International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

Reliability Investigation and Evaluationof Off-Grid Solar Photovoltaic (PV)Power System

[1, *]Awoyinka Tunde Dare.,[2]Adepoju Taiwo Sholagbade.
[1]*Department of Physics, Olabisi Onabanjo University, Ago-Iwoye.*
[2]*Federal University of Technology, Akure.*

Submitted: 31-10-2022 Accepted: 08-11-2022

ABSTRACT:
The reliability of solar photovoltaic power system is the ability of the system to supply to the load, a reasonable continuity and quality of power supply. Reliability of off-grid solar photovoltaicpower system has been a cause for concern, especially in Nigeria, where several solar photovoltaic projects has failed and do not last, majorly due to poor understanding of energy consumption [Adeyemo 2013]. This poor understanding of energy consumption propel this work to investigate and evaluate the reliability of an off-grid solar pv powersystem in order to recommend an appropriate percentage of electrical load suitable forany off-grid solarpowersystem. Recommendingthis suitable percentage load for off-grid solar pv systems, willensure a lasting and reliable off-grid solar power electricity in Nigeria or elsewhere. The loadpercentage recommended in this work,was determinedby investigating and evaluating the reliability of 3.5kVAoff-grid solar pv power system under different electrical loads. This3.5Kva off-grid solar pv power system comprises of 2.4kW solar panel, 9.6kWh Battery capacity, 80A MPPT charge controller and 3.5kVA inverter.The percentage of electrical loadsused in investigatingthe system reliability range from 8.5% to 71% of inverter capacity, 12.5% to 104% of solar panel capacity and 3% to 26% of battery nominal capacity.
The field investigationtook a duration of 5days and several hours. During investigation, solar panelcurrent, load current, and battery voltage were measured and recordedwith time, to calculate the back-up time,depth of discharge, power consumption and energy generated, battery voltage depletion rate and current drawn by load.After investigation,the reliability of the system was evaluatedand conclusion drawn. The results reveal that the reliability ofany off-grid solar pv powersystemis certain and unfailing ifthe electrical load is not beyond 25% of solar panel capacity, 6.3% of battery capacity and 17% of inverter capacity.

KEYWORDS: Off-Grid; Battery; Inverter; Solar panel; Electrical Load; Back-up Time; Depth of Discharge; Power Consumption; Energy Generated.

I. INTRODUCTION

Solar energy is a renewable source of energy emitted from the sun, which is harnessed using photovoltaic cells to provide a continuous source of electrical power. The harnessing of solar energy has been globally adopted, such that global solar energy market is projected to reach $223.3billion by 2026(Shruti 2019).

Shruti (2019), described that the global solar energy market which was valued at $52.5billion in 2018, is projected to reach $223.3billion by 2026, growing at a CAGR (compound annual growth rate) of 20.5% from 2019 to 2026. This isdue to increase in environmental pollution and provision of government incentives and tax rebates to install solar panel. In addition, decrease in water footprint associated with solar energy systems has fueled their demand in power generating sectors and that the demand for solar cells has gained major traction owing to rooftop installations.

This astonishing growth has made the adoption of solar electricity, as an alternative means of power generation widely, especially in Nigeria where epileptic power supply is constantly met (Aremu J.O 2019). The power problem in Nigeria gave a rise in demand for solar power electricity and this has led to so many quick and improperly planned solar projects which later resulted to failed and abandon projects.

According to Adeyemo (2013), who studied the challenges facing solar energy projects in Nigeria, pointed out that poor understanding of energy consumption rate and the lack of planning for expected consumption rate can lead to usage of wrong materials or even batteries of lesser capacity in solar project. He buttressed that the capacity and performance of batteries is a major challenge in solar powered projects, and if batteries can be well managed it would minimise the failure in solar powered projects.Also Mohamed Khalil (2019) pinpoint that, inverter is the most fragile components in the solar pv system and a potential source of failure due to the unexpected failures that can occur in its internal component when overloaded. This explains that no matter how vast a solar power system is, if the battery and inverter is not well managed, the pv system would fail and become unreliable.

To ensure the overall reliability of any solar pv electrical system, good managing of battery and inverter is very essential, and this can be achieved by placing and appropriate percentage of load on the battery and inverter, as the two are the major potential source of failures in a solar pv system.

Ankit Bansal(2016)explains that reliability of solar power system covers all aspects of supplying reliable power to consumers, including adequate facilities required to generate sufficient energy and to distribute energy to consumers. He definesthe reliability of solar photovoltaic power system as the ability of the system to supply to the load, a reasonable continuity and quality of power supply.

Hence this work then proceeds to provide the required percentage loadfor an off-grid solar power system, so as to increase the life span of battery and inverter, and to enhancea continuous and quality power supply. This is achieved by using 3.5kva off-grid solar photovoltaic power system as a sample for reliability investigation and evaluation in this work. The reliability investigation and evaluation ofthe 3.5kva off-grid solar photovoltaic power system was carried out on the field byconnecting four different electrical loads to an installed off-grid 3.5Kva solar power system. The loads are equivalent to different percentage of solar panel capacity, battery capacity and inverter capacity,andthe results were determining from the following:the back-up time, depth of discharge, power consumption and energy generated, battery voltage depletion rate and current drawn by load

This 3.5Kva off-grid solar photovoltaic power system used as a sample, is an electricalpower system installed 3months earlier before the investigation,to generate 3.5kW solar electricity, and to power a maximum electrical load of 3Kw by means of photovoltaics only. The major componentsinclude 2.4kW solar panels to absorb and convert sunlight into direct current electricity, 9.6kWh battery capacity to store the dc energy generate, and 3.5kVA inverter to convert thedc electricity from solar panels and batteries to alternating current, for AC load consumption.

II. MATERIALS AND METHOD

i. MATERIALS

Battery

Used to store the energy generated from the solar panel and to provide energy source during sunset. Four (4) batteries wereused, and each battery is rated 12V 200Ah, connected in series to give 24V and also in parallel to give 400Ah. Therefore, the nominal battery capacity in Ampere hour is 400Ah, and in Kilowatt-hour is 9.6kWh.
i.e. 24V× 400Ah = 9600Wh or 9.6kWh

Solar Panel

Eight (8) pieces of solar panel rated 300W each was used to converts sunlight into direct current electricity. The solar panel was connected in series and parallel to supply a higher voltage above the battery voltage, and to yield a total solar energy capacity of 2.4kW. The solar panel brand name is Africell, whose voltage at maximum power (Vmp) is 31.7V and current at maximum power (Imp) Imp is 9.46A

Solar Charge Controller

A 60A Maximum Power Point Tracking (MPPT) solar chare controller was used so that it can provide boost charging in cold temperatures and when the battery is low. It charges the battery with current higher than the current drawn from the solar panel, by reducing the high voltage coming from the solar panel to the voltage required to charge the battery, in the process the current is increased in the same ratio the voltage is dropped. The charge controller was also used to monitor the battery voltage via it screen display

Inverter

3.5Kva, 24V pure sine wave inverter was used to power the electrical loads used for evaluation. This inverter can power an electrical load up to 3kw

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

Electrical Load
200W and 100W incandescent light bulbswas used as load measurement.The load capacityis 2500W, 1200W, 600W and 300W, as described below.

- 2500W loadis equivalent to 71% of inverter capacity, 104% of solar panel capacity, and 26% of battery nominal capacity.It consists of 12 pieces of 200W bulbs and a 100W bulb
- 1200W load is equivalent to 34% of inverter capacity, 50% of solar panel capacity, and 12.5% of battery capacity.It was made up of 6 pieces of 200W bulbs.
- 600W load is equivalent to 17% of inverter capacity, 25% of solar panel capacity, and 6.3% of battery capacity. 3 piece of 200W bulbs
- 300W load isequivalent to 8.5% of inverter capacity, 12.5% of solar panel capacity, and 3% of battery capacity.A 200W and 100W bulbs

Digital Multimeter / Clamp meter
RMS digital multimeters and clamp meters were used to measure the voltage and current generated by solar panel and consumed by the loads during investigation.

ii. METHOD

The methodology employ is presented in fig.1. The investigation took a duration of five (5) different days. On each daythe investigationbeginsfrom 12pm in the day when the sun was at its peak and when the batteries has been fully charged. Then datawere measured and recoded every hour from 12pm till the timethe inverter signals a low battery voltage.Two digital clamp multimeter was used to measure solar panel currentand load current each hour, multimeter was used in measuring the battery voltage.The investigation was carried out on March 9, March 11, March 16, and March 19 – 20in the year 2021, in Ago-Iwoye Ogun state, Nigeria.

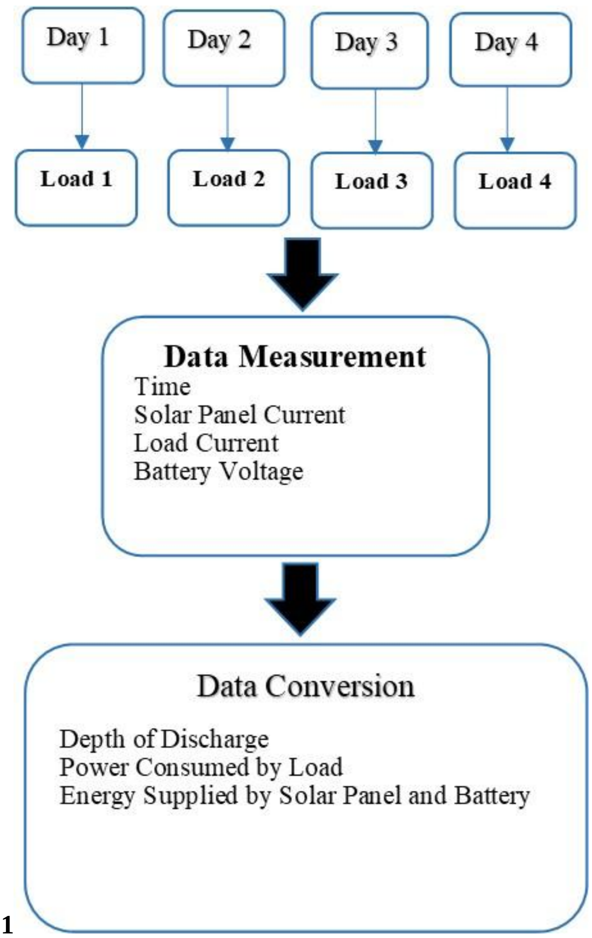
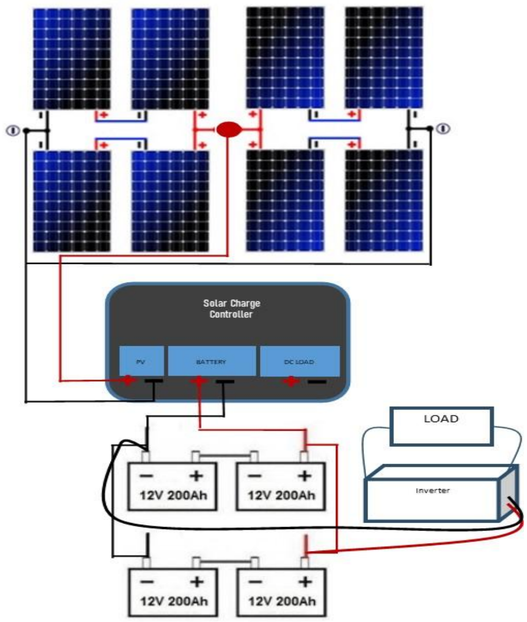


Fig. 1



Procedures:
The steps of the method are explainedbelow:

- System Inspection

The batteries terminal, wires and other terminals connections were inspected and retightened to ensure a tight connection. The strength of the battery was also checked, usingbattery analyser to ensure that the battery is still strong and suitable for this work. The system was installed in December 2020. Fig.2 is a description of how the solar power system was installed and connectedto the load

- **Data Measurement:**

On each day, as described in fig.1, field investigation was carried out and the data were measure and recorded. Day 1, March 9, 2021,2500W load was connected to the solar power system, and measurement of data were taken per hour till the inverter signals a low battery voltage. On Day 2, March 11, 2021, 1200W load was connected to the system and measurement of datawere taken per hour till the inverter signals a low battery voltage. On Day 3 and Day 4, 600W and 300W load was connected to the system respectively, and same measurement procedures were followed.
Table 1 – 4 presents the measured data from Day 1 to Day 4

Table 1, Day 1: March 9,2021

Time	Load	Current Generated by Solar Panel (Charging Current)	Current Consumed by Load (Inverter)	Battery Voltage
12Pm—1pm	2500W	54.1A	113.1A	26.0V
1pm—2pm	2500W	63.3A	119.5A	24.6V
2pm—3pm	2500W	55.8A	128.9A	22.8
3pm—3.30pm	2500W	32.6A	136.7A	21.5

Table 2, Day 2: March 11,2021

Time	Load	Current Generated by Solar Panel (Charging Current)	Current Consumed by Load (Inverter)	Battery Voltage
12Pm—1pm	1200W	52.8A	51.5A	27.4V
1pm—2pm	1200W	60.2A	51.3A	27.5V
2pm—3pm	1200W	57.5A	51.3A	27.5V
3pm—4pm	1200W	35.6A	52.2A	27.0V
4pm—5pm	1200W	20.3A	54.3A	26.0V
5pm—6pm	1200W	7.8A	57.1A	24.7V
6pm—7pm	1200W	2.4A	60.8A	23.2V
7pm—8pm	1200W	0	65.3A	21.6

Table 3, Day 3: March 16,2021

Time	Load	Current Generated by Solar Panel (Charging Current)	Current Consumed by Load (Inverter)	Battery Voltage
12Pm—1pm	600W	53.4A	25.3A	27.9V
1pm—2pm	600W	62.8A	25.2A	28.1V
2pm—3pm	600W	56.2A	25.2A	28.0V
3pm—4pm	600W	36.6	25.2A	28.0V
4pm—5pm	600W	19.3	25.3A	27.9V
5pm—6pm	600W	9.6	25.7A	27.4V
6pm—7pm	600W	2.6	26.4A	26.7V
7pm—8pm	600W	0	27.2A	25.9V
8pm—9pm	600W	0	28.1A	25.1V
9pm—10pm	600W	0	29.0A	24.3V
10pm—11pm	600W	0	30.0A	23.5V
11pm—12am	600W	0	31.1A	22.7V
12am—1am	600W	0	32.2A	21.9V
1am—1.30am	600W	0	32.8A	21.5V

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

Table 4: Day 4: March 19 – 20, 2021

Time	Load	Current Generated by Solar Panel (Charging Current)	Current Consumed by Load (Inverter)	Battery Voltage
12Pm—1pm	300W	56.2A	12.7A	27.8V
1pm—2pm	300W	58.7A	12.6A	28.1V
2pm—3pm	300W	53.4A	12.6A	28.1V
3pm—4pm	300W	30.8A	12.6A	28.0V
4pm—5pm	300W	14.2A	12.6A	28.0V
5pm—6pm	300W	6.4A	12.7A	27.8V
6pm—7pm	300W	2.6A	12.8A	27.5V
7pm—8pm	300W	0A	13.0A	27.1V
8pm—9pm	300W	0A	13.2A	26.7V
9pm—10pm	300W	0A	13.4A	26.3V
10pm—11pm	300W	0A	13.6A	25.9V
11pm—12am	300W	0A	13.8A	25.5V
12am—1am	300W	0A	14.0A	25.1V
1am—2am	300W	0A	14.2A	24.7V
2am—3am	300W	0A	14.5A	24.3V
3am—4am	300W	0A	14.7A	23.9V
4am—5am	300W	0A	15.0A	23.5V
5am—6am	300W	0A	15.2A	23.1V
6am—7am	300W	0A	15.5A	22.7V
7am—8am	300W	6.7A	15.6A	22.5V
8am—9am	300W	19.2A	15.6A	22.5V
9am—10am	300W	36.6A	15.5A	22.7V
10am—11am	300W	41.6A	15.3A	23.0V
11am—12pm	300W	56.5A	15.0A	23.5V
12pm—1pm	300W	60.1A	14.6A	24.1V
1pm—2pm	300W	62.7A	14.2A	24.7V

- **Conversion of Data**

After the field investigation of the system was completed, the measured data were converted tocalculate the parameters needed in determining the results. The parameters are: depth of discharge, power consumed by load and energy generated from solar panel and battery, battery voltage depletion rate and current consumed by load.

Depth of Discharge

Depth of discharge indicate the percentage of the battery that has been discharged relative to the capacity of the battery. Depth of Discharge is defined as the capacity that is discharged from a fully charged battery, divided by the nominal capacity

DoD =$(E_L \div E_B) \times 100$

E_L = Capacity of Energy discharge by load from battery measured in kWh or Ah

E_B = Nominal battery capacity or Capacity of Energy stored in batterymeasured in kWh or Ah.

The Nominal battery capacity in this work is 400Ah or 9.6kWh. Depth of discharge is usually expressed in percentage points, 100% means empty and 0% means full.

Power Consumed by each Load

The power consumed by each load is expressed in kilowatt-hours kWh is calculated using the formula:

Power Consumed = (P × t) ÷ 1000

Where, P = power units in watts and t = time over which power or energy was consumed

Table 5 – 8 presents theDepth of Discharge and Power Consumed per load using the measured parameters, from day 1 to 5

Table 5: Day 1

Time	Power Consumed	Battery Capacity (E_B)	Discharge Capacity by Load (E_L)	Depth of Discharge
12Pm—1pm	2.5kWh	400Ah	59Ah	14.8%
1pm—2pm	2.5kWh	341Ah	56.2Ah	16.5%
2pm—3pm	2.5kWh	285Ah	73.1Ah	25.7%
3pm—3.30pm	2.5kWh	212Ah	52.1Ah	24.6%

Table 6: Day 2

Time	Power Consumed	Battery Capacity (E_B)	Discharge Capacity by Load (E_L)	Depth of Discharge
12Pm—1pm	1.2kWh	400Ah	0	0%
1pm—2pm	1.2kWh	400Ah	0	0%
2pm—3pm	1.2kWh	400Ah	0	0%
3pm—4pm	1.2kWh	400Ah	16.6Ah	4.2%
4pm—5pm	1.2kWh	383Ah	34Ah	8.9%
5pm—6pm	1.2kWh	349Ah	49.3Ah	14.1%
6pm—7pm	1.2kWh	300Ah	60.8Ah	20.3%
7pm—8pm	1.2kWh	239Ah	65.3Ah	27.3%

Table 7: Day 3

Time	Power Consumed	Battery Capacity (E_B)	Discharge Capacity by Load (E_L)	Depth of Discharge
12Pm—1pm	0.6kWh	400Ah	0	0%
1pm—2pm	0.6kWh	400Ah	0	0%
2pm—3pm	0.6kWh	400Ah	0	0%
3pm—4pm	0.6kWh	400Ah	0	0%
4pm—5pm	0.6kWh	400Ah	6Ah	1.5%
5pm—6pm	0.6kWh	394Ah	16.1Ah	4.1%
6pm—7pm	0.6kWh	378Ah	26.4Ah	7%
7pm—8pm	0.6kWh	352Ah	27.2AH	7.7%
8pm—9pm	0.6kWh	325Ah	28.1Ah	8.6%
9pm—10pm	0.6kWh	297Ah	29.0Ah	9.7%
10pm—11pm	0.6kWh	268Ah	30.0Ah	11.2%
11pm—12am	0.6kWh	238Ah	31.1Ah	13.1%
12am—1am	0.6kWh	207Ah	32.2Ah	15.6%

Table 8: Day 4 – 5

Time	Power Consumed	Battery Capacity (E_B)	Discharge Capacity by Load (E_L)	Depth of Discharge
12Pm—1pm	0.3kWh	400Ah	0	0
1pm—2pm	0.3kWh	400Ah	0	0
2pm—3pm	0.3kWh	400Ah	0	0
3pm—4pm	0.3kWh	400Ah	0	0
4pm—5pm	0.3kWh	400Ah	0	0
5pm—6pm	0.3kWh	400Ah	6.3Ah	1.6%
6pm—7pm	0.3kWh	394Ah	12.8Ah	3.2%
7pm—8pm	0.3kWh	381Ah	13.0Ah	3.4%
8pm—9pm	0.3kWh	368Ah	13.2Ah	3.6%
9pm—10pm	0.3kWh	355Ah	13.4Ah	3.8%
10pm—11pm	0.3kWh	341Ah	13.6Ah	4.0%
11pm—12am	0.3kWh	327Ah	13.8Ah	4.2%
12am—1am	0.3kWh	313Ah	14.0Ah	4.5%
1am—2am	0.3kWh	299Ah	14.2Ah	4.7%
2am—3am	0.3kWh	285Ah	14.5Ah	5.1%
3am—4am	0.3kWh	270Ah	14.7Ah	5.4%
4am—5am	0.3kWh	255Ah	15.0Ah	5.9%
5am—6am	0.3kWh	240Ah	15.2Ah	6.3%
6am—7am	0.3kWh	224Ah	15.5Ah	6.9%
7am—8am	0.3kWh	215Ah	8.9Ah	4.1%
8am—9am	0.3kWh	215Ah	0	0
9am—10am	0.3kWh	236Ah	0	0
10am—11am	0.3kWh	262Ah	0	0
11am—12pm	0.3kWh	303Ah	0	0
12pm—1pm	0.3kWh	348Ah	0	0
1pm—2pm	0.3kWh	395Ah	0	0

Energy Generated fromSolar Panel and Battery

The energy suppliedby solar panel and the stored energy from the batteries are both refers to as energy generated, and is calculated per houron each day

$E_{SB} = E_S + E_B$

E_{SB}= Energy Generated (Energy generated by solar panel and battery altogether, measured in kWh).

E_S = Energy from Solar panel in kWh = (Solar panel Charging Current ×Solar Panel Vmp× 1hour)÷ 1000

Solar Panel (Vmp) = 31.7V

Voltage at maximum power (Vmp)was used in calculating E_S, because the MPPT charge controller reduced the high voltage from the solar panel to varyingcharging voltages,closer or equal to solar panel Vmp to charge the battery.

E_B = Energy stored in Battery in kWh = (Battery Ampere× Battery Voltage × 1hour) ÷ 1000

Table 9 to 12 presents the energy generatedper hour from day 1 to 5

Table 9

Time	Power Consumed	Battery Energy (E_B)	Solar Panel Energy (E_S)	Energy generated (E_{SB})
12Pm—1pm	2.5kWh	10.4kWh	1.71kWh	12.1kWh
1pm—2pm	2.5kWh	8.39kWh	2.01kWh	10.4kWh
2pm—3pm	2.5kWh	6.50kWh	1.77kWh	8.3kWh
3pm—3.30pm	2.5kWh	4.56kWh	1.03kWh	5.6kWh

Table 10

Time	Power Consumed	Battery Energy (E_B)	Solar Panel Energy (E_S)	Energy generated (E_{SB})
12Pm—1pm	1.2kWh	10.96kWh	1.63kWh	12.6kWh
1pm—2pm	1.2kWh	11.0kWh	1.91kWh	12.9kWh
2pm—3pm	1.2kWh	11.0kWh	1.81kWh	12.8kWh
3pm—4pm	1.2kWh	10.8kWh	1.13kWh	11.9kWh
4pm—5pm	1.2kWh	9.96kWh	0.64kWh	10.6kWh
5pm—6pm	1.2kWh	8.62kWh	0.25kWh	8.9kWh
6pm—7pm	1.2kWh	6.96kWh	0	6.9kWh
7pm—8pm	1.2kWh	5.16kWh	0	5.2kWh

Table 11

Time	Power Consumed	Battery Energy (E_B)	Solar Panel Energy (E_S)	Energy generated (E_{SB})
12Pm—1pm	0.6kWh	11.16kWh	1.69kWh	12.9kWh
1pm—2pm	0.6kWh	11.2kWh	1.99kWh	13.2kWh
2pm—3pm	0.6kWh	11.2kWh	1.78kWh	13.0kWh
3pm—4pm	0.6kWh	11.2kWh	1.16kWh	12.4kWh
4pm—5pm	0.6kWh	11.16kWh	0.61kWh	11.8kWh
5pm—6pm	0.6kWh	10.8kWh	0.3kWh	11.1kWh
6pm—7pm	0.6kWh	10.09kWh	0	10.1kWh
7pm—8pm	0.6kWh	9.12kWh	0	9.1kWh
8pm—9pm	0.6kWh	8.16kWh	0	8.2kWh
9pm—10pm	0.6kWh	7.22kWh	0	7.2kWh
10pm—11pm	0.6kWh	6.30kWh	0	6.3kWh
11pm—12am	0.6kWh	5.40kWh	0	5.4kWh
12am—1am	0.6kWh	4.53kWh	0	4.5kWh

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

Table 12

Time	Power Consumed	Battery Energy (E_B)	Solar Panel Energy (E_S)	Energy generated (E_{SB})
12Pm—1pm	0.3kWh	11.1kWh	1.78kWh	12.9kWh
1pm—2pm	0.3kWh	11.2kWh	1.86kWh	13.1kWh
2pm—3pm	0.3kWh	11.2kWh	1.69kWh	12.9kWh
3pm—4pm	0.3kWh	11.2kWh	0.98kWh	12.2kWh
4pm—5pm	0.3kWh	11.2kWh	0.45kWh	11.7kWh
5pm—6pm	0.3kWh	11.1kWh	0.20kWh	11.3kWh
6pm—7pm	0.3kWh	10.84kWh	0	10.8kWh
7pm—8pm	0.3kWh	10.33kWh	0	10.3kWh
8pm—9pm	0.3kWh	9.83kWh	0	9.8kWh
9pm—10pm	0.3kWh	9.34kWh	0	9.3kWh
10pm—11pm	0.3kWh	8.83kWh	0	8.8kWh
11pm—12am	0.3kWh	8.34kWh	0	8.3kWh
12am—1am	0.3kWh	7.86kWh	0	7.9kWh
1am—2am	0.3kWh	7.39kWh	0	7.4kWh
2am—3am	0.3kWh	6.93kWh	0	6.9kWh
3am—4am	0.3kWh	6.45kWh	0	6.5kWh
4am—5am	0.3kWh	5.99kWh	0	6.0kWh
5am—6am	0.3kWh	5.54kWh	0	5.5kWh
6am—7am	0.3kWh	5.08kWh	0	5.1kWh
7am—8am	0.3kWh	4.84kWh	0.21kWh	5.1kWh
8am—9am	0.3kWh	4.85kWh	0.61kWh	5.5kWh
9am—10am	0.3kWh	5.36kWh	1.16kWh	6.5kWh
10am—11am	0.3kWh	6.03kWh	1.32kWh	7.4kWh
11am—12pm	0.3kWh	7.12kWh	1.79kWh	8.9kWh
12pm—1pm	0.3kWh	8.39kWh	1.91kWh	10.3kWh
1pm—2pm	0.3kWh	9.76kWh	1.99kWh	11.8kWh

III. RESULT AND DISCUSSION

The reliability of solar photovoltaic power system was evaluated from the result of the following parameters:

- The Back-up time and Load
- Depth of Dischargeand Load
- Power Consumed andEnergy Generated
- Battery Voltage Depletion and Current drawn by Load

The resultsof these parameters are presented in fig.3 – 12 below. The resultsobtainedare from the measured and converted data during investigation, as shown in table 1 – 12 above.

i. Back-up Time versus Load

Back-up time is the total time the battery in the solar pv power system provides power backup on full load until it is fully discharge. The result shows that the higher the load the lesser the time the off-grid solar pv power system provides power backup.

On 2.5Kw load,the backup time was 3hours and within this three hours, the battery voltage drops very rapidly. The cause of this rapid voltage drop was due to high current consumed by the 2.5kW load, as discussed better in fig.11.A 3hours backup is an inadequate backup time for any off-grid solar power system, as it does not make it a reliable solar

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

power system.Similar low backup time occurred for 1.2kW load, the backup time was8hours and also not reliable enough for an off-grid solar pv system. On 0.6kW and 0.3kW load, the solar pv power system provide more than 12hours power backup fortheseloads, which is considered areliable backup time per day, especially the 0.3kW loaddefines a recommended load percentage to make a continuousbackup time and ahighly reliable off-grid solar power system.

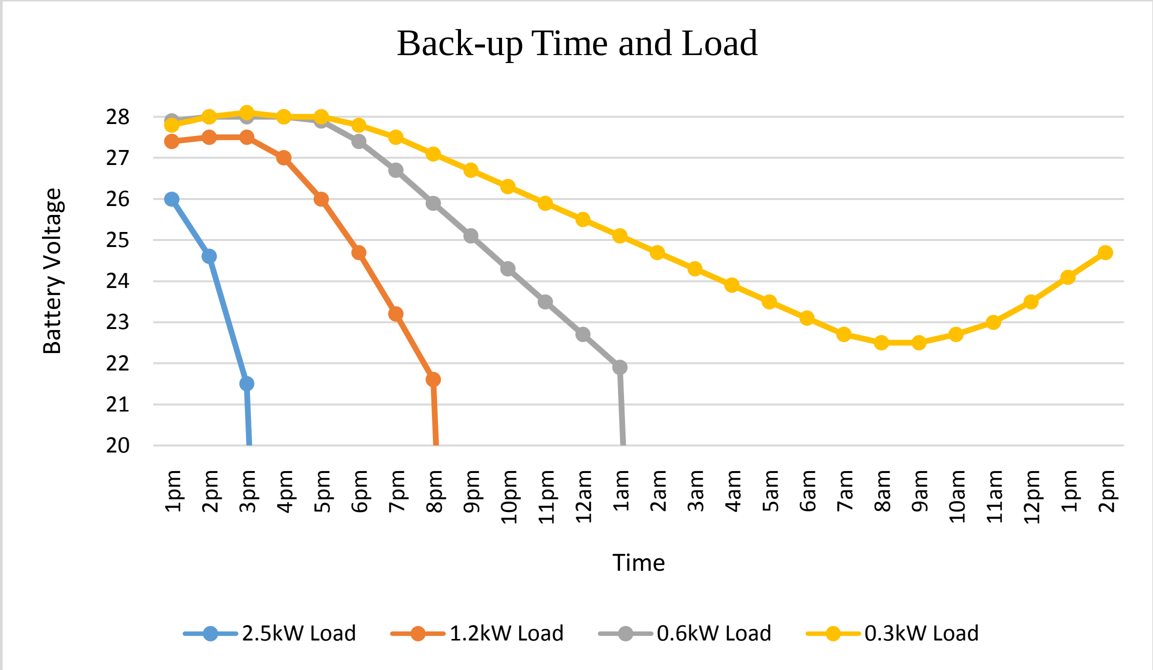


Fig. 3

ii. **Depth of Discharge and Load**

Fig. 4 to 8present the rate of depth of discharge with each load. A depth of discharge at 0% means the battery has not been discharged, while at 100% means it has been completely discharge. When the battery is fully charged with excess energy generated by the solar panel, the DoD will be closer to 0%. Thismakes the DoD on 0.3kw load reducesgradually back to 0% on day 5 after 20hours of discharge.The DoD on 0.3kw load for20hoursdischarge duration was 66% and the DoD on 0.6kwloadwas 78.5% with 13hours discharge duration.This DoD is highlyreliable for the batteries lifespan, especially when considering the duration of discharge. The duration of discharge determines how faster a battery is cycled or how soon a battery will complete a cycle.A battery cycle is one complete discharge and recharge cycle. A battery completes a cycle when it discharges 100% and recharge 100%. if a battery is discharged to 50% and then recharged, it has completed a half cycle, while discharging it to 50% again and recharging it again results in one complete cycle — 100%

On 0.3kw load, the batterieswere discharged for 20hours to 66%, and thenrecharge again from 66% to complete atwo-third 2/3 cycle, as a result, the batteries will complete a cycle in 3days. Similarly, on 0.6kw load, the batteries will complete a cycle in 2days at 78.5%DoD and 13hours of discharge. Considering the DoD of 2.5kw and 1.2kw, 2.5kw DoDwas 81.6% at 3hours discharge duration, thereby completing a cycle in 1day. The same applies to1.2kw loadat 74.8% DoD and a discharge duration of 8hours.This high rate of discharge on both 2.5kw and 1.2kw load is not good for the cycle and lifespan of the battery.The lifespan of a battery depends on how deep a battery is cycled each time. Therefore, the batteriescycle rate on 2.5kw and 1.2kw load was fasterthan the cycle rate of 0.6kw and 0.3kw load, and this will quickly shorten the batterieslifespan, thereby making the off-grid solar power system unreliable.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

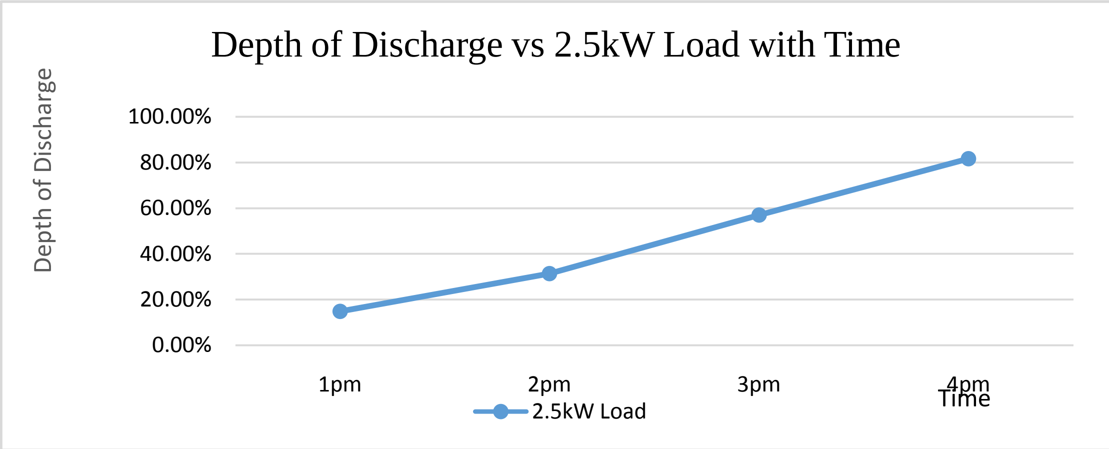


Fig. 4

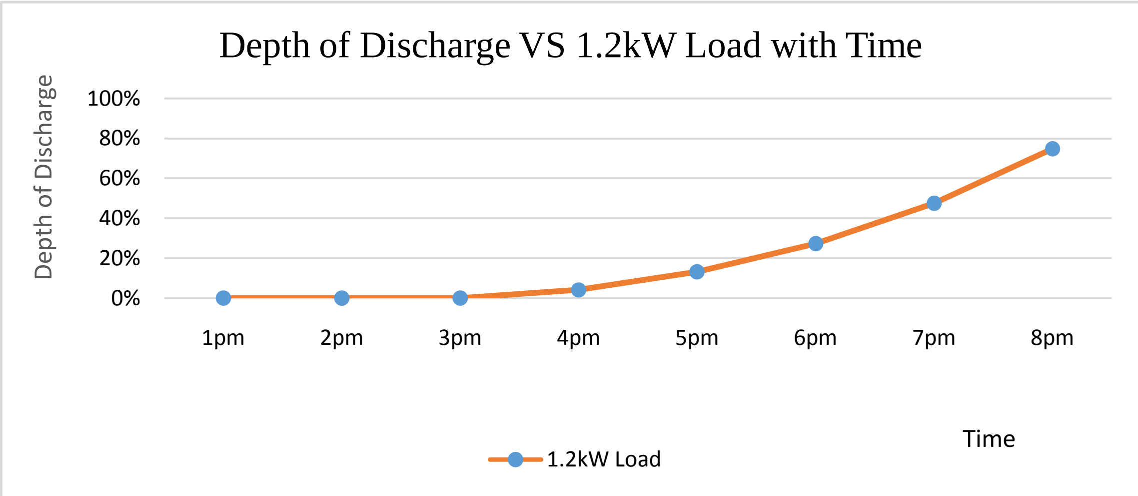


Fig. 5

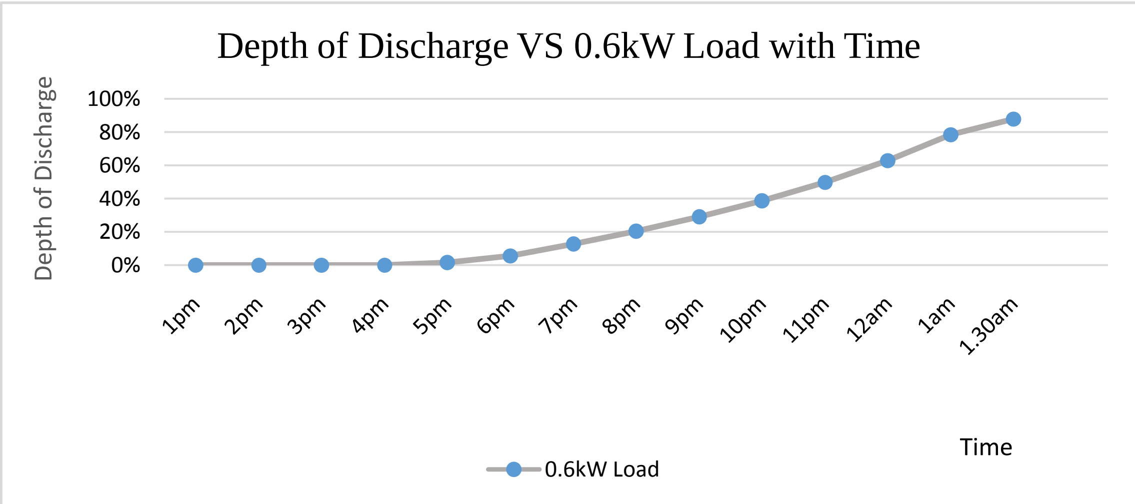
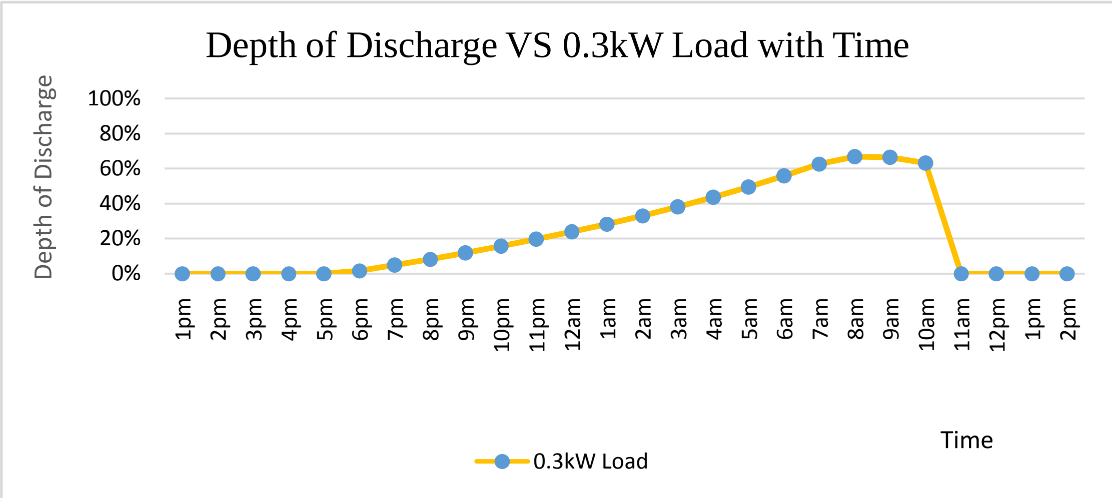


Fig. 6

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

Fig. 7



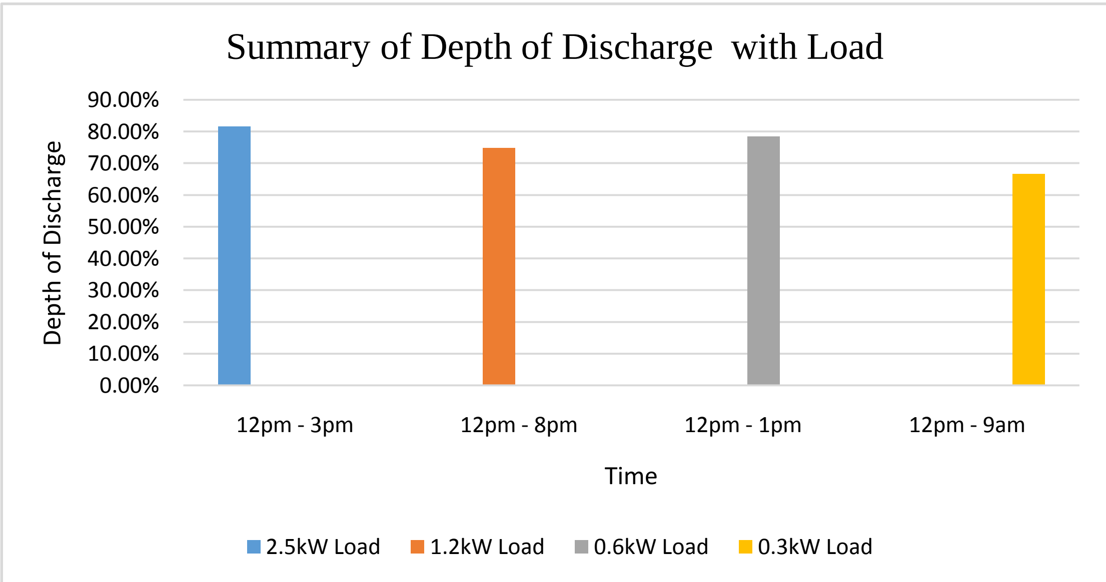


Fig. 8

Power Consume and Energy Generated

As shown in Fig 9 – 10,the result shows that power consumed by 2.5Kw and 1.2kW load drained the energy generated by solar panel and battery at a very high rate, compare to 0.6kw and 0.3kw load. On 2.5kw load, a total power of 7.5kWh was consumed within the 3hour backup time and the total energy generated within this backup time was 36.4Kw. For 1.2kw load,the powerconsumed and the energy generated/supplied was 9.6kWh and 81.8kWh respectively, within the 8hour backup time. 7.8kWh power was consumed by 0.6kW load and a total of 125.2kWhenergy was suppliedfor 13hours duration, while 7.8kWh power was consumed by 0.3kW load and a total energy of 232.2kWh was supplied for 24hours duration and above. This shows in fig.10 that despite the total power consumed by each load are closer, the energy supplied by battery and solar panelwere drained at different rate. This can be explained by the current consumed by each load which are highly different. 2.5Kw and 1.2Kw load drawn a current greater than the current generated from the solar panel and thereby compliment this current differences by drawing additional current from the battery which makes the battery voltage and the combined energy supplied decreases with time. While 0.6kw and 0.3kw uses current far below the current generated by the solar panel, and this makes room for excess current from the solar panel to be stored by the battery, thereby allowing the battery to have ample time to store more energy for supply. This enhances a reliable solar power electricity on 0.3kw and 0.6kw load per day.Using 2.5kw and 1.2kw load, considering its high power and current consumption, will make an off-grid solar power system unreliable fail with time

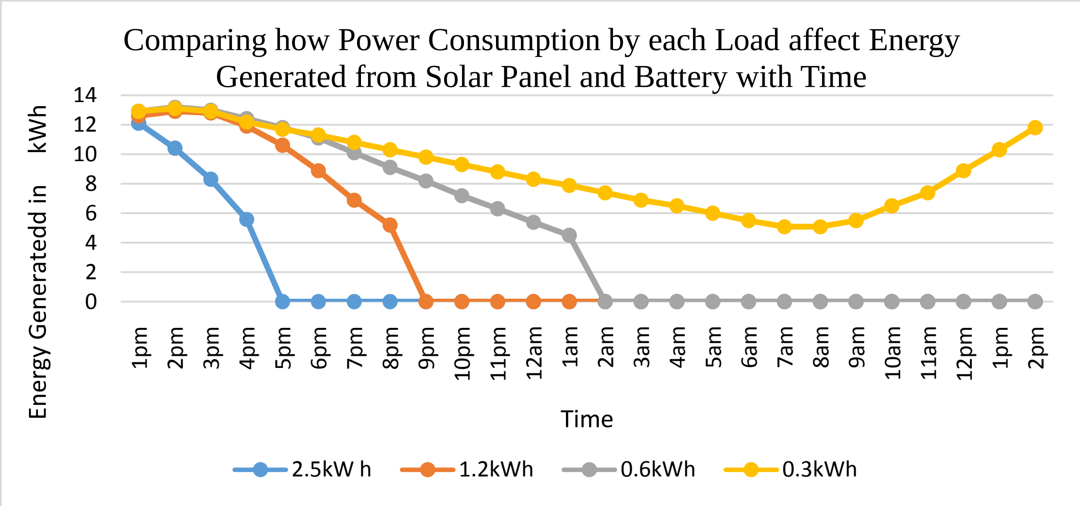


Fig. 9

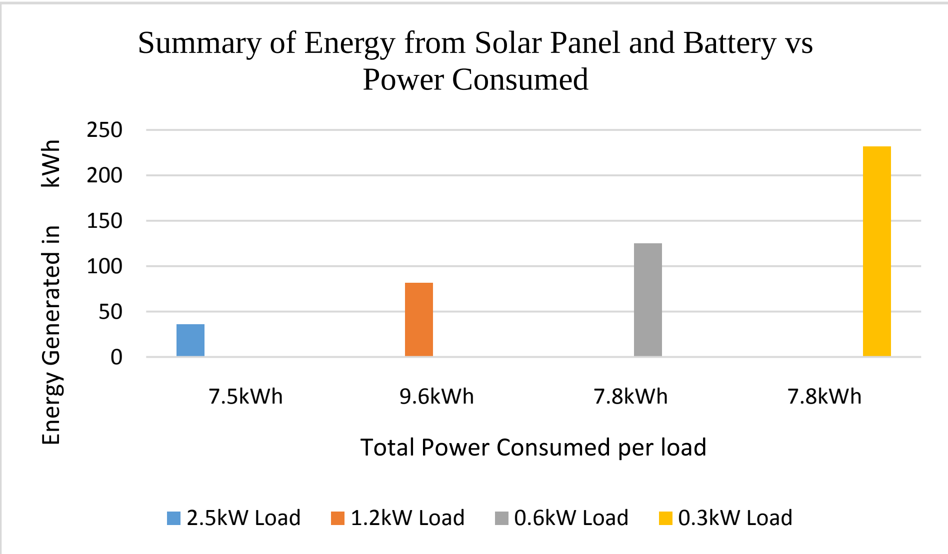


Fig. 10

Battery Voltage Depletion and Current drawn by Load

Fig11 – 14 depicts the rate at which battery voltage drops with the current drawn by each load.The graph shows that the higher the current drawn by load through the inverter, the faster the battery voltage drop and the lower the current the lesser the battery voltage drop. On 2.5Kw and 1.2kW load, the battery voltage drops very rapidly to 21v within 3hoursThis high depletion of battery voltage on 2.5kw and 1.2kw load occurs due to high current,drawn by the loads, which makes the battery voltage deplete very rapidly and generally resulted to low backup time, high depth of discharge, and low energy stored/supplied by the battery. This continuous rapid voltage depletion like this will not makean off-grid solar power system continuous and reliable.Dissimilarly, on 0.6kw an 0.3kw load, the battery voltage depletes slowly due to the low current drawn by the load, which allows enough excess energy from the solar panel to be stored by the battery, and this generally enhances high backup time, low depth of discharge, and high energy stored/supplied by the battery and thereby making an off-grid solar pv power system reliable and continuous.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

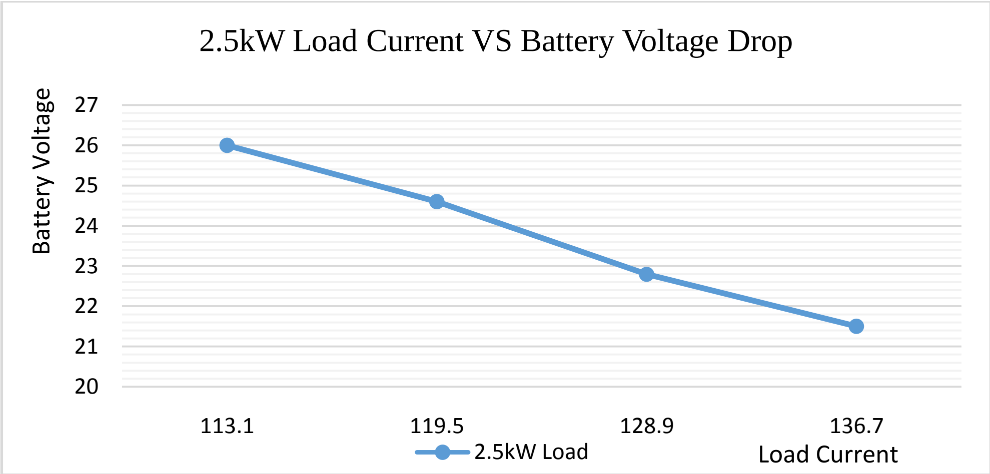


Fig. 11

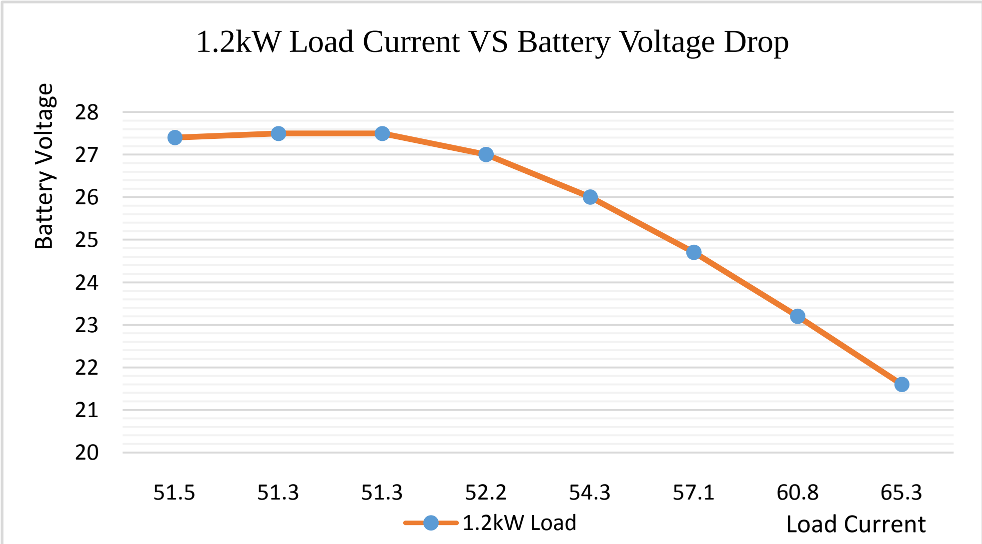


Fig. 12

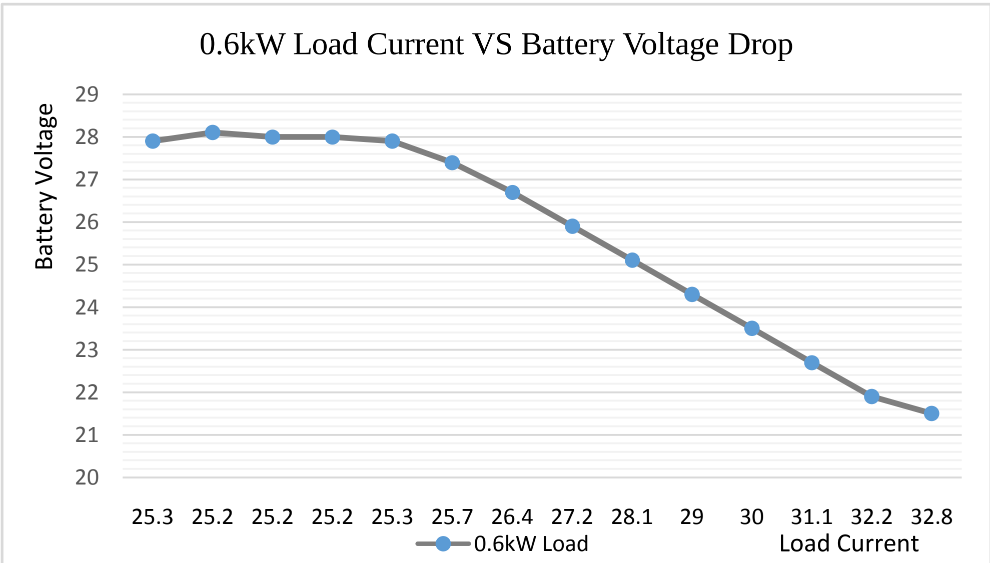


Fig. 13

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 102-118www.ijaem.net ISSN: 2395-5252

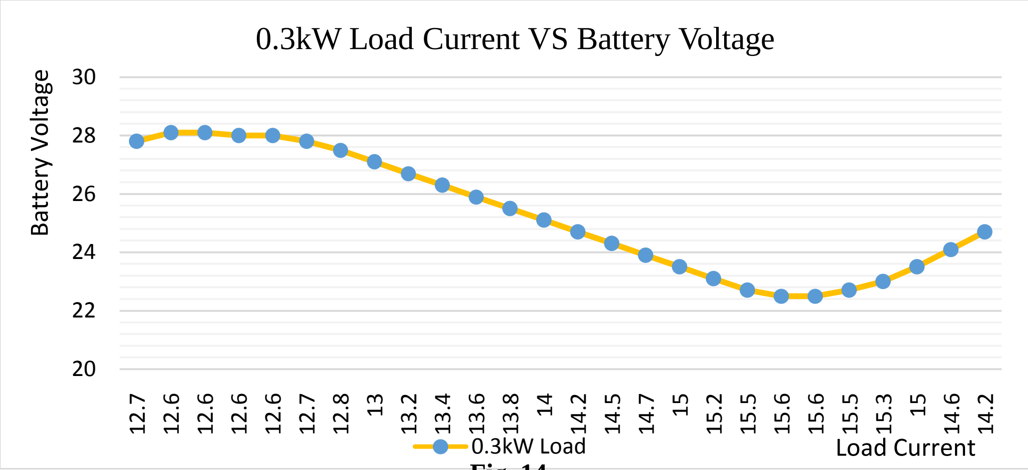


Fig. 14

IV. CONCLUSION

The reliability of off-grid solar photovoltaic system has been investigated and evaluated under different electrical loads percentage, by using 3.5kva off-grid solar power system as a sample. The parameter evaluated during investigation were, the back-up time, depth of discharge, power consumption and energy generated, battery voltage depletion rate and current drawn by load. The result reveals that an off grid solar pv power systemwill fails and become unreliable whenconnected to electrical loadsthatexceed 25% of its solar panel capacity, 6.3% of its battery capacity and 17% of its inverter capacity.These is attributed to four main reasons: low back-up time, high depth of discharge, high power consumptionabovethe energy generated, high battery voltage depletion rate due tohigh current drawn bysuch load. The result further depicts that for an off-grid solar pv systemto be reliable and continuous, itshould have a long backup time ranging from 12hoursbackup per day an above,a moderate depth of discharge not exceeding 80% and a minimal energy consumption so thatthe energy generated from solar panel would beexcess to charge the batteryeffectively, thereby reducingthe rate of battery voltage depletion. In achieving this, it istherefore concluded base on the higher backup time, low depth of discharge and low current consumption and voltage depletion achieved in this work using 0.6kw and 0.3kw loads,that the percentageelectrical loadappropriate for an off grid solar pv system to make it reliable,should range from 12.5% - 25% of solar panel capacity for excess energy generation, 3% - 6.3% of battery capacity for efficient storage of the excess energy and 8.5% - 17% of inverter capacityfor ensuring a minimal current consumption and forpreventing a rapid battery voltage depletion. Any electrical load above this percentage range will make an off-grid solar photovoltaic power system unreliable.

REFRENCES

[1]. Shruti Hariharan. (Oct. 2019). “Solar Energy Market.” [On-line] Available:www.alliedmarketresearch.com/solar-energy-market[April5,2021].

[2]. Adeyemo Hakeem, 2013, “Challenges Facing Solar Energy Projects in Nigeria: A Case Study of Lagos State.” Bachelor’s thesis, HAMK University of Applied Science – May 2013

[3]. Aremu, J.O. 2019, “Epileptic Electric Power Generation and Supply in Nigeria: Causes, Impact and Solution. Journal of Contemporary Research in Social Science

[4]. Mohamed Khalil, 2019, “Failure Prediction of PV Inverters under Operational Stresses” DOI:10.1109/EEEIC.2019.8783241 Conference: 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power System Europe – June 2019.

[5]. Ankit Bansal 2016 “Reliability Evaluation of Solar Photovoltaic Power System: A synopsis submitted in partial fulfilment of the requirement for the degree of doctor of Philosophy” Department of Electrical Engineering, Dayalbagh Educational Institute– Sept 2016