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Performance evaluation of 2.4kVA grid-tie inverter

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ABSTRACT

This paper is focused on experimenting the overall performance of a 2.4kVA direct solar power supply system. The overall aim is to implement a solar power supply system without a battery back-up in order to minimize cost. The objectives include measuring the performance of grid-tie inverter, determine its period of operation under load conditions, to make the use of batteries optional in solar power supply system and minimize initial cost of installation. Various tests (variable load, fixed load and no-load) were carried out for the purpose of analysis. A dual trace digital storage oscilloscope was used to monitor the output waveform of the inverter to observe possible harmonic distortion on the waveform. The inverter takes its input power directly from the solar modules (panels) through the maximum power point tracker (MPPT) charge controller. Each category of test was conducted for at least three days of different weather conditions, to determine how variation in the sun's intensity (irradiance) affects the operation of the inverter and its output power. Test results show that the inverter performs its function during the day apart from the early hours in the morning and later in the evening of each day, and the loads were powered successfully during the period of test. The output waveform as observed from the oscilloscope is not purely sinusoidal; it is rather a modified sine wave.

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1. Introduction

Solar power or photovoltaic (PV) is the energy produced when a very small portion of sun's energy is converted to electricity by the action of a semiconductor (such as silicon and germanium) whose chemical properties changes under the influence of incident rays of light from the sun. Solar power is one of the best alternative sources of electrical energy, owing to the fact that it is abundantly available and has no effect on the environment in terms of pollution and other environmental hazards [1]. Solar power supply system can be in the form of a stand-alone where the components are assembled to provide electrical power for remote consumption in residential or commercial areas. It can also be in the form of a grid (grid-tied) where the components are connected to a central power supply network involving other sources of power or solar grid. The components of a solar power system are batteries, charge

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controller, solar panels and inverter. Most grid-tied solar power systems do not involve the use of battery back-up, but some domestic stand-alone direct solar power systems can incorporate a battery (even if it is a dead one), just to regulate the dc input voltage of the inverter, depending on the type of charge controller circuit being employed. In a direct solar or grid-tie solar power supply or photovoltaic system, the converted output dc voltage of the solar modules (panels) is connected to the input of the inverter through a maximum power point tracking (MPPT) charge controller whose function is to track the peak voltage produced by the solar modules, regulate and apply to the inverter.

Availability of uninterrupted electrical power supply is still a major problem in Nigeria, as only less than half of the total population have access to electricity supply [2]. The national power grid is beyond the reach of a vast majority of the people, particularly those who reside in the rural communities. Only about 5,300MW of electricity produced by conventional system of power generation is currently being distributed across the country [3]. There is need to diversify our power generation system by embracing alternative energy such as solar. Solar photovoltaic (PV) power supply system is a very reliable alternative to the existing challenges facing the power supply sector of the national economy. It is a renewable energy with lower cost as regards to grid extension and maintenance. Ekpeyong et al. [3] has indicated that, apart from hydro power, Nigeria is yet to significantly develop other renewable electricity resource. And the country's location around the equator exposes it to high radiation from the sun, which is fairly well distributed across all parts of the country. Also, Nigeria enjoys a total solar radiation that varies from about 12.6 MJ/m^2 per day in the coastal latitude to about 25.2 MJ/m^2 per day in the far North. With an average of 19.8 MJ/m^2 per day and average sunshine hours of 6 hours per day, Nigeria is capable of getting 100% of its electrical energy need through solar power [3]. The light emissions from the sun are harnessed and converted to dc power by the solar modules or panels, which can either be used directly for dc applications or converted into ac power with the aid of an inverter for ac loads.

Inverters convert dc voltage into ac depending on the type of system. Grid connected solar power supply system utilizes the generated electrical power from the sun more effectively, with low cost of installation since batteries are not required for it to operate. Batteries are considered to be more expensive than other components of a solar power supply system, and they are required to be replaced after a period of time when the battery chemistry is worn out [4], [5]. When a PV system is connected to a power utility grid, there could be a reduction in the cost of electrical energy consumption, provided all the technical requirements are satisfied to ensure the safety of the PV system and the reliability of the utility grid [6] – [8]. A boost converter is simply a dc-to-dc converter whose function is to increase the output voltage of the solar panel to a level high enough to charge the battery: for instance, if a 48V battery bank is used, a boost converter is needed to maintain the 48V or increase the voltage slightly higher so that the batteries can be charged particularly during the period of low radiation from the sun. The boost converter comprises a diode, capacitor, an inductor and a switch, and their values are designed according to the voltage required. The switching operation is controlled by the duty cycles generated by the MPPT. The procedures described in [9] – [11] indicate the use of battery back-up for storage and voltage regulation as well as dc-to-dc conversion, whose configuration is not known. A huge investment is involved in setting-up solar power supply such as this because, batteries are very expensive and they are required to be replaced after a period of time when the battery electrolysis becomes weak as a result of worn-out chemistry. There is need for further research into other forms of PV systems where the involvement of batteries becomes optional either in the form of back-up regulation or for energy storage in places where there is no other source of electrical power supply available apart from solar.

Solar inverters that can operate without battery are available in the market. The inverter is connected directly to the load terminals of an MPPT. So long as there is sunlight during the day, the desired electrical energy can be obtained with accurate load sizing and selection of appropriate PV system components such as solar panels and voltage regulator [12]-[14]. Nigeria's location in the world enables every settlement in the country to enjoy abundant solar radiation from the sun, which can be converted to electrical energy even in a cheaper way. Therefore, it is necessary to access the performance of a direct solar power supply system in a locality such as Ekpoma, Nigeria in order to encourage both private individuals and government agencies focus on providing adequate and uninterruptable power supply for the generality of the people.

2. Literature Review

The efficiency of a 5kW solar power system was analyzed in [10] by modeling the various components such as solar modules, MPPT, buck boost converter and the battery bank. The overall aim of the study was to determine how much, irradiance on solar panel and temperature affects the power output, power losses, system efficiency and the total electrical energy delivered to the load in a standalone photo voltaic system. MPPT technique is used to track the maximum available power from the solar panels, by drawing the variations in the power input to deliver maximum power output. This is done with the help of a control strategy known as perturb and observe algorithm [9]-[10].

In [15] a template for observing the performance and safety of the inverter connected in a power grid was provided. The data acquisition system used, measures the dc voltage, dc power and the real ac power generated by the inverter over an interval of time. The efficiency of the inverter can be deduced by empirical analysis and thereafter, compared to the efficiency derived from the performance model of the inverter. This will help to determine the failure in performance of the system so that appropriate repair adjustment procedures can be carried out to ensure peak level performance and avoid future malfunctioning of the inverter [14].

Hybrid power system involves the connection of different electrical energy generation systems to achieve a single output power supply [16]. There is the standalone hybrid power system and the grid connected hybrid power system. Various countries like Taiwan and Ethiopia have adopted this method of power supply in commercial and remote areas as a way of providing power supply to the populace, depending on the purpose of implementation [3], [17]. The hybrid system comprises the conventional sources such as hydro chemical and nuclear energy as well as renewable sources such as solar and named energy. Inverter is one of the major components of hybrid power system.

Grid-tied inverter is capable of feeding energy into the power distributing network, provided it is a pure sine wave alternating current with the same frequency and wave form as the power distribution system. Inverter performance is an important condition for connection to the power grid, and several researches geared towards improving on this performance are ongoing across the world by developing different models to improve on the efficiency and reliability of the hybrid power supply system [15]. Grid-connected inverter also acts as a coupling device between the generated solar power and the power utility grid. It bridges the transfer of power from the solar panels to grid, produces it, generates a pure sine wave and operates on the same frequency and voltage like that of the grid. And so, the inverter output voltage and frequency fluctuation must be controlled by synchronizing these two main parameters [12]. Voltage and current control techniques are used for this purpose [18]. Voltage control is used to maintain a constant output voltage with the utility grid voltage, because the grid voltage determines the overall operating voltage of a grid power distribution system. Current control involves the adjustment and feeding a certain amount of current that will produce a corresponding voltage approximately equal to the predetermined value of power supplied to the grid. Current control also helps to regulate the PV system with the use of MPPT. Basically, a grid-connected system comprises solar panels, MPPT input inverter and the control system [18], [19].

3. Materials and Methods

The major component of a grid-tied solar power supply system is the inverter, which converts dc voltage generated by the solar panels directly to ac. The solar modules are tilted at an angle of 24˚ to the roof-top of a building in Ekpoma, Nigeria (Latitude 6.7491ºN and Longitude 6.0732ºE). The generated voltage of the modules is regulated with the aid of a maximum power point charge controller, to maintain a steady voltage at the input of the inverter. Batteries may be used also for regulation, but for stand-alone systems. The inverter output voltage was measured and tested by applying various loads, as well as observing the waveform on a digital storage oscilloscope. The apparatus used are as follow:

(a) Bulbs: seven 60 W bulbs (load)
(b) Laptops: eleven 65 W laptops (load)
(c) Ammeter: Model-MY64
(d) Voltmeter: Model-UT 61B
(e) Clamp meter: Model-Mastech 266
(f) Oscilloscope: Model-UTD2102CEX

The main characteristics of measuring instrument used are presented in Table 1. The components design specifications are listed in Table 2. The inverter was connected through an ammeter to the terminals of the MPPT charge controller to measure the dc current drawn by the inverter. A voltmeter was connected across the charge controller terminals to measure the dc voltage. The output of the inverter was connected to the load through an ammeter, which helps to measure the load current ac. The test circuit was set up as shown in Fig. 1 with a voltmeter connected to measure the solar array voltage. Another voltmeter and an ammeter were connected between the MPPT charge controller and the inverter input to measure the voltage and current from the MPPT Charge controller. Also, another voltmeter and ammeter set to ac range was placed between the inverter and the load to measure the output voltage and current of the inverter. A 60 W bulb was connected to the output of the inverter in steps, and the values of input and output current and voltage readings for every step are recorded.

Table 1 Characteristics of measuring instrument used

Instrument Used	Measurement range	Recording resolution	Accuracy
Ammeter	0 – 10 A	0.00001 A	±0.0005 %-
Voltmeter	0 – 1000 V	0.00001 V	±0.0005 %-
Clamp meter	0 – 500 A	0.00001 A	±0.0005 %-
Oscilloscope	0 – 100 MHz	-	-

Table 2 Design specifications of components used

Inverter		Solar panel		MPPT charge controller	
Parameters	Values	Parameters	Values	Parameters	Values
Power rating	2.4 kVA	Power rating	100 W	Input/output current	80 $A_{DC\ (max)}$
Frequency	50 Hz	Number of panels	20		
AC output voltage	230 V	Voltage max. power	17.5 V_{DC}	PV voltage	150 $V_{DC\ (max)}$
DC input voltage	24 V	Current max. power	7.43 A	PV current	60 $A_{DC\ (max)}$
Efficiency	60 %	Connection	Series/parallel	Efficiency	95 %

Conversely, for the fixed load test, the inverter was connected through an ammeter to the terminals of the MPPT charge controller (Fig. 2). The ammeter helps to measure the dc current drawn by the inverter. A voltmeter is connected also across the MPPT charge controller terminals to measure dc voltage of the charge controller. Then the output of the inverter was connected to the load through an ac ammeter to measure the current drawn by the load. The test circuit was set up, as shown in Fig. 2, with a voltmeter and ammeter connected to measure the charging voltage level and current. Another voltmeter and an ammeter were connected between the MPPT charge controller and the inverter to measure the voltage and current from the MPPT charge controller. Also, another ammeter and voltmeter set to ac range was placed between the sine wave inverter and the load to measure the output voltage and current from the inverter. A fixed load of 1.135 kW was connected to the output of the inverter, and the initial conditions of the input and output characteristics of the inverter were recorded as well as the charging characteristics. The values of input and output current and voltage readings are recorded. For the no load test, a voltmeter and ammeter were connected to measure the charging voltage level and current (Fig. 2). Another voltmeter and an ammeter were connected between the MPPT charge controller and the inverter to measure the voltage and current from the MPPT. The inverter was switched ON without any load connected to the output. The experimental setup for measurement and observation is shown in Fig. 3.

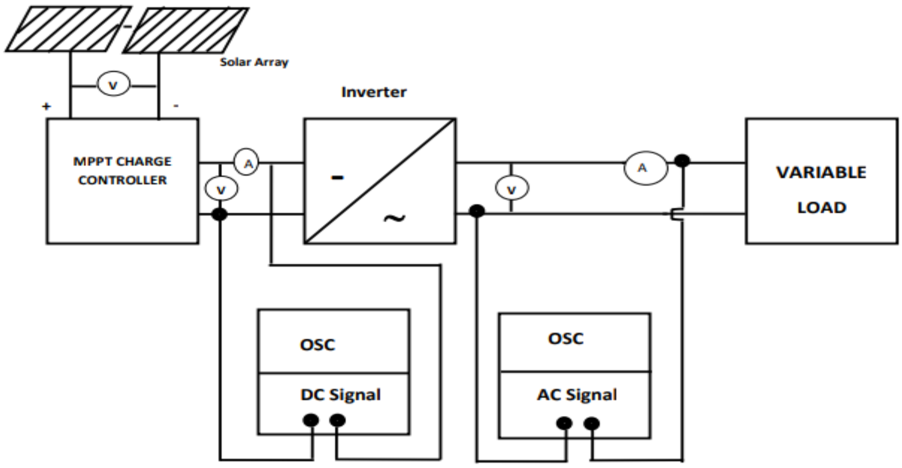

Fig. 1 Schematic of the PV system for variable load test

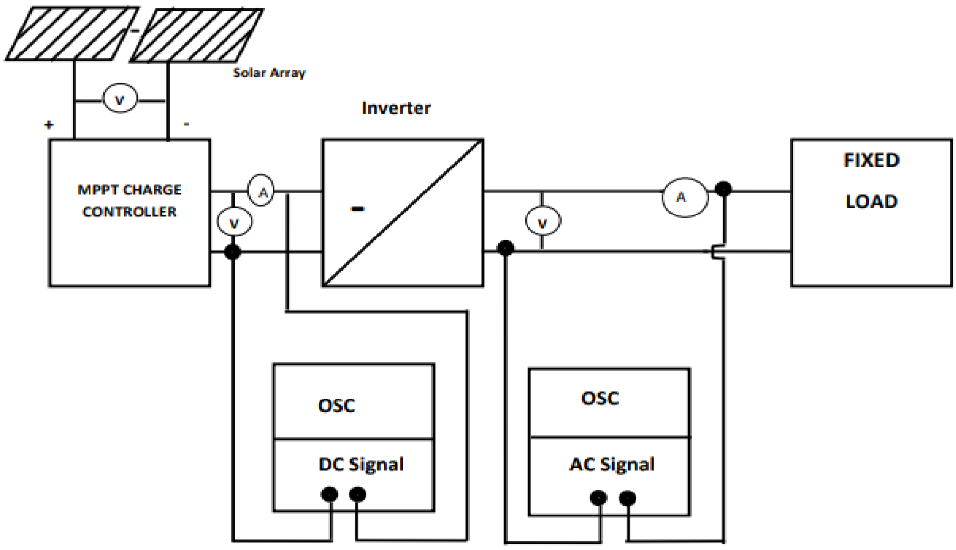

Fig. 2 Schematic of the PV system for fixed load test

Fig. 3 Experimental setup

The efficiency of the MPPT charge controller can be calculated as follow:

$$\eta = \frac{\textit{Output Power}}{\textit{Input Power}} \times 100\% \quad (1)$$

Eq. (1) was used to calculate the efficiency of the inverter for each stage of load test and the results are recorded.

4. Results and Discussion

The output waveform of the inverter under test for no load as displayed on the screen of the digital storage oscilloscope is shown in Fig. 4 while on load waveform is shown in Fig. 5, with a period of 20ms. The frequency is estimated to be 50 Hz and the shape of the waveform is an example of a modified sine wave whose harmonic distortion occurs whenever the inverter output is connected to external load. Observation shows that as the applied load increases, the distortion increases as well. Both wave shapes are typical examples of a modified sine. The distortions, as observed in the waveform of inverter under load condition are due to the effect of load applied at the output.

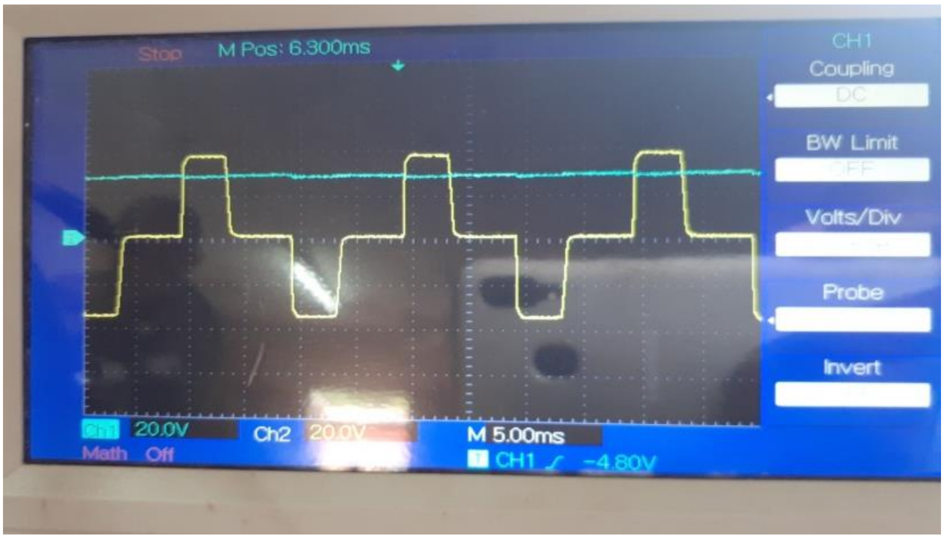

Fig. 4 Output waveform of the inverter on no load

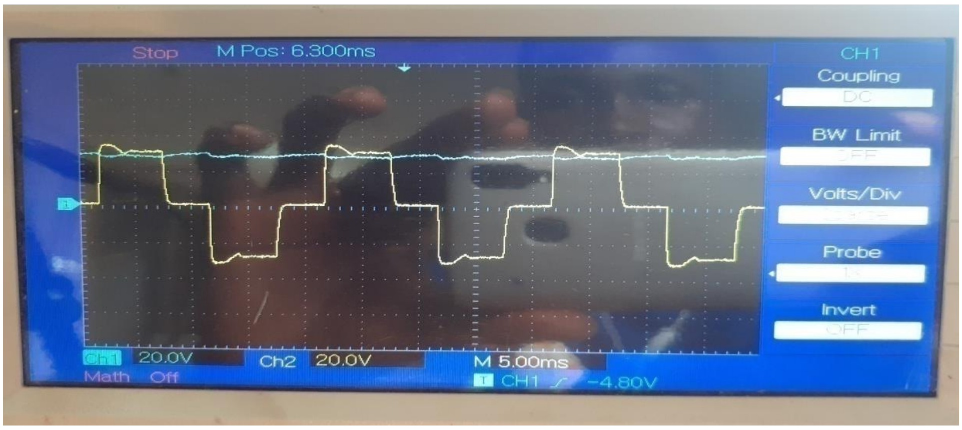

Fig. 5 Output waveform of the inverter on load

The effect of varying load on the dc input voltage supply from solar panels through the charge controller is shown in Fig. 6. As observed, that the input dc voltage decreases as the applied ac loads are increased from 60 W in steps. As the load is gradually increased, the voltage level measured across the terminals of the MPPT charge controller decreases. This is due to the fact that when the current drawn by the loads increases, there will be a drop in supply voltage, which is constant.

The graphs of Fig 7 are not linear. There is a shift in the characteristics, where the input current tends to maintain the same voltage supply at the points when the currents are dissimilar. It is observed that an increase in the current drawn by the inverter from the MPPT charge controller causes a corresponding decrease in the input voltage level. Fig. 8 demonstrates the effect of load on the input; as can be seen that an increase in current drawn by the load at the output of the inverter causes a corresponding increase in the current drawn from the MPPT charge controller at the input of the inverter, giving an almost purely linear graph. The graphs of Fig. 9 show that the output voltage is considerably stable with applied loads above 100W throughout the period of test. It further demonstrates the ability of the MPPT charge controller to maintain steady voltage input required by the inverter despite changes in solar radiation from the sun.

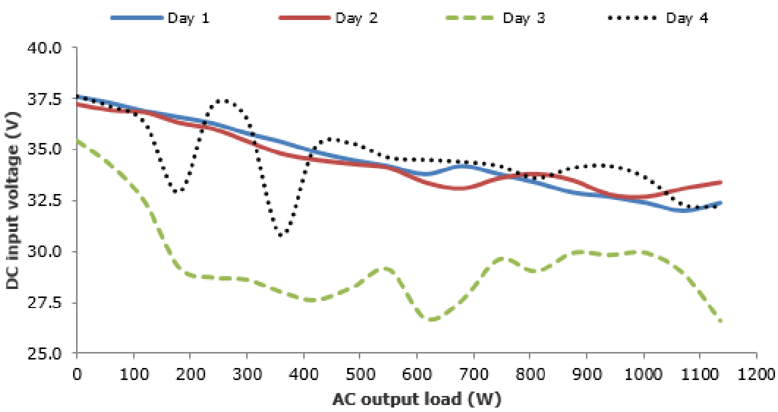

Fig. 6 Variation of input voltage with output load for different atmospheric conditions

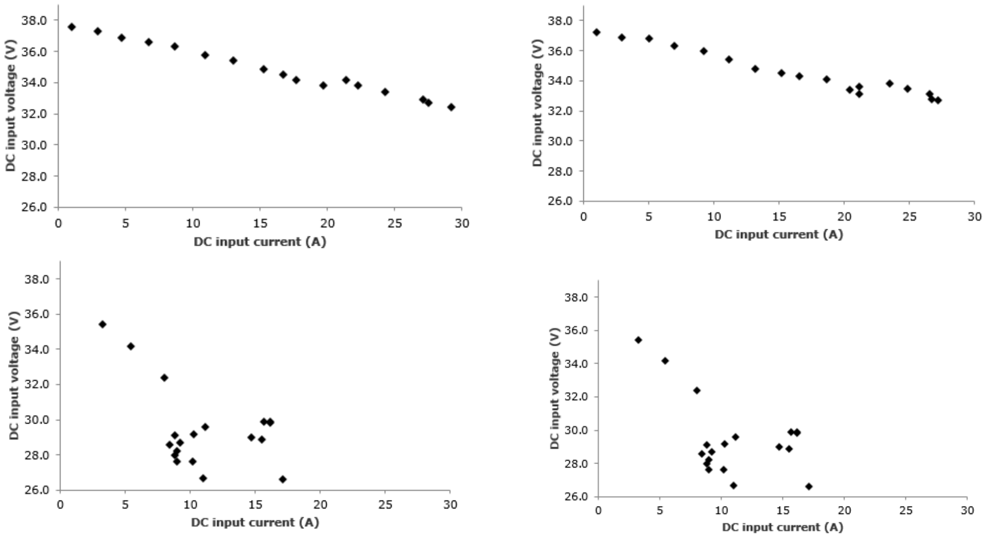

Fig. 7 Variation of dc input voltage with dc input current for different atmospheric conditions

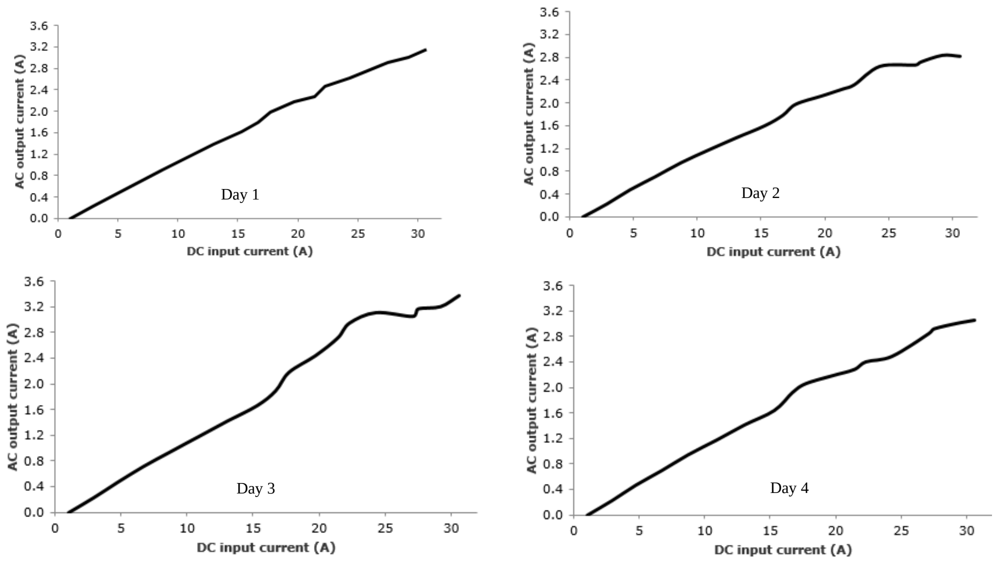

Fig. 8 Variation of ac output current with dc input current for different atmospheric conditions

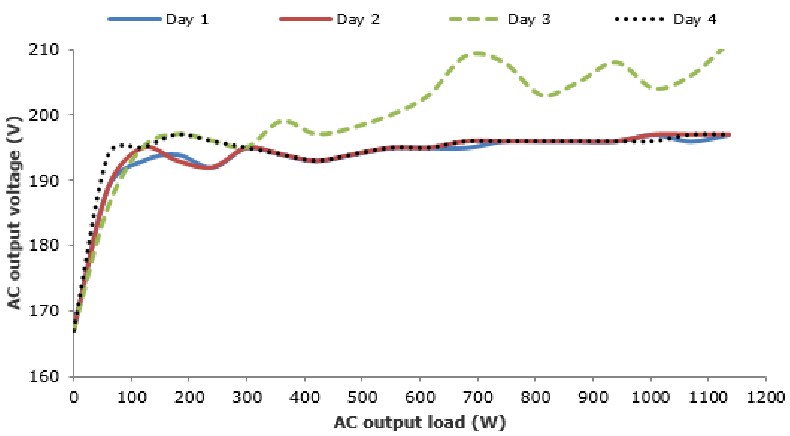

Fig. 9 Variation of ac output voltage with ac output load for different atmospheric conditions

The graphs of efficiency values plotted against input power (Fig. 10) are similar to the shape of a standard efficiency curve. Although, the rated efficiency of the inverter is 60%, the maximum efficiency obtained from experimental results is approximately 46%.

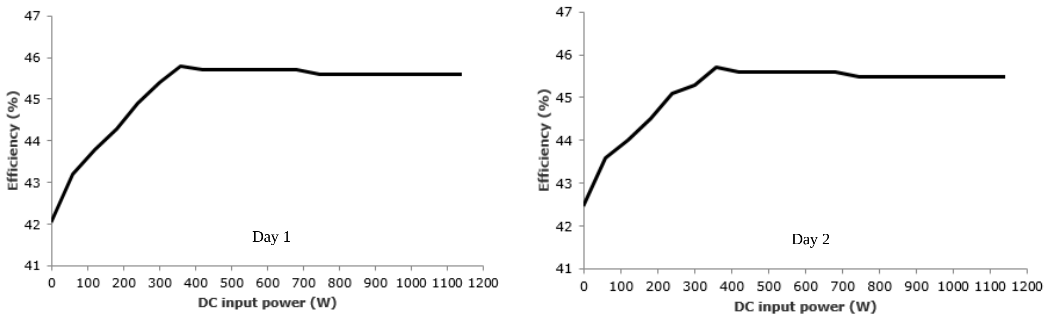

Fig. 10 Variation of inverter efficiency with ac load for different atmospheric conditions

5. Conclusion

The performance of a 2.4kVA direct solar powered supply system has been experimented as proposed in this paper. Observation from test results indicates that the MPPT charge controller converted the solar panel voltage efficiently for connection to the input of the inverter, which generated an output voltage of approximately 195Vac, at a frequency of about 50Hz. This voltage and frequency were suitable for powering the available ac loads applied during the experiments on load test. There was no interruption, apart from the period of very low solar radiation, particularly during the early hours of the morning and later in the evening. The purpose of this research is to focus on alternative means of power generation capable and cheaper enough to compensate for the incessant electrical power outages that have become a norm in Nigeria over the years. The government can undertake the installation of power sources of this kind on a large scale and feed to the national power distribution network (grid), for powering both domestic and industrial applications. This will grow our economy and aid national development. On a smaller scale, private individuals, small and medium scale business owners can venture into setting up solar power systems, either in the form of a stand-alone or a micro-grid system. Nevertheless, the main drawback of this type of solar power supply system is that in the absence of battery back-up (for storage), and other sources of power generation (which may be conventional), it can only be applied during the day.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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