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Dynamic Simulation of an Off Grid Photovoltaic System with backup battery and generator for a Remote house in Nigeria

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***Abstract*— This paper presents the simulation of an off grid Photovoltaic (PV) system with battery and generator backup for a house located in the remote areas of Edo State ,Nigeria. The case study is for a house with a peak load of 1.26kW and 3.4kWh daily energy consumption. The design was carried out using Homer Pro and simulation was performed in the Matlab Simulink software, the system is made up of 1.23kW PV comprised of 4 modules (325W, 2 in series, 2 in parallel), MPPT (maximum power point tracking), a DC –DC buck converter for stepping down the voltage, 4 batteries each of 12V, 350Ahr (48V, series connection), and a backup generator of 4.8kW. The system also incorporates a 1.6kW inverter which converts the output DC voltage from 48V to an equivalent AC. A step-up transformer connected directly to the inverter boosts the voltage from 48V AC to an output voltage of 220V AC for supply to the load. The dynamic simulation results and response to changing inputs are presented in this paper.**

Keywords—stand-alone solar PV, dynamic simulation, Matlab simulink, hybrid power systems, renewable energy.

I. Introduction

The supply of electricity in non-electrified remote areas can be produced by distributed renewable energy [4]. Ankit proposed a Matlab based model of a standalone photovoltaic system for a small rural community of 15 households located in Subardan areas, with each household taking an average electricity demand of 1.7kWh/day, the total yearly load demand for the rural community was estimated to be 9800.632kWh. Using yearly metrological data to develop the model, simulated result shows that the system is exceedingly robust and can handle the dynamics associated with irradiance, temperature, and load demand [1].

Kartika performed simulation and development of Solar PV system for the fulfilment of load demand in isolated areas. The system comprised of PV solar panel, a DC-DC boost converter and a two-level inverter connected to the load. PI controller was used in controlling and maintaining the DC link constant regardless of variation in the input and output parameters which resulted to constant inverter output [2]. Wahyu proposed a PV hybrid with battery backup system for powering a Base Transceiver Station (BTS) telecommunication system to supply telecommunications system in rural communities with inaccessibility to electricity. To supply the BTS load by 43177.78Wh/day with 48V voltage system can be generated with 50 solar panel. From the simulated results it was found that PV modules which is the major generator to supply the base station is not sufficient due to inconsistency in supply, hence, to ensure continuity of electricity supply batteries and generator backup were integrated to the system [5]. Chaudry proposed an off grid PV system for a house in Pakistan having a load of 7.81kWh/day, the system comprised of 8 batteries and 36 PV. From the design, simulated result showed that the configuration is sufficient enough to power the house efficiently independently from the national grid [6]. Arif carried out a design for an off grid solar system for a house with average energy consumption of 40kWh per month located in a remote community in Pakistan, the system comprised of 4 solar panels of 140W, giving a total of 560W PV, 4 batteries each having 125Ahr and a 1kW inverter. Result showed the system provided better electrification solution with an energy production of 726kwh per annum [7].

This paper aims to present the Matlab dynamic simulation of stand-alone PV hybrid system representing a remote residence in Edo State, Nigeria having a peak load of 1.26kW and daily energy consumption of 3.4kWh/day. The system comprises of a 1.23kW PV (325W each), MPPT for maximum power tracking, DC –DC buck converter, a backup battery and generator system with a 1.6kW inverter which converts the output DC voltage of 48V from the converter to an alternating AC. The case study is for a typical house in remote Edo State, Nigeria. The objective of this research is the dynamic simulation of the system. This paper is divided into the following: section 2 shows the site location. Section 3 gives full the system components and specifications. Section 4 provides the dynamic simulation and result. Lastly, section 5 presents the conclusion.

II. SITE LOCATION

The selected site is situated in Edo State, Nigeria. The residence is a two-bedroom bungalow with no access to the utility grid. On Google maps the selected site has the following co-ordinates: Latitude: 6°17'22.2"N, Longitude: 5°59'31.8"E (6.28949409312645, 5.992154342254569). All system components were selected using Homer Pro. Figure 2 shows all components in a block diagram. Table 1 provides a list of all selected components.

Fig. 1. Location of remote site in Edo State Nigeria

III. SYSTEM COMPONENT

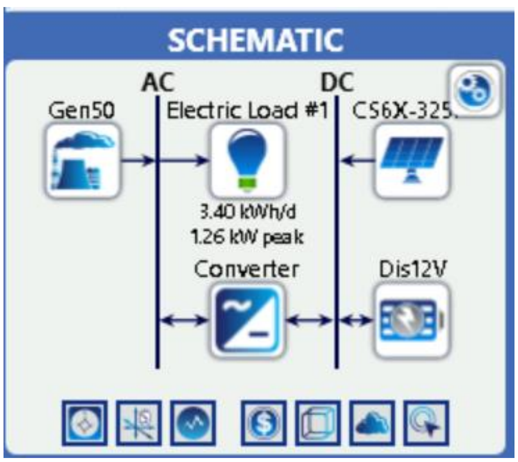

Fig. 2. Homer Block diagram of all selected components

TABLE I. LIST OF SYSTEM COMPONENTS AND SPECIFICATIONS

Appliance	***Quantity***	***Specification***
PV	4, 325W modules	1.23kW
Battery	4, 12V, 350Ahr	48V
Generator	1	4.8kW
Inverter	1	1.6kW

IV. DYNAMIC SIMULATION

The figure 3 below shows the dynamic system design carried out in the Matlab Simulink environment, the configuration of the system is made up of a PV system of 1.23kW comprised of 4 modules each of 325W, with 2 connected in series and 2 in parallel. MPPT is applied to the PV to ensure that the PV gives power at its maximum. The DC – DC buck converter is used to step down the voltage of the PV to the bus voltage of 48V, the PV charges both the battery and supplies power to the load. The system also incorporates a permanent magnet synchronous generator which serves as an emergency backup power system for charging the battery when the voltage of the battery goes below 49V due to inconsistency in solar resources. The output 48V DC from the buck converter is fed directly to the inverter which converts the DC to alternating AC. The 48V AC is stepped up by a transformer to 220Vrms AC which is used to power the load. A MPPT is used to control a DC-DC buck converter. Generator is a permanent magnet type, and its 3-phase output is connected to DC using a full bridge rectifier. Inverter produces 50Hz output that is stepped up to 220V using a transformer. Load is divided into two sets to represent a changing load. System simulation results are discussed in the following sections

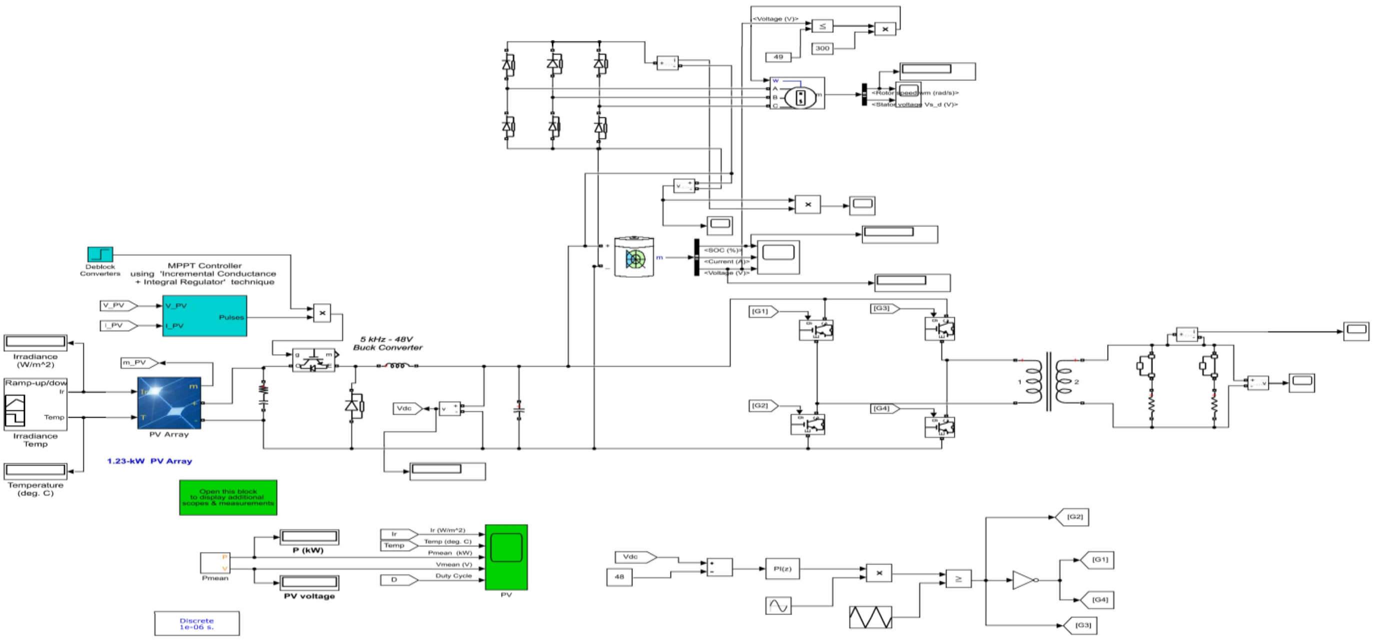

Fig. 3. PV-battery-generator hybrid system simulation in Simulink.

A. *Half load, 50% State of Charge (SOC), and Generator*

The figure below shows the Irradiation, Temperature, Power, Voltage, and duty cycle of the PV. The duty cycle varies according to the solar resources. The flow of the duty cycle follows the Irradiance and power of the PV when the battery is not connected. This result shows that the designed MPPT is able to track the input solar variation.

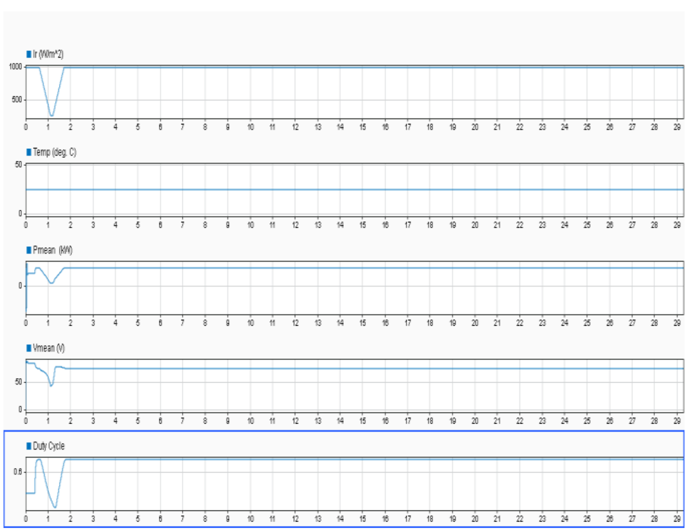

Fig. 4. PV, irradiation, duty cycle, power, voltage signal

When the battery is connected across the circuit, the duty cycle varies according to the voltage of the PV as seen in fig. 5 below. Indicating battery charging while maintaining operation at maximum operating point.

Fig. 5. Duty cycle varies according to voltage of PV

The figure 6 below shows the charging of the battery initially at 50% state of charge (SOC). At 50% state of charge, the battery’s voltage is below 49V at which point the generator of 4.8kW turns on to charge the battery up to the 49V mark and then gradually shuts down after exceeding 49V, leaving just the PV to charge the battery. From the State -of- Charge (SOC) graph it is observed that when the generator is ON the battery charges rapidly, but when the generator begins to shut down, the SOC of the battery increases slowly, this is because the power generated by the generator, 4.8kW is higher that the power generated by the PV which is 1.29kW.

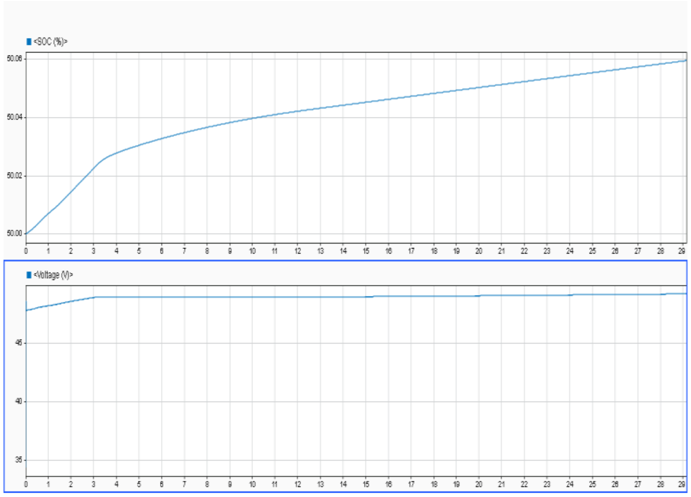

Fig. 6. Battery SOC and voltage

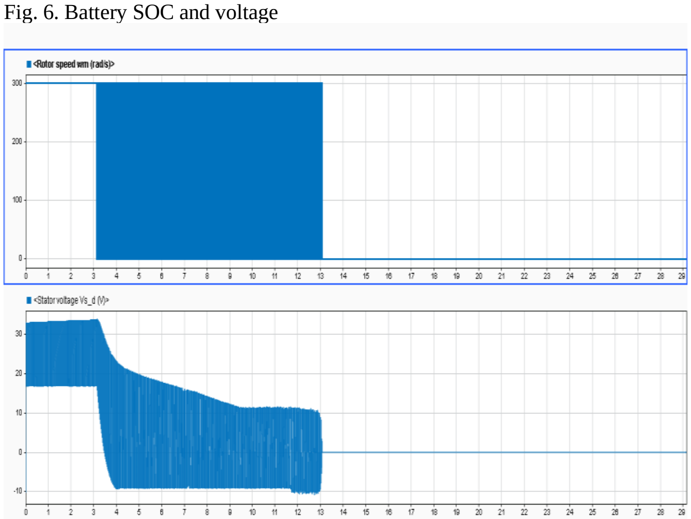

Fig. 7. Generator rotor speed and Stator voltage.

Figure 7 shows the rotor speed of the generator and stator voltage. The generator has a rotor speed of 300rad/sec. while the rotor speed is kept constant, the stator voltage increases gradually when the generator is charging the battery. At half load of 0.63kW, the generator only charges the battery for a short while before the voltage of the battery exceeds 49V and thereafter turns off. From the figure above, it can be seen that the signal changed drastically from 300rad/sec to 0 and from 33V to 0, this is because with half load there is more power going to the battery from the PV therefore the less time it will take for the voltage to exceed 49V and thereafter the generator turns off.

B. *Half load, 98% SOC, Generator*

With half load, 98% SOC, the battery's voltage is above 49V and the Generator will be turned off leaving only the PV to charge the battery and supply power to the load. Because it is half load, when the Irradiance drops to 500kW/m^2/day, the reduction in the SOC is minimal, and when the Irradiation goes back to 1000kW/m^2/day there is a rapid increase in the state of charge of the battery. The PV conveniently charges the battery faster as compared to the full load scenario while also supplying power to the load.

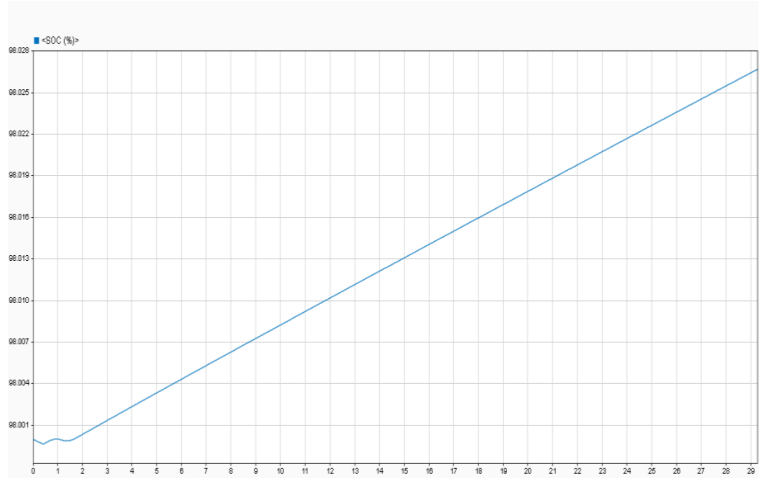

Fig. 8. Battery SOC

Figure 8 above shows the SOC of the battery for a half load scenario when there is a variation in irradiation from 1000 kW/m^2/day to 500 kW/m^2/day. From the figure it can be observed that the SOC initially at 98% only decreased slightly and thereafter a rapid increase in the state of charge. With reduction in solar irradiation, the effect of discharge of the battery is very minimal and with increase in solar irradiation come rapid increase in the SOC of the battery.

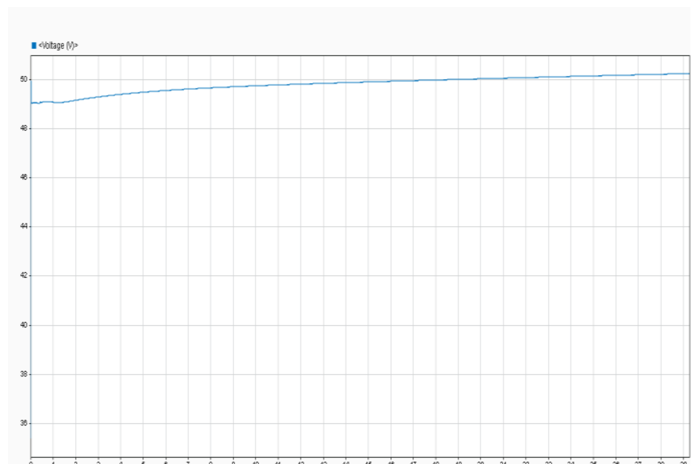

Fig. 9. Battery voltage

Figure 9 shows the voltage of the battery when at 98% SOC with slight decrease when the irradiation reduced to 500 kW/m^2/day and a steady rise in voltage as goes back to 1000 kW/m^2/day

V. CONCLUSION

This paper presented the dynamic simulation of a PV hybrid system with backup battery and generator for a remote area in Edo State, Nigeria. The simulation was tested in several conditions and configuration. The system was first simulated with the battery kept at 50% SOC and half load, it was observed that the PV charges the battery and supplies power to the load at the same time, in the condition were the voltage of the battery goes below 49V the emergency generator turns on and charges the battery until it exceeds 49V and then turns off. Another scenario shows the configuration of the battery kept at 98% SOC and the system was simulated in half load, result shows the PV charges the battery and supplies power to the load, but the difference is that for the case of the 98% SOC the generator is not operational because the battey voltage is above 49V. The system has been simulated and tested in different configurations and result shows that for a remote community, the configuration of PV, battery and emergency backup generator is the most suitable, economical, and reliable option to adopt.

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