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Integration of 16kV, 300MW PV Solar into Existing 330kV, 600MW Shiroro Transmission Grid in the DIgSILENT Environment

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Abstract----This research paper focuses on Integration of 16kV, 300MW PV (Photovoltaic) Solar into existing 330KV, 600MW Shiroro Transmission Grid in the DIgSILENT Environment, to improve power supply in the Federal Capital Territory (FCT) of Abuja, Nigeria. A hybrid energy system is a system that combines two or more sources of energy for production of electricity. Electricity generated from combination of Photovoltaic Solar and Hydro energy is known as the PV/Hydro Hybrid System. Both home users and electric power investors are attracted towards hybrid generation now due to the rising cost of fossil fuel in addition to its negative impact to the environment. In this work, the existing 330kV, 600MW Transmission Grid and 16kV, 300MW PV Solar Power are modelled in three different scenarios of varying capacity of combined Hydro and PV Solar System. The simulation results of the thermal rating of the five 330kV transmission lines directly connected to the Shiroro network; Jebba-Shiroro, Shiroro-Gwagwalada, Shiroro-Katampe, Shiroro-Mando and Gwagwalada-Katampe in the Base Case scenario are :141.30, 86.70, 131.30, 229.50 and 218.7MW respectively. The Scenario 2 results are: 182.8, 112.5, 205.4, 219.8 and 394.6MW while the third scenario are: 83.50, 13.90, 56.60, 245.90, and 125.00MW respectively. All the values are within the Operational and Statutory Limits of the National Grid Code. However, scenario 2 best validates the efficiency of the proposed integration of PV system to the national grid via the existing Hydro Power generation at Shiroro.

Index Terms---Hybrid Energy System, Solar Photovoltaic, DIgSILENT (Power Factory) Software, 330kV 600MW, Hydro Power.

1. INTRODUCTION

For any nation to attend remarkable development, power sector should not be toiled with. Almost all sectors in every country requires electricity to make positive impact in its economy. While some countries have acquired huge successes so far, others are yet to begin. The need for electrical energy can never be over-emphasised in the contemporary world; it is indeed fundamental to the fulfilment of basic individual and community needs in our modern society [1]. Due to the increased use of conventional sources of energy such as fossil fuels (coal, gas, oil and radioactive ore) all over the world and the associated environmental impacts, efforts have been directed towards minimizing dependence on these resources by increasing renewable energy supply [2]. Similarly, the modern world has consistently emphasized on using renewable energy to generate electricity, which is harmless to the environment [3]. Despite the fact that cost of conventional energy is skyrocketing; it is not environmentally friendly when compared to renewable energy sources. Nigeria as a country is richly blessed with various sources of energy both fossil fuels and renewable energy, but its renewable energy is yet to be fully harnessed. Solar energy precisely, is yet to be tapped in large quantity for commercial power generation in spite the fact that the country is blessed with adequate sunlight annually. Instead, epileptic power supply has been a major source of issue in Nigeria, especially in the Federal Capital Territory (FCT) of Abuja which is the hub capital of the nation.

This research work focuses on integration of 16kV, 300MW PV Solar Power into the existing 330kV, 600MW Shiroro Transmission Grid. Shiroro Hydro Power Plant is used as the Case Study because both Katampe 330kV and Gwagwalada 330kV transmission lines which supply bulk of electricity to the Federal FCT came from the Shiroro Transmission Substation. The modelling of this network is done in DIgSILENT software environment.

An innovative approach was used by the authors in [4] to design, implement and control a hybrid system in South Africa conditions for small rural loads. The authors suggested an implementation of the hybrid prototype system in real time and it will be done using the methodology such as literature review, optimal sizing, model development, and experimentation in other to achieve the objective of the study [4]. The proposed micro-grid hybrid system consists of solar PV, Wind, Pico-hydrokinetic, and Diesel Generator (DG) with storage [4]. The controller receives or sends a signal to any of the Renewable Energy (RE) sources including DG and battery bank on when to be ON/OFF by optimizing the power flow and the expected result was the implementation of this hybrid systems which made the system innovative because it will be deployed in real time in South Africa where many people would have had access to this prototype and make use of it but unfortunately it was not practically implemented [4].

In [5], the authors presented a paper that deals with simulation modeling of grid connected DC linked PV/hydro hybrid system using MATLAB SIMULINK where a 10kw

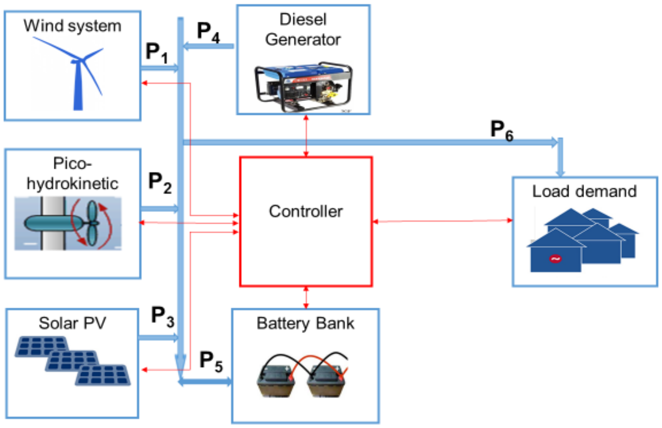

Fig. 1: Proposed System Layout [4].

PV system and 7.5 kW Pico-hydro system were connected in parallel to form hybrid system and this hybrid system was integrated with power grid to supply power to a community in rural area. The schematic diagram is as shown in fig. 2.

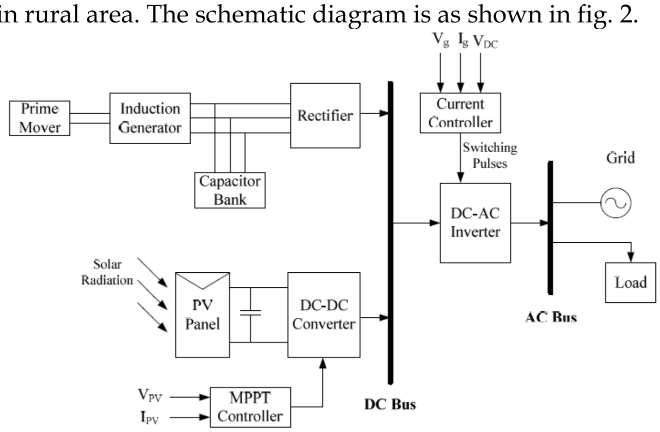

Fig. 2: Schematic Diagram of Grid-Connected DC Linked PV/Hydro Hybrid System [5].

The proposed system was modelled so that in the normal days (when solar and hydro energy are available) the PV/hydro hybrid system will feed power to load without power grid and to integrate the DC link of both the hydro and solar power plant, the generated AC voltage of the Self Excited Induction Generator (SEIG) is converted into DC voltage via diode rectifier [5], while a 132 kV, 2500 MVA power grid is connected to the hybrid system and linear R, RL and IM load are fed by the proposed system. The hybrid system acts as a dominant system where as the power grid will be a standby to compensate the deficit in the hybrid system.A similar proposed system by Sweeka M., Ganga A. and Sushma G. [5] can supply electric power efficiently to a small community with less cost and complexity as compared to the AC linked hybrid system but the reverse is the case when large power supply is required.

A hybrid renewable energy system consisting of solar photovoltaic, wind energy system and micro hydro system that supplies electricity to isolated locations or remote areas that are far from the grid supply was discussed in [6] . E.S. Acharya [6], proposed an idea of integrating the PV and Wind units into an isolated hydro generating unit in other to fulfil the power consumption demand which has risen to a great level in NEPAL.

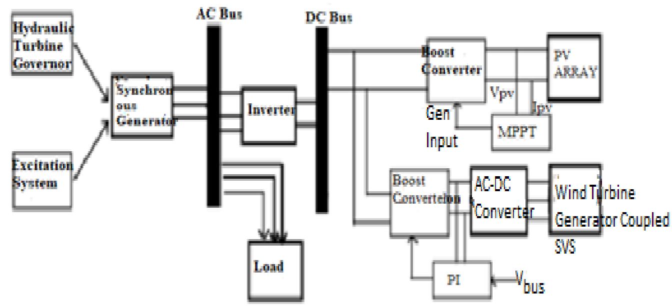

Fig. 3 Block Diagram of the Proposed Hybrid PV-Wind-Hydro System [6]

Figure 3 shows a block diagram of the proposed Hybrid PV-Wind-Hydro System. The simulation was done in MATLAB to analyze the way in which a PV-hydro-wind system can be incorporated and how the load demands of active and reactive power can be fulfilled. The simulation was successful and the main concern of the project which was to strike a balance between reactive power demand of the load and reactive power generation to maintain the system voltage within the acceptable values was achieved as the reactive power required by the load was generated within the inverter, thereby providing effectiveness and flexibility in operation of the overall system [6].Despite the success achieved in the simulation process, other methods were proposed to be incorporated within the system in [6] to make it more reliable, amongst them was to design the system in grid tied mode for the purpose of supplying additional generated power to grid.

A study to explore the best renewable energy-based hybrid configuration for powering a selected village in Burera District, in Northern Province of Rwanda was presented in [7]. The aim of this study according to Odax U. [7], was to come up with a hybrid power system solution from the best combination of RET (Renewable Energy Technology) that will use the resources available in Rwandan rural area to fulfill the electricity demand in a reliable, affordable and sustainable manner with a cost-effective solution. The hybrid was modelled and simulated in HOMER software. Figure 4 shows that AC coupled hybrid system and, the DC generating sources are linked to the AC bus. Batteries are added to the hybrid system and in order to ensure the continuity of the supply without putting severe stress on the battery bank for a reduced overall cost, a diesel generator was also incorporated. According to the authors in [7], hybrid

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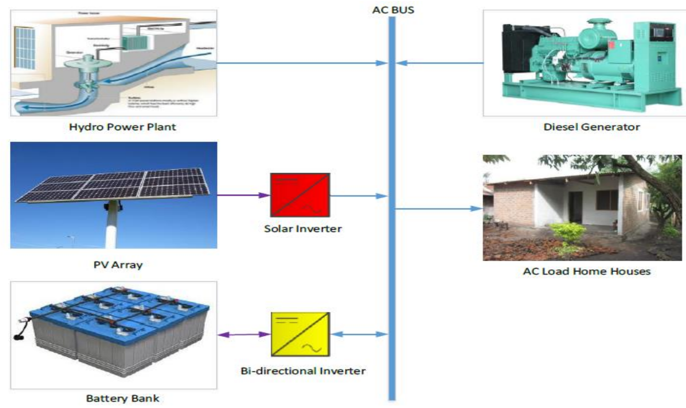

Fig. 4: AC Hybrid System [7]

power system is an excellent option as it is more economical and attractive than grid electricity for electrification of the selected rural community in northern Rwanda. However, addition of batteries cased an increased in the general cost of the system as against a lower operating cost if the system was grid-connected and establishing an energy management system for the micro grid should be considered too.

The design and implementation of a solar-grid hybrid system that provides an economical and sustainable power supply to the DC loads was presented in [8]. A charge controller is designed with Maximum Power Point Tracking (MPPT) technique using perturb and observe method and the output of the charge controller is connected to one of the inputs of diode switching circuit [8].

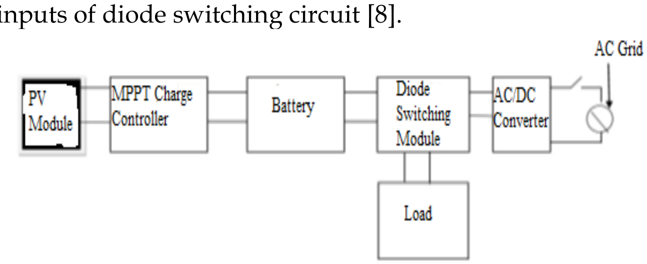

Fig. 7: Block Diagram of the Proposed System [8].

As the loads are considered to be DC only, the AC power supply from the grid is converted to DC by an AC/DC converter and this dc output is connected to the other input of diode switching circuit [8]. There are two inputs to the circuit; one is from battery and the other one is from the AC/DC converter that converts the AC to DC therefore, the battery and grid voltage will be across those inputs and their corresponding currents will flow to load [8]. From the results shown, installing this solar-grid hybrid system will actually be very fruitful because it will reduce the grid dependency as well as promotes green energy which is very important because all the energy sources are depleting day by day.

Kavya S.B et al [9] presented a detailed review of topological advancements in PV-Grid Tied inverters along with the advantages, disadvantages and main features of each different types of inverters. It is recommended that reactive power from the inverter be injected to grid for reactive power compensation in localized networks. Solar-PV panels do not possess reactive power (Q), since they provide electric power by using PV effect [9]. Figure 9 shows a picture of a generic PV-inverter-grid structure [9].

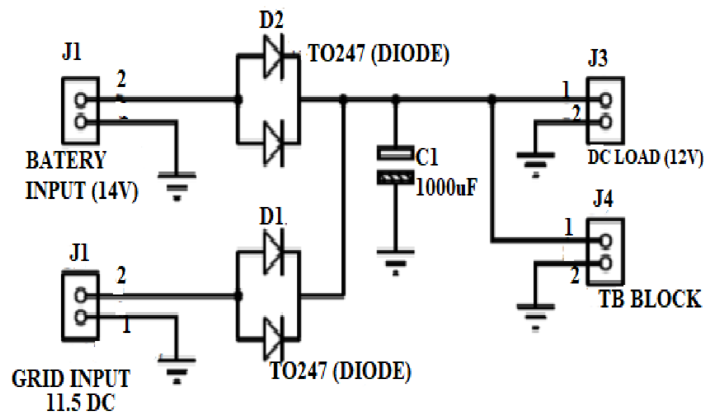

Fig.8: Schematic Diagram of the Diode Switching Circuit [8].

For successful integration to a grid, coordination between the support devices used for reactive power compensation and their optimal reactive power capacity is important for stability in grid power [9]. Now, single-phase, transformer less configurations of range 1–10 kW are gaining interest [9]. The authors in [9] reviewed different topologies of inverters with special reference to state of art topologies such as y source inverter derivatives was presented.

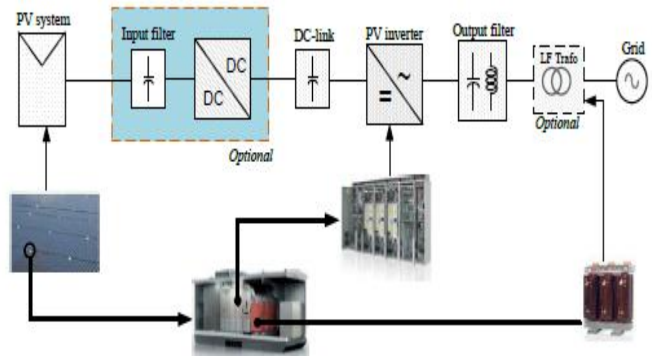

Fig. 9: A Generic Structure of A PV-Inverter-Grid Structure (Picture Courtesy of ASEA Brown Boveri. [9]

Due to the increase in PV-grid application, many standards and Grid Codes are proposed in other to have a secure transmission of power into grid and some of the well-known bodies that develop the standards are Institute of Electrical Electronics Engineering (IEEE) of USA, IEC of Switzerland and Deutsche Kommission Elektrotechnik (DKE) of Germany [9].

Johnson D.O and Ogunseye A.A in [10] worked on the design analyses of roof-mounted Grid-connected 148.5kWp Photovoltaic System with Energy Storage for use in a Local Government secretariat in Nigeria. The design was simulated using PV*SOL software to evaluate the system's production performance and to know the amount of electric power generation for every day of the year and the system energy yield was much more than satisfactory [10]. From the table 1, the least daily energy production is 445.23KWh which occurs in July and highest daily energy yield is 675.27kWh in November as against maximum 131.51kWh daily consumption [10].

Table 1 Monthly Energy Production of The PV [10]

Month	Irradiance onto Horizontal Plane (kWh/m2)	Energy Yield (kWh)	Daily Average (kWh)
January	141.20	19,398	625.74
February	138.29	18,299	653.54
March	155.34	20,053	646.87
April	149.01	18,584	619.47
May	153.20	18,294	590.13
June	129.60	15,539	517.97
July	116.02	13,802	445.23
August	114.58	14,435	465.65
September	120.96	15,521	517.37
October	142.79	18,874	608.84
November	147.40	20,258	675.27
December	140.51	19,529	629.97
TOTAL	1648.90	212,586	

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Government secretariat in Nigeria. The design was simulated using PV*SOL software to evaluate the system's production performance and to know the amount of electric power generation for every day of the year and the system energy yield was much more than satisfactory [10]. From the table 1, the least daily energy production is 445.23KWh which occurs in July and highest daily energy yield is 675.27kWh in November as against maximum 131.51kWh daily consumption [10].
e power generated far exceed demand, hence the need to export to the grid and the system could serve as good revenue source for the government by exporting more than 75% of the power generated to the grid in exchange for good cash from electricity utility; while at same time serving as motivation for home owners in the community as well as other governmental offices to generate some or all of their energy need [10]. The design system was adopted for encouragement of photovoltaic system integration to the grid.
In [11] the authors discuss the integration of renewable energy in Africa, Electricity consumption in Nigeria, and integration of renewable energy in Nigeria. To correctly capture how renewable energy is being integrated in the continent, the effect of adoption of new technology on the performance of a public utility electricity transmission firm is examined. The Transmission Company of Nigeria was used as a case study. Here, a structured questionnaire was sent to members of staff of the Transmission Company of Nigeria, to evaluate the usage of new technology in the company. A total of 400 questionnaires were given out to respondents, with 368 utilizable questionnaires returned. From the results obtained, the author emphasised that, it would be correct to say that the Transmission Company of Nigeria adopted new technology which has enhanced the company's performance, but new technology usage should be extended to utility-scale renewable solar and wind technology. Till now the country has near-zero share in the global grid tied solar PV and Concentrated Solar (CSP) power generation. Hence, the need for the country to invest in utility scale solar PV/CSP generation to boast the country's electricity capacity to the National grid. The research is adopted as hybrid integration to the grid is encouraged.
Salisu M.L., and Wan A.W.Z.A in [12] thoroughly reviewed previous research work conducted on wind energy systems that are hybridized with a PV system. It explored the most technical issues on

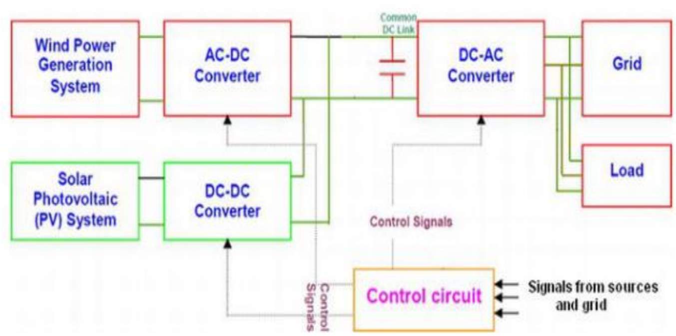

Fig. 10: Schematic diagram of a grid PV-Wind system [12]

wind drive hybrid systems and proposes possible solutions that can arise as a result of integration in off-grid and grid-connected modes [12]. Special attention was given to the issues related to the wind and photovoltaic (Wind-PV) systems. Figure 10 is the system model which systematically shows the different methodology used in the design, simulation, optimization and techno-economic aspects of PV-Wind Systems. Hybrid renewable energy power system can offer socio-economic return when enough power is available in rural areas as business activities is going to be established and the communities do some corn/wood mills, small scale industrial ventures to engage more youth in entrepreneurship [12], but this network was not tied to the grid even when large amount of energy was produced.
The authors in [13], presented the modelling and simulation of solar and hydro hybrid energy sources (HEPS) interface with EU for solving power crisis problems and the simulation was done in MATLAB/SIMULINK environment. All quantities of Hybrid Electrical Power system (HEPS) such as AC output current of the inverter injected to the load/grid, load current and grid current were simulated [13]. Also, the power output from PV and Hydraulic Turbine

Generator (HTG), power delivered to or from the grid and finally power factor of the inverter for PV, HTG and grid were simulated too [13].

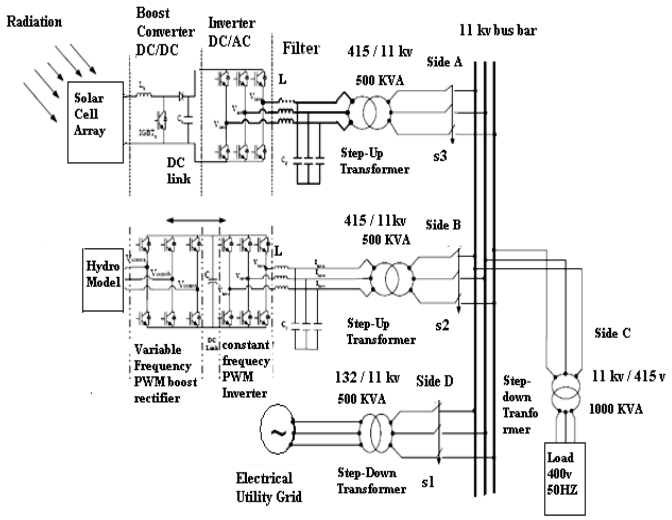

Fig. 11: Power and Control of PV/HTG HEPS Interconnected with EU to Feed the Load [13]

The result showed that the control circuit for the converter for all radiation and hydraulic turbine speed was successfully simulated and the Total Harmonic Distortion (THD) at the local bus was within acceptable limits [13], however the real time environment of the simulation could not be predicted in Simulink simulation, which can be overcome by using real time DIgSILENT Software.

In a related work by Ali Q. et al. [14], the authors presented a paper on the power quality assessment and management of single-stage three-phase Photovoltaic power plants (PVPP), connected to the Medium Voltage (MV) side of the electrical grid. The production and installation of PVPPs have seen a huge increase all over the world and the level of penetration continues to grow, with approximately 100 GW of generated power has been added last year (2019) only, which makes photovoltaic (PV) systems contribute to about 55% of the newly added renewable energy capacity across the globe [14]. Figure 12 illustrates the amount of PV system capacity and annual addition in the recent ten years. According to [14], fulfillment of the standards at the connection point between the PVPP and the main grid will assure that no bad quality of the generated power will be injected into the power system and this increase the system security and stability. Ali Q. et al [14] proposed that the fulfillment of the standards at the connection point between the PVPP and the main grid will assure that no bad quality of the generated power will be injected into the power system and then increase the system security and stability. For power quality, grid codes from countries such as Germany [15], Italy [16], USA [17], and many international standards like IEC standards and IEEE standards [18] have enforced strict power quality rules for PV and other renewable energy sources (RESs) integration. The work is adopted as the proposed research will improve the system security and stability of power system if integrated to the grid. [19] did a study of the hybrid system which consists of small Hydropower, Solar PV and Wind for electrification of the Tadacha Ararasa settlement area with 4100 households (24,600 people).

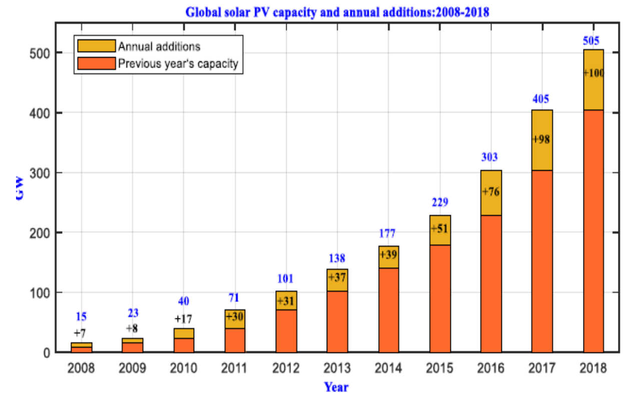

Fig. 11: Photovoltaic (PV) Capacity and Annual Addition in the Last Ten Year [14]

The small hydropower, solar PV potentials and the wind power potential in the site are studied and evaluated. The optimization and sensitivity analysis of the proposed hybrid system model was carried out using HOMER software. In the optimum hybrid system of Hydro/PV/Battery configuration; the PV has a rated capacity of 2,000 kW, mean power output of 410 kW (with minimum output of 0 kW and maximum output of 2,191 kW), daily mean power output of 8,356 kWh and shares 19% of the total annual electric production (3,588.324 MWh/yr) [19]. Electric loads of the community were estimated bearing in mind the irrigation, fishery and other opportunities which will arise after the multipurpose project completion in addition to basic household demand, unfortunately, the hybrid system was a standalone system.

2.0 MATERIALS AND METHODS

2.1 Data Collection

Below is the method used for modelling the system network:

1. The transmission lines, transformers, buses and load data were collected from Transmission Company of Nigeria Corporate Headquarter.
2. The existing 330kV, 600MW Transmission Grid and 16kV, 300MW PV Solar Power are modelled in three different scenarios of varying capacity of combined Hydro and PV Solar System.
3. The modelling, simulation and analysis of results was carried out in DIgSILENT (Power Factory) power tool environment.

2.2 Block Diagram of the PV/Hydro Hybrid System

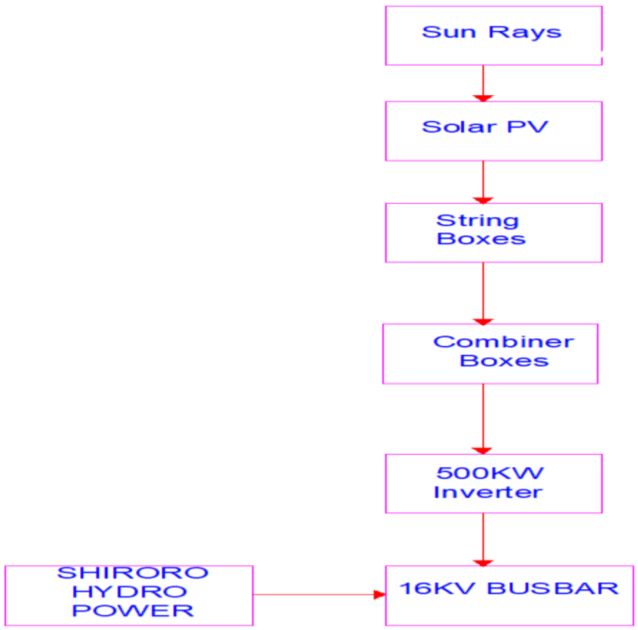

Fig. 12: Block diagram of the PV/Hydro Hybrid System [20]

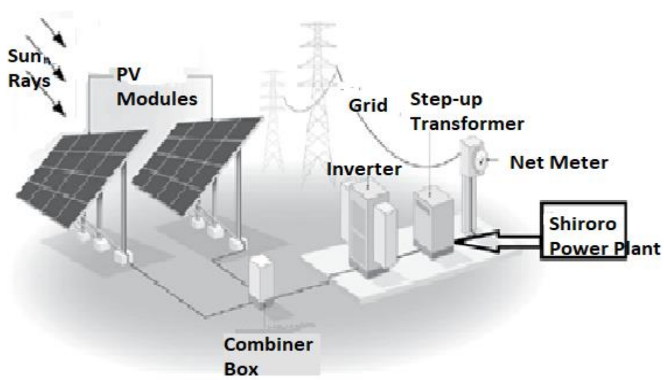

Fig. 13: Pictorial Diagram of the Hybrid System Model

The above picture represents the pictorial diagram of the hybrid system and its major components.

2.3 Single Line Diagram of 100mw Solar PV Plan

A design of 100MW of Solar PV depicts a sample of how the general model of the PV system looks like. The design is done using AutoCAD 2013 tool. A number of solar PV panels are connected through string boxes to different Combiner boxes. The DC output voltage from the Combiner box becomes an input to the modern DC-AC Inverter.

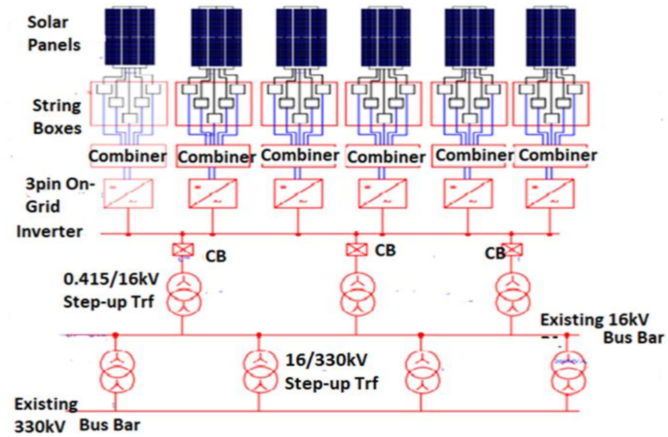

Figure 14: Single Line Diagram of 100MW Solar PV Plant.

The inverter then converts the DC to AC voltage while a step-up transformer further steps the voltage to 16kV which is same as the existing Shiroro generator bus voltage. From this bus, a 16kV/330kV step-up transformer steps the voltage up to 330kV voltage for on-ward transmission to the grid.

2.4 Solar System Calculation

The active power output of a single PV System, i.e. an array of panels connected to the grid through a single inverter is calculated based on irradiance input data and the local time and date [21]. The following equations for the panel and system output are as proposed in [21].

$$P_{panel} = \frac{E_{g,pv} \times P_{pk,panel} \times \eta_{rel} \times \eta_{inv}}{E_{STD}} \quad (1)$$

And

$$P\_system = P\_panel \times [\![num]\!] \_panels \quad (2)$$

where:

- P_{panel} = the active power output of the panel in kW
- P_{system} = the single system active power output in kW
- num_{panels} = the number of panels per inverter
- $E_{g,pv}$ = the global irradiance on the plane of the array in W/m2.
- E_{STD} =the standard irradiance value of 1000 W/m2
- $P_{pk,panel}$ = the total rated peak power of the solar panel in kW.
- η_{rel} = the relative efficiency of the panel, unit-less.

- η_{inv} = the efficiency factor of the inverter, unit-less.

2.5 Practical Calculations of Solar Power Plant Connection

The PV total module for the 100MW solar farm is 285,715 modules with a specification type as TR – 672320WW and a maximum power of 350Wp. The power plants consist of 285,715 modules whose DC output shall be connected to 198nos of 550KVA inverters through a combiner box. The DC output shall be converted to AC by the inverter at 415V. The output of the inverter is connected to a step up 0.415/16kV transformer that steps the voltage up to 16KV for connection to the 16KV existing Shiroro generator busbar.

2.6 Summary of 100mw Solar Farm Equipment Specification

Solar Panel rating is 350Wp, 24Vdc

Inverter power rating is 500KVA

Inverter input voltage is 320 – 1300Vdc

Inverter Output voltage is 415V.

Solar PV arrangement calculation;

Total power to be generated = 100MW

Total no of modules connected into the string box = 36modules shall be connected in series to get a string voltage for the inverter input Vdc.

Therefore;

$$\text{String voltage} = 36 \text{ modules} \times 24\text{Vdc} = 864\text{Vdc} \quad (3)$$

A combiner box collects the power generated from the solar panels as connected in the string boxes. The number of string boxes connected into the combiner box would be determined by the size of the combiner box. The maximum no of string boxes connected to a combiner box is;

$$\frac{Inverter\ size}{series\ connected\ Modules\ x\ Panel\ Watt} = \frac{550000}{36\ x\ 350} = 43.7 \quad (4)$$

Therefore; the total number of string boxes connected to the combiner box is 40 string boxes. The combiner box collects the energy from the string boxes and connects it to the inverter as shown in the connection arrangement diagram in Figure 14.

The maximum combiner box power = No. of string boxes x No. of series connected modules x PV Watt (p) = 40 x 36 x 350 = 504,000W

Total number of modules required for a 100MW PV Solar farm;

$$\text{Pn}\ \frac{\textbf{Power required x No.of srting boxes x no.of modules connected in series}}{\textbf{Maximum Combiner box power}} =$$

$$\frac{100MW\ x\ 40\ x\ 36}{504\text{KW}} = 285{,}715 \text{ modules} \quad (5)$$

The total number of modules required to generate 100MW of power is, 285,715 modules. Hence, to generate a maximum of 300MW of power, about 857,145 modules (i.e. 285,715 x 3) are required.

2.7 Three Different Operational Scenarios

Scenario 1: 80% of Hydro (480MW) plus 40% PV Solar (120MW).

Scenario 2 75% (450MW) of Hydro plus 50% PV Solar (150MW).

Scenario 3 50% (300MW) of Hydro plus 100% PV Solar (300MW).

The reason for the choice of the above different percentage capacities for both the Hydro generation and the PV Solar generation is to ensure that at every scenario, the total generation capacity of the existing 600MW is maintained.

2.8 Case Model

Different combination capacities of a 330KV, 600MW Shiroro Transmission Grid together with a 16KV, 300MW PV Solar are simulated in the DIgSILENT software environment as scenarios 1,2 and 3 as shown below:

a. **SCENARIO 1: 80% (480MW) OF HYDRO PLUS 40% (120MW) OF PV SOLAR**

In this scenario, only 80% of the total capacity of the Hydro Power generation (i.e. 80% of 600MW) and 40% of the total proposed PV Solar (i.e. 40% of 300MW) are connected to the national grid and the simulations are carried out while observing the steady state behaviour of the network as well as its statutory limit.

The amount in capacity of Hydro was reduced, while augmenting the difference in MW with the capacity of PV Solar, which still maintained a total generation of 600MW connection to the grid. The screen shot of the simulation is as seen in Figure 15 and the results are noted.

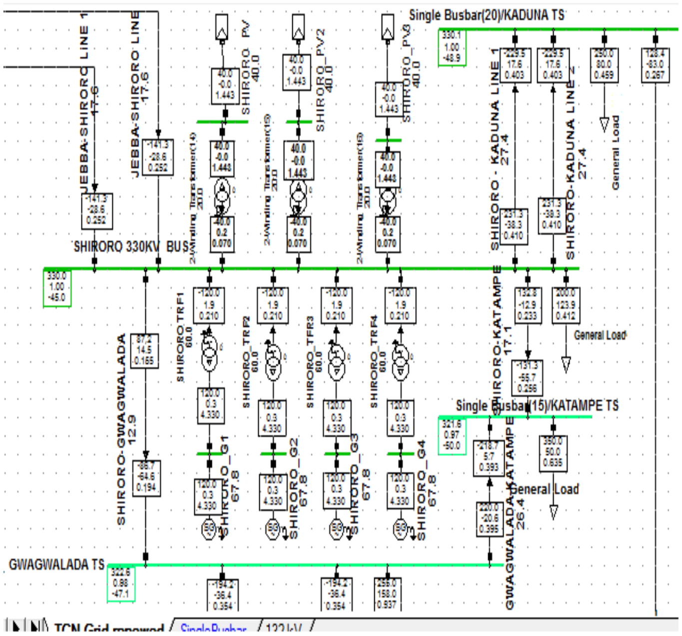

Figure 15: Load flow diagram of Scenario 1: 80% Hydro plus 40% PV Solar

b. Scenario 2: 75% (450MW) of Hydro plus 50% PV Solar (150MW).

This scenario considered 75% of total Hydro generation together with 50% of the total proposed PV

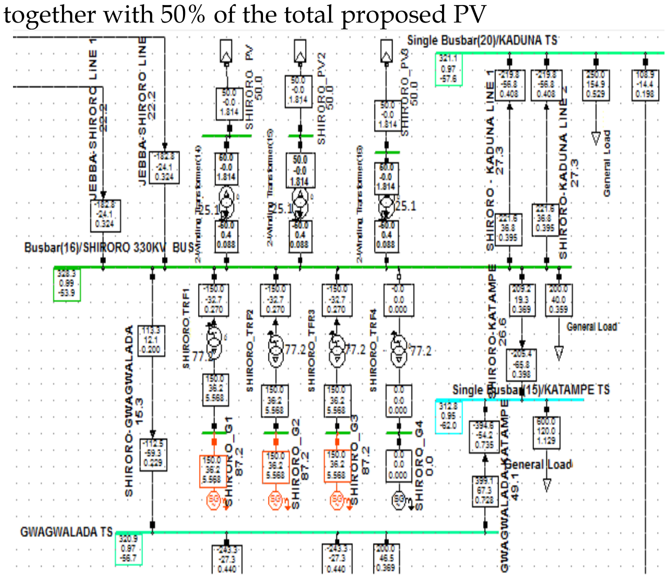

Figure 16: Load-flow Diagram, Scenario 2: 75% (450MW) of Hydro plus 50% (150MW) of PV Solar.

Solar connection to the grid and the simulation are also carried out to see the effect it will have in terms of voltage profile and thermal loadings of the lines. The screenshot of the load flow simulation of the load and the results in figure 16 are further noted.

c. Scenario 3 50% (300MW) of Hydro plus 100% PV Solar (300MW).

Finally, the capacity of hydro was further reduced to 50% while that of PV Solar was increased to the 100%of the proposed 300MW capacity.

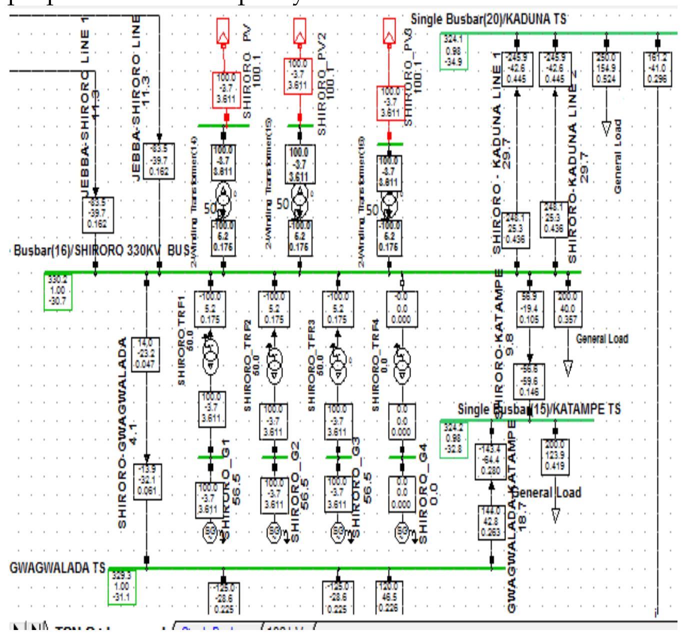

Figure 17: Load flow Diagram, Scenario 3: 50% (300MW) of Hydro plus 100% (300MW) of PV Solar

The simulation was carried out in the DIgSILENT software once again to check its effect in the stability of the system.

3.0 SIMULATION RESULTS

3.1 Scenario 1: 80% (480MW) of Hydro plus 40% (120MW) of PV Solar

The generation capacity of hydro power was reduced to 80% while 40 % of PV solar was integrated to it, bringing the total generation capacity to 600MW.The simulation results as in Tables 2 and 3 showed that both the voltage profile and thermal ratings of the lines are all within operational limits as stipulated in the national grid code.

Table 2: Scenario 1, 80% (480MW) Hydro Plus 40% (120MW) PV Solar

S/N	BUS BAR	VOLTAGE (kV)	VOLTAGE (P.U)
1	Jebba	331.6	1.00
2	Shiroro	330.0	1.00
3	Gwagwalada	332.6	0.98
4	Katampe	331.6	0.97
5	Kaduna	330.1	1.00

Table 3: Scenario 1, Lines Loading: 80% (480MW) Hydro Plus 40% (20MW) PV Solar

S/N	330KV T/L	Loading (%)	Real Power (MW)	Reactive Power (Mvar)
1	Jebba-Shiroro	17.6	141.3	28.6
2	Shiroro-Gwagwalada	12.9	86.7	64.6
3	Shiroro-Katampe	17.1	131.3	55.7
4	Shiroro-Mando	27.4	229.5	17.6
5	Gwagwalada-Katampe	26.4	218.7	5.7

A graphical representation of the lines loadings is as shown in Figure 19. None of the lines is overloaded too.

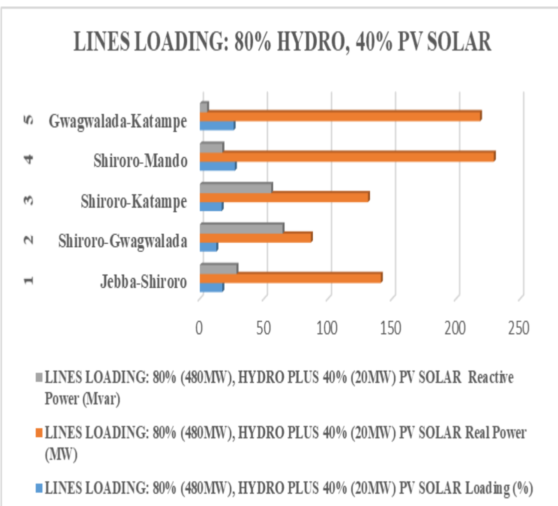

Figure 19: Graphical Representation of Scenario 1 Line Loadings

3.2 Scenario 2: 75% (450MW) of Hydro plus 50% (150MW) of PV Solar

The simulation results as the capacity of Hydro generation was further reduced to 75% whereas the PV solar was increased to 50% bringing the total generation capacity still to 600MW are shown in tables 3 and 4.

Table 3: Scenario 2, 75% (450MW) Hydro Plus 50% (150MW) PV Solar

S/N	BUS BAR	VOLTAGE (kV)	VOLTAGE (P.U)
1	Jebba	331.4	1.00
2	Shiroro	328.3	0.99
3	Gwagwalada	320.9	0.97
4	Katampe	312.8	0.95
5	Kaduna (Mando)	321.1	0.97

Table 4: Scenario 2, Lines Loading: 75% (450MW) Hydro Plus 50% (150MW) PV Solar

S/N	330KV T/L	Loading (%)	Real Power (MW)	Reactive Power (Mvar)
1	Jebba-Shiroro	22.2	182.8	24.1
2	Shiroro-Gwagwalada	15.3	112.5	59.3
3	Shiroro-Katampe	26.6	205.4	65.8
4	Shiroro-Kaduna	27.3	219.8	56.8
5	Gwagwalada-Katampe	49.3	394.6	54.2

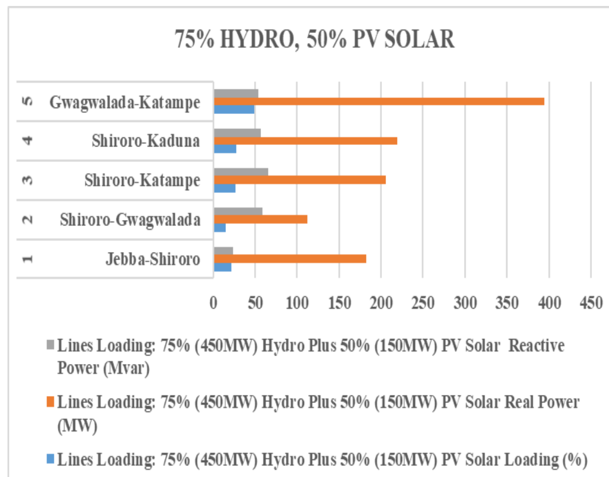

Figure 20: Graphical Representation of Scenario 2 Line Loadings

The simulation results as in Tables 3 and 4 showed that both the voltage profile and thermal ratings of the lines are also within operational limits. The graphical representation of the Line Loadings and the Active Power transmitted is as shown in Figure 20. A continous supply of real power generated is also seen in all the lines, Gwagwalada and Katampe feeding the FCT not withstanding a slight reduction noticed in some of the other lines. Hence, an integration of 50% of the proposed 300MW of PV solar power into the Shiroro network validates the efficiency of the proposed integration of PV system to the national grid as a way of improving the power supply to FCT.

3.3 SCENARIO 3: 50% (300MW) OF HYDRO PLUS 100% (300MW) OF PV SOLAR

Lastly, the simulation results when only 50% capacity of hydro generation with integration of the proposed 100% PV solar in the network was considered are shown in Tables 5 and 6.

Table 5: Scenario 3, 50% (300MW) Hydro Plus 100% (300MW) PV Solar

S/N	BUS BAR	VOLTAGE (kV)	VOLTAGE (P.U)
1	Jebba	331.6	1.00
2	Shiroro	330.2	1.00
3	Gwagwalada	324.2	0.98
4	Katampe	314.9	0.95
5	Kaduna (Mando)	327.1	0.99

Table 6: Scenario 3, Lines Loading: 50% (300MW) Hydro Plus 100% (300MW) PV Solar

S/N	330KV T/L	Loading (%)	Real Power (MW)	Reactive Power (Mvar)
1	Jebba-Shiroro	11.3	83.5	39.7
2	Shiroro-Gwagwalada	4.1	13.9	32.1
3	Shiroro-Katampe	9.8	56.6	59.6
4	Shiroro-Kaduna	29.7	245.9	42.6
5	Gwagwalada-Katampe	18.7	143.0	64.4
6	Lokoja-Gwagwalada	15.7	125.0	28.6

The generation was still maintained at 600MW and the simulation results as recorded for both the voltage profile and the thermal ratings of the lines are as shown in tables 5 and 6 respectively.

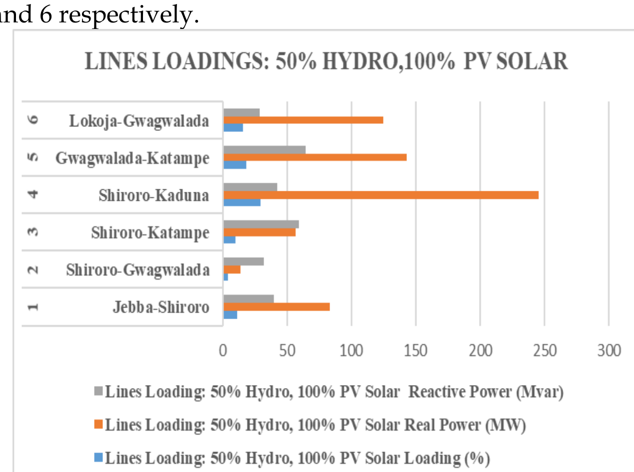

Figure 21: Graphical Representation of Scenario 3 Line Loadings

A graphical reperesentation of the lines loading and the power generated in scenario 3, is also shown in Figure 21.

4.0 CONCLUSION

The PV Solar/Hydro hybrid integration study was carried out for the proposed integration of 300MW PV Solar into an existing 600MW Shiroro Hydro Power Plant via an existing 330/132kV Substation at Shiroro from where bulk power supply to the Federal Capital Territory (FCT) are transmitted. The aim is to reduced seasonal water management usually employed by the management of Shiroro Hydro Power due to lack of adequate power supply during dry season to turn the turbine blades for greater power generation and for improvement of reliable power supply to the Federal Capital Territory (FCT) which is the capital hub of the nation. The simulation results of the thermal rating of the five 330kV transmission lines Jebba-Shiroro, Shiroro-Gwagwalada, Shiroro-Katampe, Shiroro-Mando and Gwagwalada-Katampe in the Base Case scenario are :141.3, 86.70, 131.30, 229.50 and 218.7MW respectively. The Scenario 2 results are: 182.8, 112.5, 205.4, 219.8 and 394.6MW while the third scenario are: 83.50, 13.90, 56.60, 245.90, and 125.00MW respectively. Active power of the lines obtained from the load flow analysis were seen to be within Operational and Statutory Limits in accordance with the National Grid Code. It can be said therefore that it is technically feasible to integrate 16kV, 300MW PV Solar System into the existing 330kV Nigeria Grid via the existing 330kV Shiroro Hydro Power Plant. Among the three scenarios conducted, the best integration for a better robust system is scenario 2, when 75% of 600MW Hydro was integrated with 50% of the proposed 300MW PV as this gave better result in terms of active as well as reliable power supply to F.C.T. Mixed power generation is demonstrated to be better than one single source of generation since one can always compliment the deficiency found in the other.

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