, $E_{r-IN(t)}$ the rectified input energy, $\varkappa_r$ the rectifier efficiency, $E_{load\,(t)}$ load per hour, $E_{vrv(t)}$ is the energy generated by the variable renewable sources.

Model of the Gas Plant

The gas plant was modeled using the general gas turbine transfer function relating weight of the gas, the volume of the turbine, gas density, and the mass transfer rate per given period as shown below;

$$\frac{dTw}{dt} - V\frac{d\rho}{dt}F_{in}(t) - F_{out}(t) \quad 24$$

Where Tw is the gas weight, V is the volume, ρ is the gas density, F is the mass transfer, and t is the time (s). Where the gas glow out of the turbine is defined based on Boyle's law as shown below

$$F_{out} - P\frac{F_o}{P_o} \quad 25$$

And P is the gas pressure, F_o is the outflow of the turbine, $P_o$is the pressure at constant temperature presented as equation 26;

$$\frac{d\rho}{dt} - \frac{dP}{dt} * \frac{d\rho}{dP} \quad 26$$

Combining the models in the last three equations above presents the gas turbine plant as in equation 27, where $\frac{d\rho}{dP}$is the change in gas density with respect to pressure at a given temperature.

$$F_{in}(t) - F_{out}(t) - V\frac{dP}{dt} * \frac{d\rho}{dP} - V\frac{d\rho}{dP} * \frac{dF_{out}}{dt} - T_T\frac{dF_{out}}{dt} \quad 27$$

The transfer function of the gas turbine model in time a and frequency domain using the Laplace function is presented as equations 27 and 28 respectively;

$$T_\tau\frac{dF_{out}}{dt} + F_{out}(t) - F_{in}(t) \quad 28$$

$$H_\tau(s) - \frac{F_{out}(s)}{F_{in}(s)} - \frac{1}{T_\tau s+1} \quad 29$$

Where $T_\tau(t) - V\frac{P_o}{F_o} * \frac{d\rho}{dP}$ is given as a time constant in seconds. While the torque at which the turbine is operated is related to the gas flow rate as shown with equation 30 with k being proportionally constant;

$$T_{in}(t) - k * F(t) \quad 30$$

The signal in equation 30 was controlled and with an excitation system, provides a transient response, stability, and reliability of operation to power a synchronous motor (which converts the torque to power) at a speed modeled in equation 31;

$$S_b = \frac{2ЛF_{rated}}{N} \quad 31$$

Where $S_b$the mechanical speed of the motor, F_{rated} is the frequency rating, N is a number of poles in the motor, Л is the damping coefficient. The relationship between the speed and the torque signal was transformed to model the power capacity (P_{mw}) of the gas plant as shown below;

$$Pmw = \frac{T_{in}(t)}{S_b} \quad 32$$

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1927-1938 www.ijaem.net ISSN: 2395-5252

Variable renewables energy (VRE)

The connection of the VRE was done to integrate the power generated by the three plants as the improved power generated. However before this was done, load flow analysis was performed using Newton Raphson technique in [17]. The essence is to study the variation in the voltage signal based on the network short circuit and impedance angle at the connection point. The analysis also related the behavior of the transformers, transmission lines, and generating plants. The relative increase in the voltage signal (Δ_{vm})was determined using equation 33;

$$\Delta_{Vm} = \frac{[p_m * \cos(\varphi_{ak} + \varphi)]}{p_a} \qquad 33$$

Where φ_{ak} is the value of the impedance angle at the point of connection; φ is the angle between the generator's current and voltages, pa is the power at the connection point, pm is the peak apparent power of the generators.

Now that the load flow has been performed and the behavior of the NNG was determined. The VRE was specified to the compatibility of the load flow result based on equation 33 and then interconnected using the model below;

These three models were combined to produce the hybrid grid presented using the model below as the proposed improved power;

$$E_{GEN}(t) = E_{PV}(t) + E_{WG}(t) + Etw(t) \qquad 34$$

Where E_{GEN} is the hybrid power generated from the three plants, E_{PV} is the power generated by the photovoltaic farm E_{WG} is the power generated from the wind farm and (t) is the running time.

Hybrid renewable grid

The hybrid grid is an interconnection of the variable renewable grid and the Nigerian national grid (NNG). The dataflow model of the hybrid renewable grid is presented as shown below;

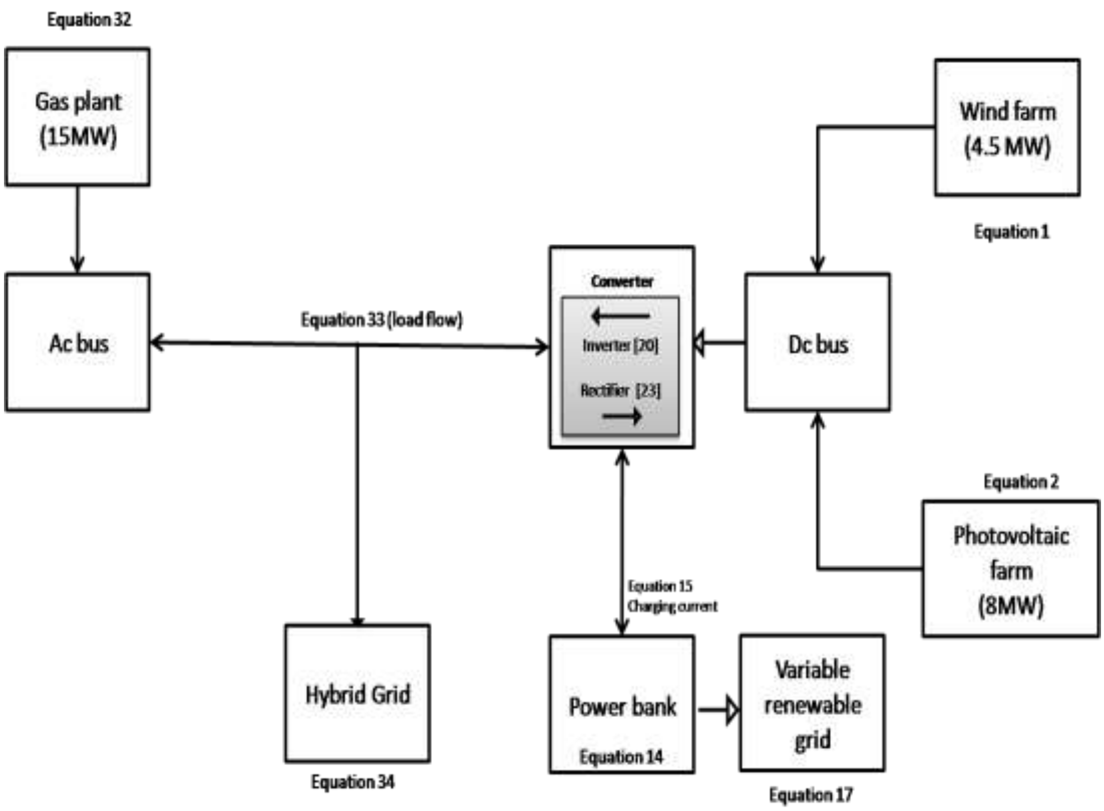

Figure 3: Block diagram of the hybrid grid

From the diagram the equations represented the data flow from each of the plants developed as they are interconnected and supplied to the grid. The power generated by the wind farm in equation 1 was interconnected with the power generated by the photovoltaic system in equation 2 and supplied to stored in the power bank design with equation 14 as via the DC bus as a variable renewable grid with overall capacity in equation 17. When demand arises, the VRE via the power bank is inverted using equation 20 to AC and then supplied to the grid. When the AC is in excess as in the case of equation 21 the signal was rectified using equation 32 to DC and then charged the power bank as in equation 15. The grid is interconnected with the gas plant as shown in equation 32 and before integrating the VRE into the system, the NERC standard which suggests load flow analysis was performed to ensure compatibility between the NNG and the VRE interconnection as the hybrid grid as shown in equation 34.

IV. IMPLEMENTATION

The new generating station was implemented using the mathematical models developed in the system design section and the necessary toolbox with Simulink. The implemented system is presented as shown below;

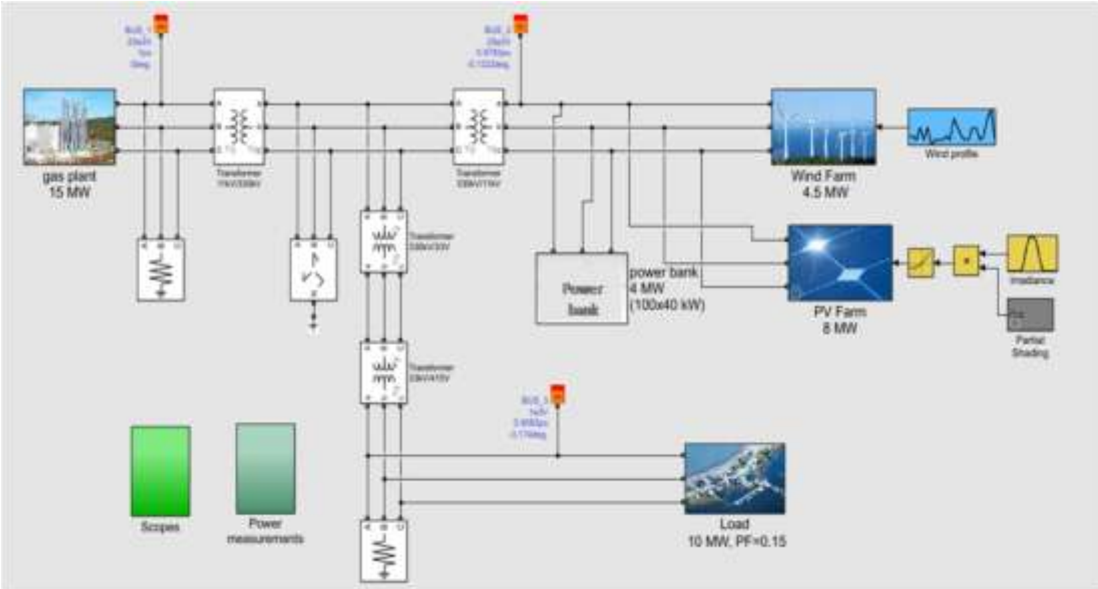

Figure 4: Simulink model of the hybrid renewable integrated grid

Figure 4 showed the hybrid grid system developed with the VRE grid and the gas plant integrated to optimize the generating capacity of the Nigerian power system. From the model, the 4.5MW power-generating wind turbine as modeled in equation 1 was integrated with an 8MW power-generating solar system modeled in equation 12 as a variable renewables grid in equation 17 was interconnected with the conventional 15MW gas plant modeled in equation 32 to produce an optimized power generating capacity in equation 34. The excess power generated was stored in the power bank modeled in equation 14 which is usually rectified in equation 21 to charge the power bank using the charging current in equation 15. When the need for supply arises, the inverter model in equation 20 was used to convert the DC to AC and then supply as a hybrid grid. The Simulink model of the converter is presented as shown below;

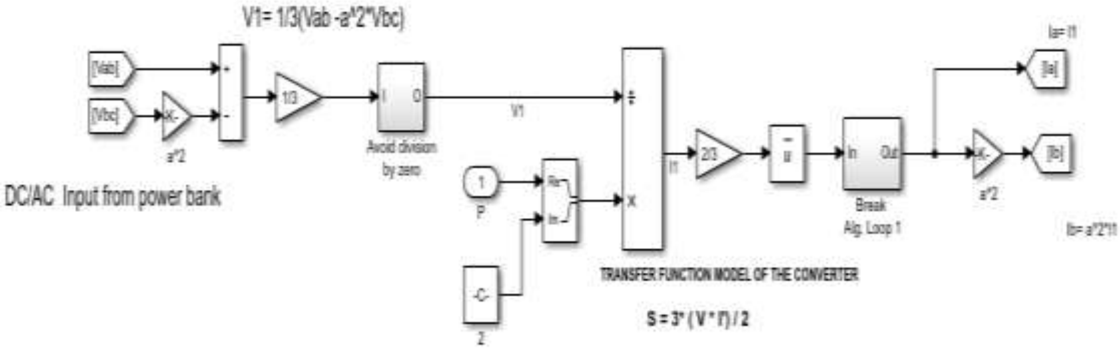

Figure 5: Simulink model of the converter

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1927-1938 www.ijaem.net ISSN: 2395-5252

Table 1: simulation parameters

Parameters	Values
Wind farm Generating capacity	4.5MW
PV generating capacity	8MW
Gas plant generating capacity	15MW
Frequency	50Hz
Runtime	24Hr
Power bank capacity	13MW
Voltage magnitude difference	±0.1

V. RESULTS

The Simulink model was simulated using the simulation parameters in table 1 to produce the results of the power generated by the wind farm, photovoltaic farm, gas plant, VRE, and the hybrid grid. The results in figure 6 present the power generated by the wind farm.

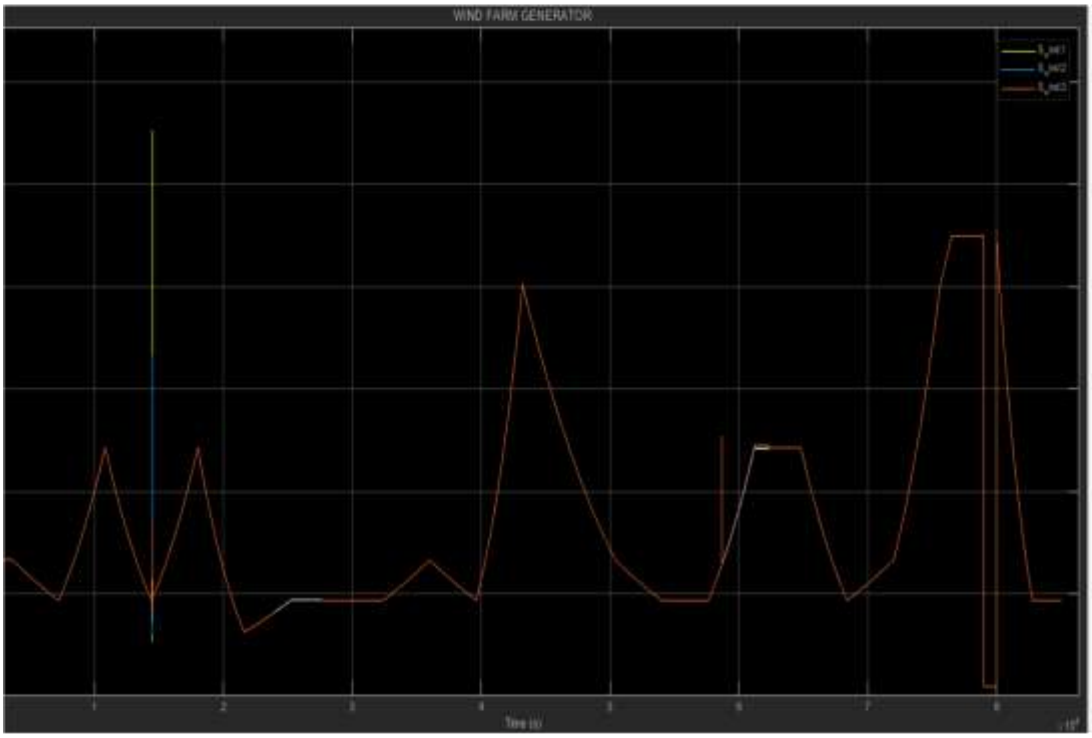

Figure 6: power generated by the wind farm

Figure6 presented the performance of the wind turbine which extracts wind and convert to electrical energy to produce the output power in equation 1. This signal generated from the wind turbine was rectified using a converter into a DC signal as in equation 23 which modeled the rectifier and then supplied in the power bank via the DC bus for storage. The next result presented the power generated by the photovoltaic farm. This generator collects irradiance from the sun and converts it to photo voltaic modules using equation 4 into rectified current in equation 7 and stored in the power bank just like the wind power was stored after conversion in the previous result. The power generated by the photovoltaic farm is presented below;

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1927-1938 www.ijaem.net ISSN: 2395-5252

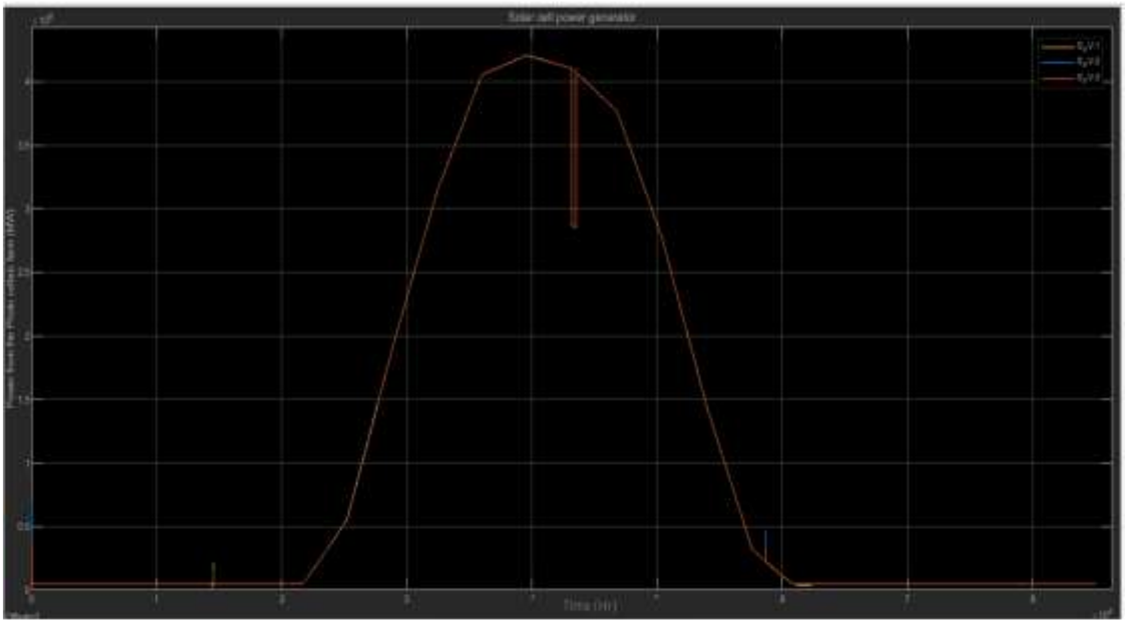

Figure 7: the result of the photovoltaic farm

Figure7 shows the power generated by the photovoltaic farm and integrated into the renewable grid. The peak power is determined as equation 13. The next result discussed how the overall power generated by the wind turbine and photovoltaic farm was integrated as a variable renewable grid using equation 17 and stored in the power bank modeled in equation 14 until when the need for supply arises.

Before this need for supply arises, load flow analysis was used to ensure compatibility between the national grid and the VRE. The energy stored in the power bank was then converted into AC and interconnected to the national grid as a hybrid grid (the overall result will be presented shortly). However, in when the available AC signal exceeds the grid demand, it is rectified and then used to charge the power bank. The charging current is presented in the figure 8 while the power supplied from the renewable grid is presented in figure 9 respectively below;

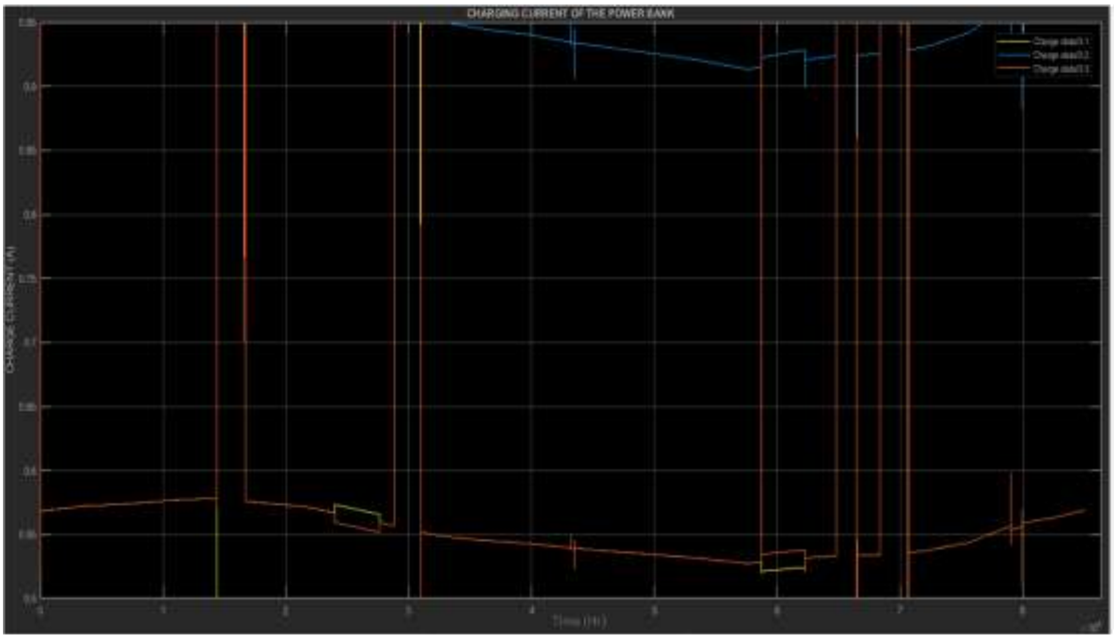

Figure 8: charging current of the power bank

International Journal of Advances in Engineering and Management (IJAEM)
Volume 5, Issue 3 March 2023, pp: 1927-1938 www.ijaem.net ISSN: 2395-5252

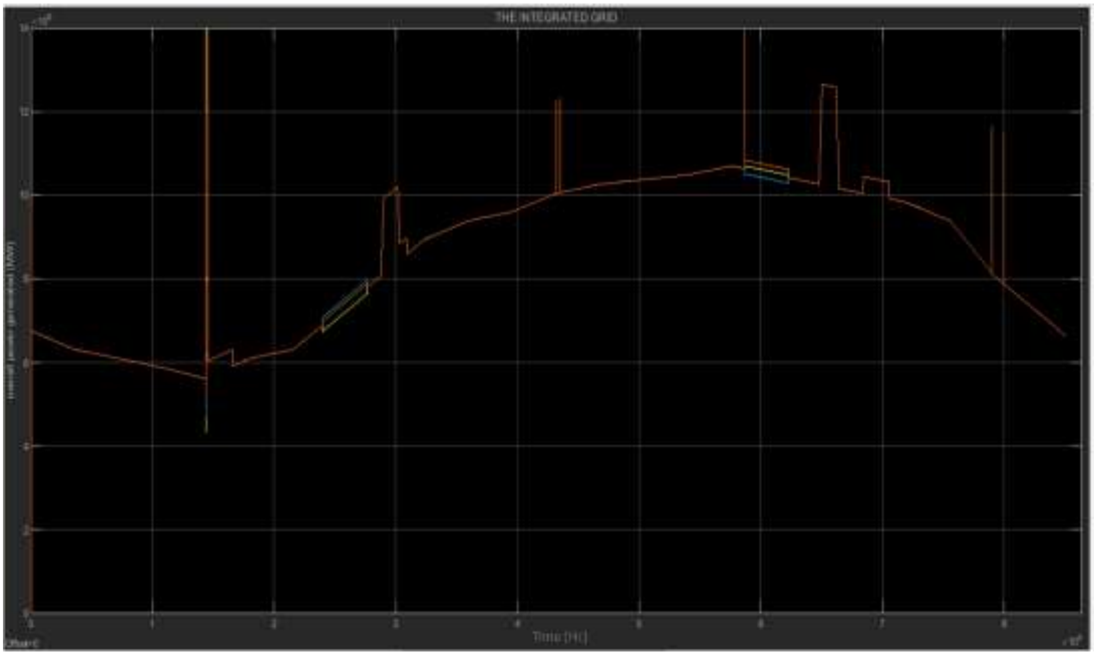

Figure 9: Power generated by the renewable grid

Figure8 and figure 9 presented the charging current and the renewable power generated from the solar and wind turbine collectively as the variable renewable energy grid. This variable energy is then supplied to the grid which is previously feedfeda gas turbine only. This power from the renewable grid has combined the power generated at the gas plant designed in equation 32 already on the grid to form the hybrid integrated grid. The result of the power generated by the gas plant is presented as shown below;

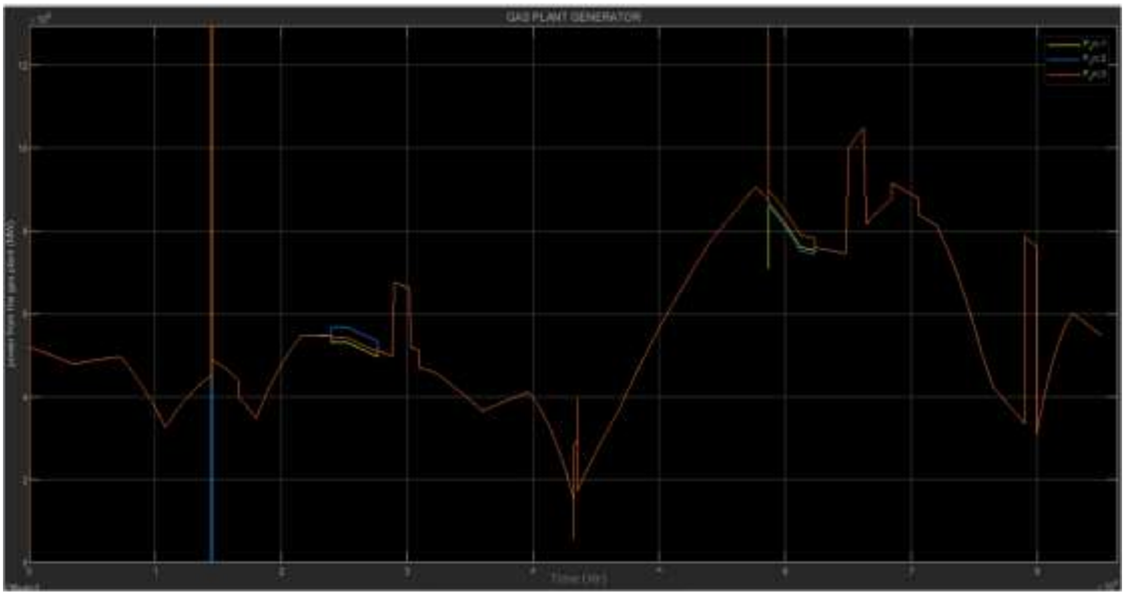

Figure 10: a model of the gas plant

Figure10 showed the power generated by the gas plant. This was integrated with the variable renewable grid already explained earlier to form the hybrid grid as the improved power generating plant which is presented in figure 11.

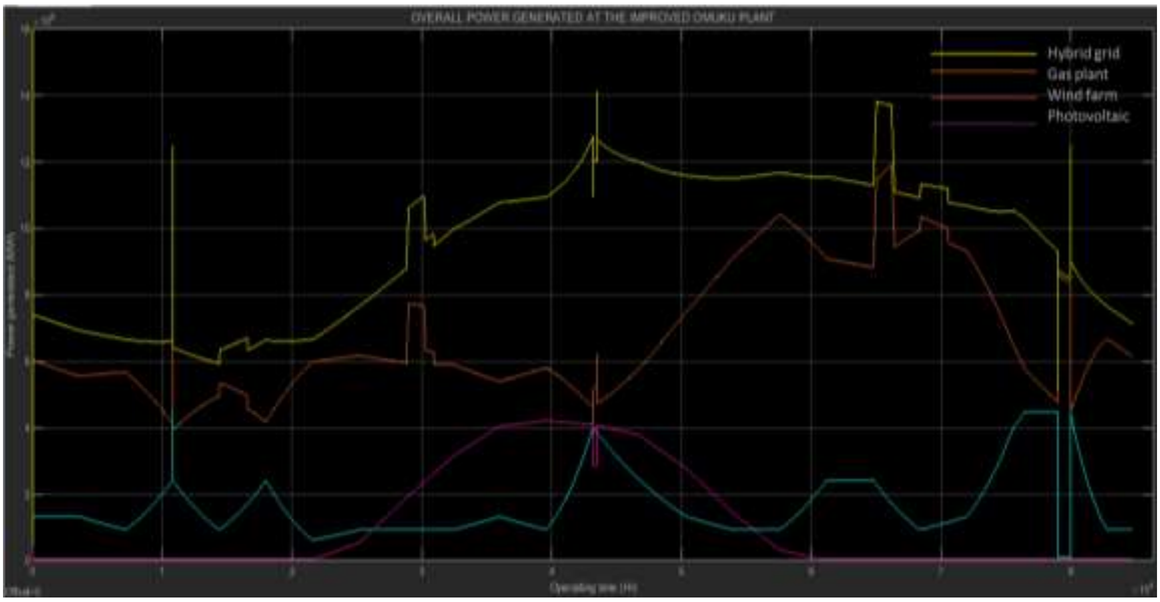

Figure 11: overall power generated

Figure11 presented the overall performance of the three interconnected power-generating plant developed as the hybrid grid system. The result showed the power generated by the photovoltaic farm which is measured with equation 12; the power generated by the wind farm which is measured with equation 1 and the power of the gas plant measured with equation 32. These three models were combined to produce the hybrid grid presented using the model in equation 34.

VI. CONCLUSION

This paper has successfully developed a hybrid grid using variable renewable energy to improve the power generation capacity in the national grid. This was achieved by designing 4MW wind farm, an 8.5MW solar farm to optimize the conventional 15MW generator which supplied the grid. The supply was done following the standard of the NERC which recommends load flow analysis of the grid before integrating variable renewable energy. The improved generating capacity is 27.5 MW.

CONTRIBUTION TO KNOWLEDGE

a) The overall power generation capacity of Nigeria was increased by 12.5MW
b) A 4MW wind farm was developed and implemented
c) An 8.5 MW photovoltaic system was developed and implemented
d) The quality of daily power supply in Nigeria was improved

REFERENCE

[1]. Afolabi E. and Daniel O. ” Embedded power generation and distribution in Nigeria legal and commercial realities” LeLaw Articles; May 2020.

[2]. AwwalHassan ”Excerpts from President Buhari's speech at the commissioning of the Ariaria Market Power Project in Aba on 29.01.2019.

[3]. OgbohV. C. and T. C. Madueme, (2015),“Investigation of Faults on the Nigerian Power System Transmission Line Using Artificial Neural Network, International Journal of Research in Management, Science & Technology 3(4), pp. 87–95.

[4]. Tsado Jacob, Usman Abraham Usman, SakaBemdoo, AjagunAbimbola Susan. Short-term Electrical Energy Consumption Forecasting Using GMDH-type Neural Network. Journal of Electrical and Electronic Engineering. Vol. 3, No. 3, 2015, pp. 42-47. doi: 10.11648/j.jeee.20150303.14

[5]. Salau S. “Nigeria’s Power Demand to Hit 88,282 MW by 2020” Organization of the Petroleum Exporting Countries;

[6]. Mbah N. “TCN Announces New National Peak Of 5,375MW Transmission Company of Nigeria, 2019.

[7]. Ali. MEKKAOUI, Mohammed. LAUER, Younes MIMOUN” Modeling and Simulation for Smart Grid Integration of Solar/Wind energy”Leonardo Journal of

Sciences ISSN 1583-0233 Issue 30, January-June 2017 p. 31-46

[8]. RamadoniSyahputra, Imam Robandi, and MochamadAshari"Performance Analysis Of Wind Turbine As A Distributed Generation Unit In Distribution SYSTEM" International Journal of Computer Science & Information Technology (IJCSIT) Vol 6, No 3, June 2014; DOI:10.5121/ijcsit.2014.6303 39

[9]. DarihunSawkmie, JuleneSeka H. Thabah, MaitshaphrangLyngdoh, SmritiDey "A Review on Stability Improvement of Wind Farm using FACTS Device"ADBU Journal of Electrical and Electronics Engineering (AJEEE) | Volume 2, Issue 1 | February 2018

[10]. Blessing U. Adedoyia A., Stefano P., Joshua M., and Pierluigi L. " Decentralized renewable hybrid mini-grid for rural communities: Sustainability **2020**, 12, 7411; doi:10.3390/su12187411

[11]. Eissa M. Medhat H. "centralized protection scheme for smart grid integrated with multiple renewable resources internet of energy" Global Transitions 1 (2019) 50e60

[12]. Gelma B. Design of a Photovoltaic-Wind Hybrid Power Generation System for Ethiopian Remote area, Ph.D. thesis, Institute of Technology Department of Electrical and Computer Engineering, Addis Ababa University, 2017.

[13]. Getachew B., Björn P. "Feasibility Study for a Standalone Solar–Wind-Based Hybrid Energy System for Application in Ethiopia". Applied Energy, 87(2):487–495,2017.

[14]. Hughes K. "Wind Energy Generation: Modeling and Control". Wiley, 2014

[15]. Jaradat M., Jarrah M., Jararweh Y., Al-Ayyoub M., Bousselham A., Integration of Renewable Energy in Demand-Side Management for Home appliances, International Renewable and Sustainable Energy Conference (IRSEC), Ouarzazate, October 2014, pp. 571-576.

[16]. Quaschning V. Understanding Renewable Energy Systems, Routledge, 2016.

[17]. Solomon T.B " Design and analysis of an off-grid hybrid renewable energy system to supply electricity to rural areas; KTH School of Industrial Engineering and Management Energy Technology EGI-2013-115MSC EKV976 Division of Heat and Power Technology SE-100 44 STOCKHOLM

[18]. Kobia D. and Ilo F. (2017) " Determination of the effect of temperature changes on the power output of solar panel" International Journal of Research in Engineering and Applied Science (IJREAS)