DESIGN OF STAND-ALONE SOLAR ENERGY FOR RURAL DWELLERS IN ZAMFARA STATE, NIGERIA

BY

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Abstract
The convenient way to provide rural areas that have no admission to the utility grid and far from the grid is stand-alone solar energy; the size of the photovoltaic array depends on the energy required for a rural dweller. Therefore, this paper takes an organized and technical approach to predict the minimum energy demand of rural inhabitant. The load demand had forecasted; the PV module, DC-DC boost converter, transformerless inverter had designed and simulated using MATLAB/Simulink in this work. Analysis of PV array, open-loop DC-DC boost converter, closed-loop DC-DC boost converter was carefully studied and decided the most desirable suitable for residential utilization. Battery management system (BMS) and smart technology had also incorporated in the model. The researcher proposed to design a solar energy system that will provide clean drinking water, communication for satellite receiver, education, lighting and security for the rural resident in Zamfara state, Nigeria.
Keywords: solar array, Boost converter, transformerless inverter, SMART, BMS

1. Introduction

Solar energy is one of the natural resources that are not diminishing, unlike coal, gas, and diesel. Therefore, it is paramount to concentrate on solar energy as an alternative for the electricity generation, more especially rural areas that have no admission to the utility grid. Nigeria is one of the notable countries which receive a long period of a sunny day with a very high intensity of irradiation (Nwaigwe&Dintwa, 2019). However, 50 per cent of the population have limited or no access to electricity. The research paper focuses on the solar generation as an option for rural electrification in some part of the region of northern Nigeria.

1.1 Background of the Research

Rural dwellers are most people that have no access to the utility grid more particular African countries; meanwhile, they are the producers of the most agricultural output, which is the section of the economy of every nation. However, they are the inhabitant with a high rate of illiteracy, poor drinking water, inadequate health care. For example, Nigeria currently has a population of 206,424,277 and is expected to rise to 262,977,337 by the year 2030 (Worldometer-united nation Data). Still, the total installed capacity is 10,396MW (Ibrahim, 2019), which is equivalent to 50W per individual.

Therefore, devise a mechanism to mitigate this problem and ensure that rural dwellers electrified at economical cost, stand-alone solar energy is the most desirable alternative, because of the transportation of utility grid far from rural inhabitant is capital intensive. Meanwhile, the fuel of solar energy is sunlight at no cost, emission-free, no rotating part, and it is reliable. Furthermore, the current global approach to the provision of sustainable energy to the rural dwellers, solar energy is the dominant solution of all renewable energy for rural electrification (Ali et al. 2018). (Rohit et al. 2018) addressed the problem of unelectrified rural areas in part of India using the solar energy system in order to boost education, create job opportunities and enhance the standard living of dwellers. Malaysia initiates the program called rural electricity supply that will provide stand-alone photovoltaic power supply (SAPVPS) to mitigate uninterrupted power supply in their rural areas (Idris et al. 2010). Health care in Shiyala village in Zambia had electrified with the solar home system in order to powered refrigeration meant for vaccines storage for rural inhabitant; this solved the problem of several diseases such as tuberculosis, yellow fever and polio with the aid of rural immunization programme (Jones et al. 2016). This research aims to design self-monitoring analysis and reporting technology (SMART) stand-alone solar energy that will meet the minimum requirement of rural dwellers of Zamfara state, Nigeria. Zamfara located north-west with longitude 10.38220 N and latitude 6.60270E 200KM away from the capital city Sokoto State. In the design, lightening, refrigeration, solar pumping machine to provide clean drinking water and communication power for a satellite receiver that will bring the awareness to the dwellers as well as updating the security personnel. This benefit will provide economic sustainability, security, and a good standard of education. Meanwhile, the high rate of illiteracy for rural dwellers will minimize, and social vices affecting the region will also decrease.

1.2 Aims of the research

1-This project aims to ensure a reliable and sustainable power supply in rural communities of the northern part of Nigeria, Zamfara state.

2-To ensure the socio-economic and education standard in these rural communities is achieved.

3-To ensure communication between villagers and security personnel because of the rapid increase of banditry, cattle rustling confronting the rural dweller.

4-To replace hand drilled borehole with solar water pumping machine

1.3 Objective of the Research

The objective of the project is to devise sustainable renewable energy (solar system) that will meet the minimum requirement of the villagers, so that standard of education is achieved for a younger generation in that community as well as hygiene drinking water. To bring awareness for younger generations to understand does and do not with the aid of communication satellite because most of the social vices in the area are associated with a younger group.

2. Literature Review

Diminishing natural resources such as nuclear energy, gas and coal are the contributory factors of carbon emission and greenhouse. Now most of the researchers of renewable energy, for example, solar energy, biomass, tidal, which has greenhouse and carbon emission-free is a field of investigation. Meanwhile, renewable energy is also a focus of research for rural electrification that has no access to the utility grid, which will make life comfortable and improve their socio-economic and education standard. Researchers came up with different strategies for rural electrification; for example, a hybrid of solar energy and wind turbine, solar energy and backup generator, solar energy, biomass and wind turbine, solar energy itself. (Wong & Chai 2012) highlighted different configuration of solar installation for rural electrification.

1. DC couple configuration where DC load is directly supplied from a PV panel via MPPT controller that will modulate power from photovoltaic to ensure maximum power. 2. AC configuration which comprises series and parallel configuration. In a series configuration, PV panel and backup generator with battery charger are connected to DC bus; an inverter is connected between DC bus and the AC load, all the other connection remain the same as DC coupling. In a parallel configuration, a bidirectional inverter is incorporated between the battery and AC bus. In contrast, a backup generator is directly connected to the AC bus all other connection remains the same as a series configuration. The researchers finally, concluded with a parallel configuration in the design because DC coupling configuration no provision for AC load and failure of inverter in a series configuration that is connected between DC bus and AC load will result in total blackout. (Patel & Singal, 2018) also suggested off-grid electrification using integrated renewable energy for rural electrification. They highlighted that extension of existing grid to rural areas that are far from a utility grid not economical. Different configuration of the integrated renewable system had mentioned by the researchers, such as DC bus configuration, AC bus configuration and hybrid AC-DC bus configuration.

They recommended hybrid AC-DC bus configuration as the best and reliable for integrated renewable energy because the strength of one energy source can overcome the weakness of the other. (Michael & Ramesh 2019) design a hybrid renewable energy system for electrification of Idanre, Nigeria. The researchers analyzed Solar PV, windmill, battery bank, power converter and total electrical load using homer software; their investigation revealed that the system was found to be financially and technically workable compared when considering conventional sources like thermal and hydro, which are capital intensive and time consuming. (Aganah et al., 2019) review existing plug-and-play powered generator and also modern plug-and-play solar-powered generator architecture that will be of benefit for most African countries. Researchers further highlighted that some of the African countries, Nigeria in particular utilized petrol generator or local language "I better pass my neighbor" as a means of backup when a utility grid failed to deliver power. Authors propose PnP solar power system due to its easy installation and maintenance; it also has the features of overvoltage protection, short circuit protection and overcharge protection. Based on their design, the PnP solar power system is interchanging automatically with a utility grid. When a utility grid is available, the solar generator will go on standby mode and automatically reconnect when a utility grid is not available. Researchers concluded that PnP solar power system would help the residential when a utility grid is not available, and compliance with the grid code requirement not required because the PnP solar system only comes in when a grid is not present. (Malakani et al. 2019) design an off-grid PV power system and highlighted the economic analysis and technical analysis using Homer pro and MATLAB/Simulink, respectively. Authors further described that perturb and observe algorithms had used in designing battery, DC-DC converter, inverters that used in an off-grid power system. Meanwhile, their expectation of the design able to develop off-grid solar PV that will meet the demand for supply energy to Pirien village, Indonesia. In homer simulation, authors compared economic analysis between pure Genset and pure PV, they concluded that pure PV is the best to use in Pirien village because the average radiation Kw/m2/day and daily temperature throughout a year are respectively 4.74 and 24.6. (Harish et al. 2019) presented peer to peer sharing power architecture of solar power generation for rural electrification; authors further explained that the sharing power architecture reduces power loss, and the limitation of cost of solar installation had reduced. Moreover, other Authors used solar home system not only to compare the economic and technical perspective alone but purposely to implement a means of overcoming grief to rural dwellers.

For example, (Idris et al. 2010), (Jones et al. 2016), (Rohit et al. 2018) had utilized solar energy system for rural inhabitant in order to strengthened health care, education, clean drinking water. Based on the related literature review; therefore, the aims of the research also to ensure security, awareness to the younger generation using communication satellites so that social vices confronting the rural inhabitant is minimized.

3. METHODOLOGY

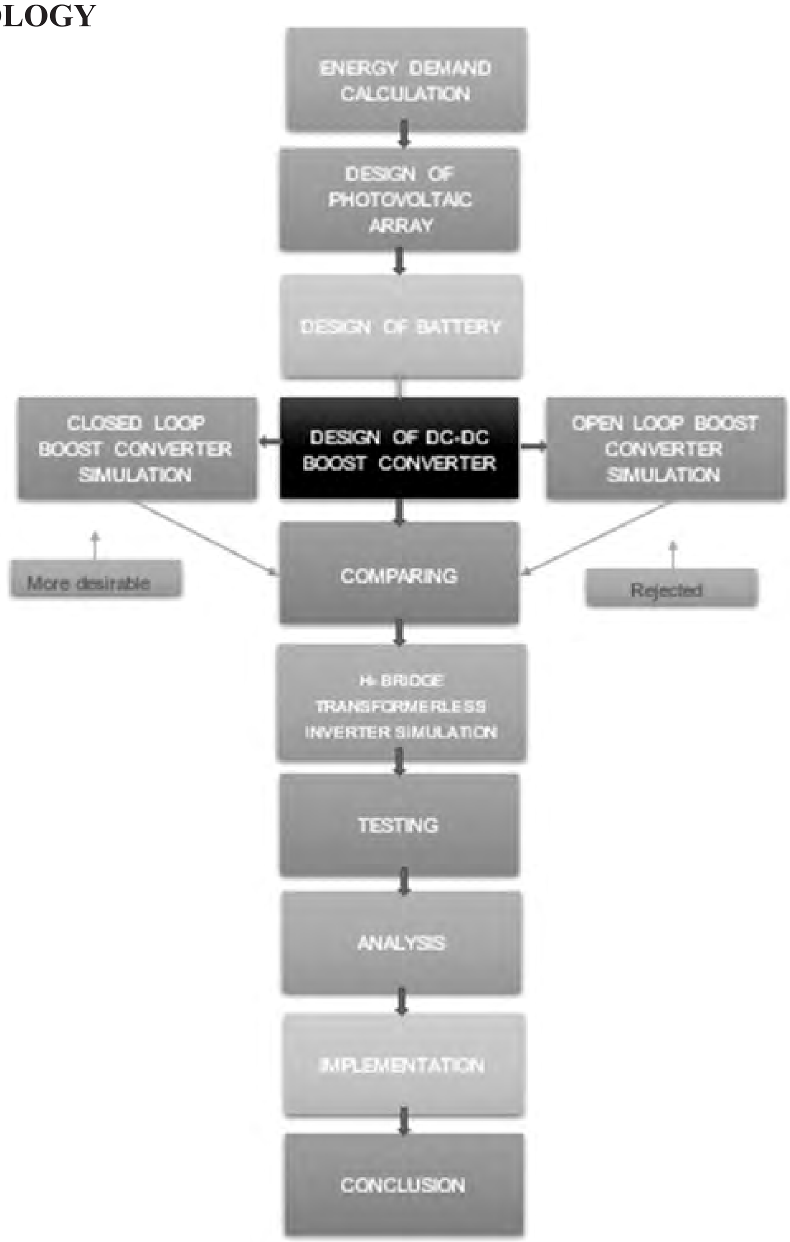

Figure Methodology chart for the implementation of stand-alone solar energy

The calculation of the energy that will meet the minimum demand of rural dwellers was the first methodology conducted in determining the size of a photovoltaic array, battery bank, DC-DC boost converter and the inverter. After the design, the simulation had made using MATLAB R2020a to observe the I-V and P-V characteristic with varied irradiation and temperature. Meanwhile, due to unregulated PV output voltage, boost converter had simulated with and without PID controller, i.e. closed-loop and an open-loop boost converter that will extract the maximum power of the PV array regardless of varied weather condition. While comparing, Closed-loop boost converter was then identified and proper to feed the H-bridge transformerless inverter to transform the 230 fixed DC boost voltage to 240 fixed AC voltage for AC appliances and for charging the battery bank. Additionally, waveforms had plotted to prove the validity of the design.

4. Analysis

4.1 Photovoltaic array

Different PV panel had studied in order to select the best that will suit the scheme; four various company with the same wattage had selected from MATLAB/Simulink library R2020a. Figure 2&3, 4&5 has almost the same characteristic; meanwhile, both the panel produces the same power. However, figure 2&3 has an identical current while 4&5 is slightly different. An investigation had further made that the panel with the highest number of cells produces higher amount voltage regardless they have similar power. Thus, before deciding a PV panel datasheet is essential in order to select the best that will match the design. Additionally, datasheet guide the designer to select wire gauge, charge controller and protection devices; for example, figure 2&3 has the higher current small voltage, which is the reverse situation of figure 4&5. Hence, figure 4&5 require a charge controller with the highest voltage, which is expensive and very rare in the market; yet it is applicable for industrial usage. For the examination, sharp ND-130UJF or solar liberty SLX130P6-18 is more efficient for the scheme and more suitable for domestic application.

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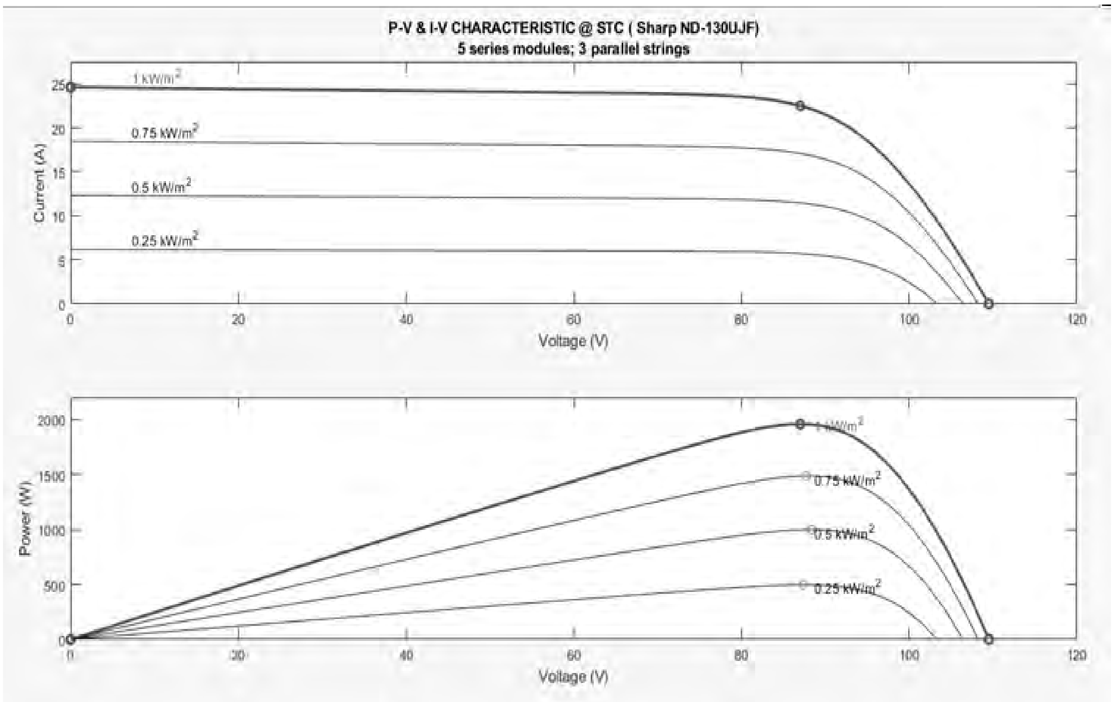

Figure PV array characteristic (sharp ND- 130UJF)

S/N	DISCRIPTION	VALUE
1	Power	130
2	open circuit voltage	21.9
3	maximum voltage	17.4
4	short circuit current	8.2
5	maximum current	7.5
6	cell per module	36

Table Datasheet (sharp ND- 130UJF)

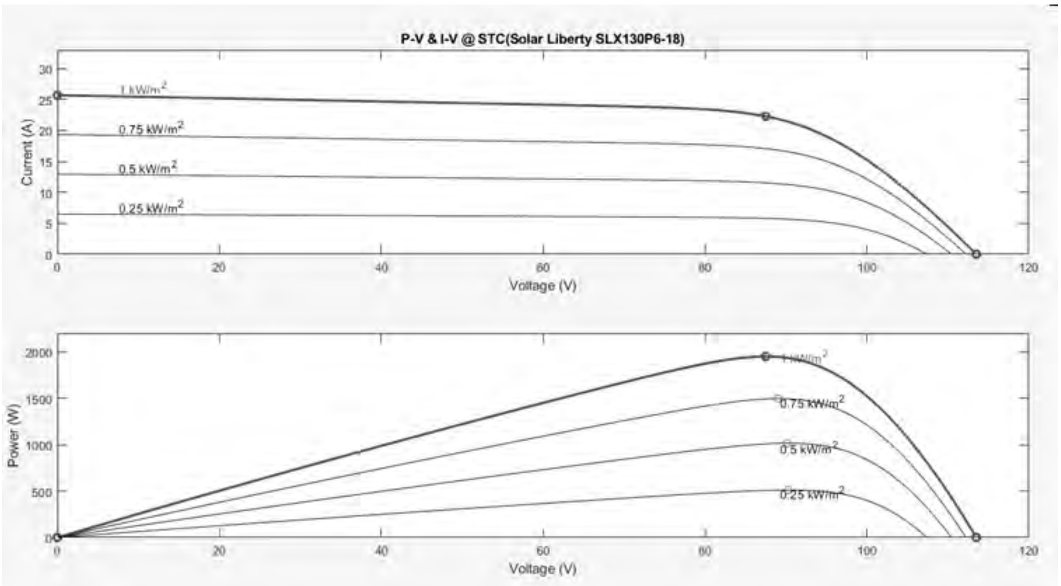

Figure PV array characteristic (solar liberty SLX130P6-18)

S/N	DISCRIPTION	VALUE
1	Power	130
2	open circuit voltage	22.7
3	maximum voltage	17.5
4	short circuit current	8.56
5	maximum current	7.43
6	cell per module	36

Table Datasheet (solar liberty SLX130P6-18)

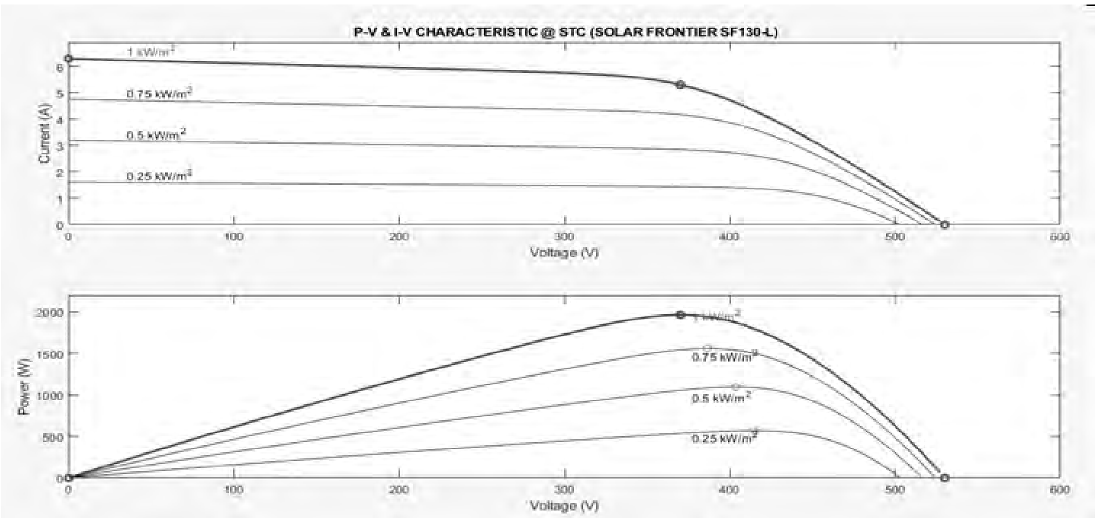

Figure PV array characteristic (solar frontier SF130-L)

S/N	DISCRIPTION	VALUE
1	Power	130
2	open circuit voltage	106
3	maximum voltage	74
4	short circuit current	2.1
5	maximum current	1.77
6	cell per module	170

Table Datasheet (solar frontier SF130-L)

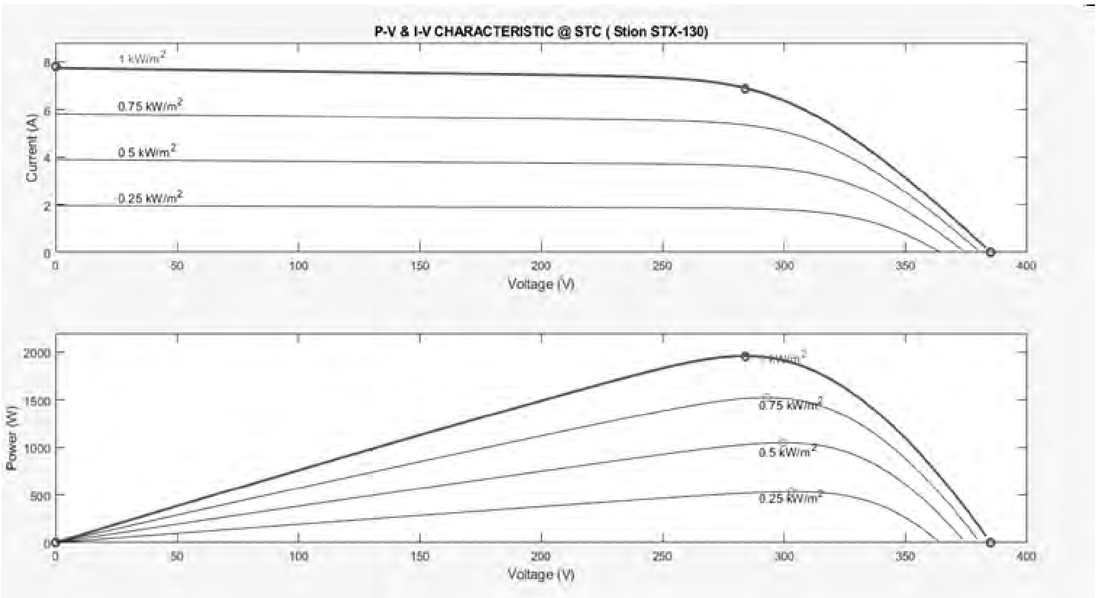

Figure PV array characteristic (Stion STX-130)

S/N	DISCRIPTION	VALUE
1	Power	130
2	open circuit voltage	77
3	maximum voltage	56.8
4	short circuit current	2.6
5	maximum current	2.29
6	cell per module	134

Table Datasheet (Stion STX-130)

4.2 Boost converter

The boost converter consists of an inductor, capacitor, MOSFET or IGBT, diode, DC source and load resistor. It has two modes of operation shown in figure (6). Mode one to absorb magnetic field in the inductor when the MOSFET is ON state at t = 0, mode two to inject the stored magnetic field to the load via diode and capacitor when the MOSFET is in OFF position at t = kT (Chan &Masri, 2010). This process maintains the ON and OFF switching made by the MOSFET device. Furthermore, boost converter output voltage is affected by the variation of the photovoltaic output voltage due to weather condition. Also, it has the downside of peak overshoot, settling time and rise time. Hence, the boost converter transient waveform is under-damped. Its drawback could be solved using a PID controller to control the switching of IGBT or MOSFET. The diagram using the PID controller to serve as feedback or closed-loop system had simulated and overcome such problem shown in figure (22). Nevertheless, the issue of the noise is another challenge that shall be work on in future work.

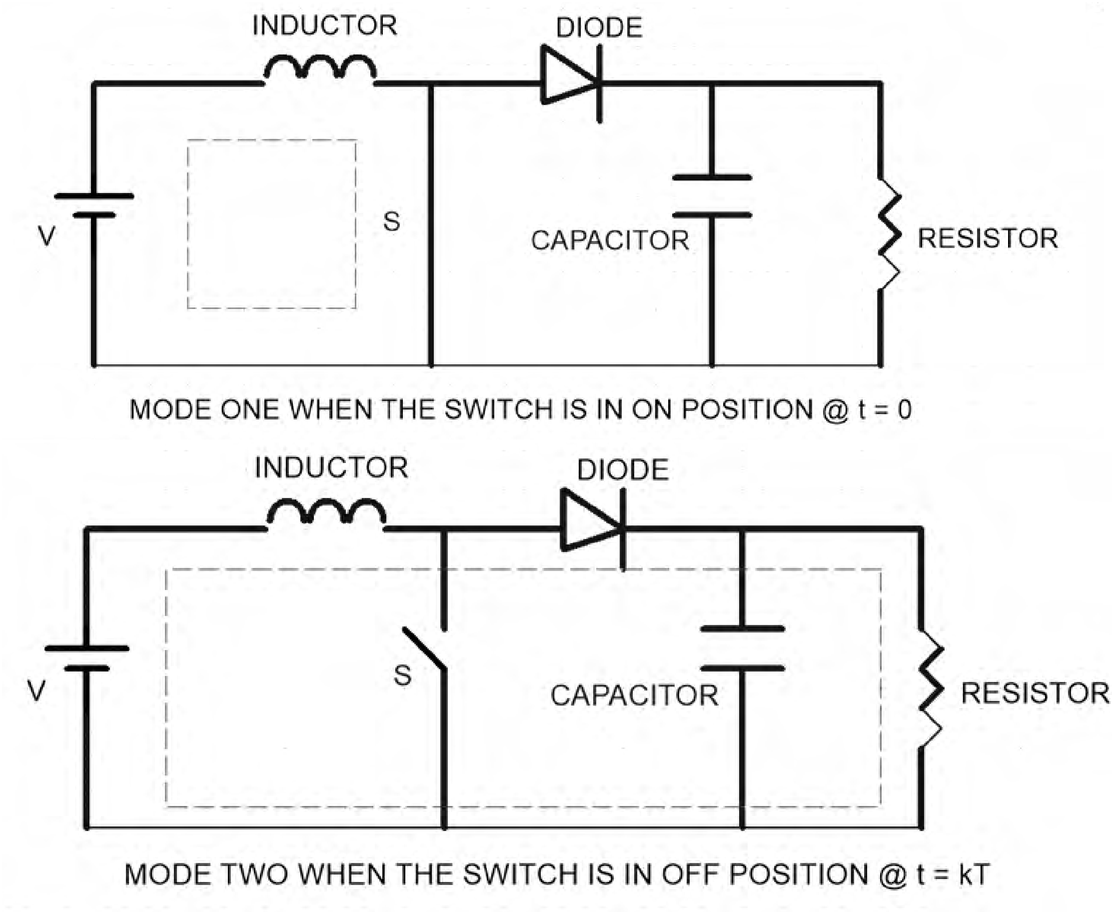

Figure ON & OFF mode of the boost converter

5. DESIGN AND SIMULATION

5.1 Calculating energy need

The energy needed for rural electrification is one of the primary considerations in order to avoid under-sizing of the system. Therefore, it is significant to know the wattage of individual appliances and the time required to run them. The standalone system mainly required such steps of calculating energy demand before determining the PV array for its reliability and efficient operation (Ali et al. 2018). Following is the tabulation of energy demand for the rural dwellers.

S/N	LOAD	QTY	WATT	TOTAL WATT	HOUR/DAY	KWH	KJ
1	Energy saving bulb	20	15	300	5	1.5	5400
2	Refrigeration	1	200	200	16	3.2	11520
3	Television	1	100	100	7	0.7	2520
4	Satellite receiver	1	20	20	7	0.14	400
5	Ceiling fan	3	60	90	15	1.35	4860
6	AC submersible machine	1	500	500	1	0.5	1800
7	Boiler	1	1000	1000	1.6	1.6	5760
	TOTAL			**2210**		8.99	**32260**

Table Energy demand for rural dwellers

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	oct	Nov	Dec
monthly Radiation $w/m^2/day$	6.70	7.39	6.63	6.38	5.87	5.12	4.58	4.66	5.24	5.87	6.75	5.75

Table Annual solar insulation in Zamfara state (Gusau) source (Linus &Olimpo, 2017)

5.2 PV module size calculation

- Total Kwh/day = 8.99
- Average hour per day of sunshine = 6h/day
- System voltage 24V then

PV module size = $\frac{Total\ daily\ watt\ hour}{6h/day} = \frac{8.99}{6} = 1498\ watt$

Thus, number of modules required is equal to wattage divide by rating of PV module (130, 7.5, 12v)

$$= \frac{1498}{130} = 12\ number$$

To avoid under sizing (Ebtesam et al. 2013) recommend that, the module need to increase for efficient running and reliability. Therefore, 15 number of PV module is recommended in the design.

5.3 Determination of number of modules to be connected in series and parallel

Number of modules connected in series = $\frac{system\ voltage}{nominal\ voltage\ of\ each\ module} = \frac{60}{12} = 5\ number$

Number of module connected in parallel = $\frac{whole\ modules\ number}{number\ of\ series\ panel} = \frac{15}{5} = 3\ number$

Connection configuration

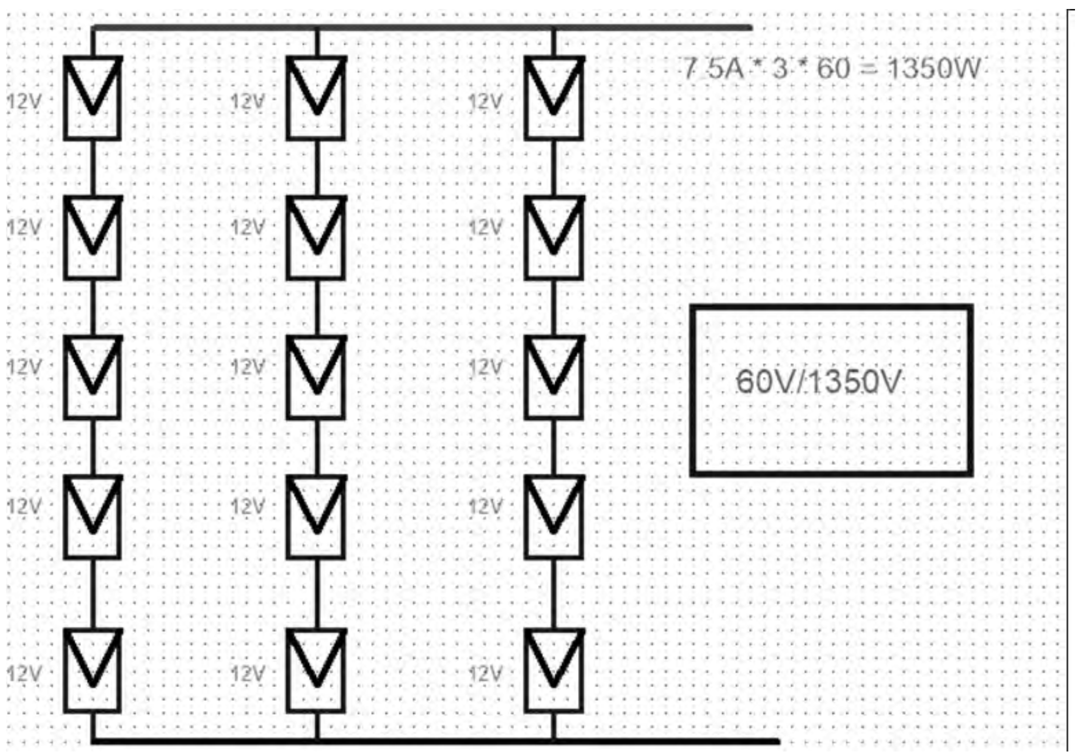

Figure photovoltaic array configuration

5.4 dc-dc boost converter

Boost converter steps up voltage from a lower level DC voltage to a higher-level DC voltage. Boost converter also used for interfacing between the battery and solar module load to achieve excellent matching (Ranjit 2019). The operational principle of the boost converter is the inductor capacity that will never let unexpected changes of current to destroy the magnetic field (Girdhar et al. 2018). Additionally, boost converter, the output voltage is always higher than the input and can track the MPP at times of low irradiation (Glavin& Hurley, 2006).

5.4.1 Mathematical equation of the boost converter

Duty cycle $D) = 1 - \frac{Vin}{Vout}$ ……………………1

Duty cycle is the ratio of Time ON to the total time of any cycle of a power device. Note that an increase in duty cycle due to unregulated output power of PV array results in increasing output voltage and current (Rai et al., 2017). Thus, the PID controller overcome this scenario.

$$L = \frac{V_{IN}\ X\ (V_{OUT} - V_{IN})}{\Delta I_l\ X\ f_s\ X\ V_{OUT}}$$ ……………………2

Where L = inductor, which helps to ensure that the sudden changes of current will not destroy the magnetic field.

fs = switching frequency,

ΔI_l inductor ripple current, which is estimated between 20% to 40 of the output current. Thus,

$$\Delta I_l = (0.2 - 0.4)\ X\ I_{OUT(max)}\ X \frac{V_{OUT}}{V_{IN}}$$ ……………………3

$$C_{OUT(min)} = \frac{I_{OUT(max)}\ X\ D}{f_s\ X\ \Delta V_{OUT}}$$ ……………………4

$\triangle Vout = Vout\ x1/100$ ……………………5

5.4.2 boost converter dc-dc design

Converter design is essential in order to know the parameter of the individual component; the mathematical equation of the DC-DC boost converter had presented above, and the calculated values as shown in table (8) below. Meanwhile, the parameters used to calculate the converter values is obtained from PV array Sharp ND-130UJF in MATLAB/Simulink library block R2020a shown in table (7) below.

S/N	DISCRIPTION	VALUE
1	Power	130W
2	input Voltage	60V
3	Ripple	40%
4	Switching frequency	25KHZ

Table Design values of the boost converter

S/N	DISCRIPTION	VALUE
1	Duty cycle	0.75%
2	Inductor	3 mH
3	Capacitor	6.75 µF
4	Load resistor	400?

Table calculated values of the boost converter

5.5 Battery sizing calculation

Different category of rechargeable batteries is obtainable in the market. However, the most typical battery used in a stand-alone solar PV system is a lead-acid battery because of its less cost and its durability (Ali et al. 2018). It is significant to provide a backup battery for the stand-alone solar electric system so that during night hour or cloudy condition, the storage will be utilized.

$$Battery\ bank\ size(Ah) = \frac{Energy\ consuption\ (wh) * Autonomy\ days * 1.25}{system\ voltage}$$

$$= \frac{1498 * 3 * 1.25}{60} = 94Ah$$

Where 1.25 is the scale factor

5.5.1Determination of number of batteries connected in series and parallel

The 12v/150Ah battery is chosen for the design Number of batteries connected in series

Number of battery connected in parallel $= \frac{system\ voltage}{voltage\ of\ one\ battery} = \frac{60}{12} = 5\ number$

Therefore, total number of batteries = number of series x number of parallel = 5*1 = 5 number Therefore, I recommend gel or AGM lead-acid battery (12v/100Ah) because they operate in a broader temperature, less maintenance and fit for a remote location.

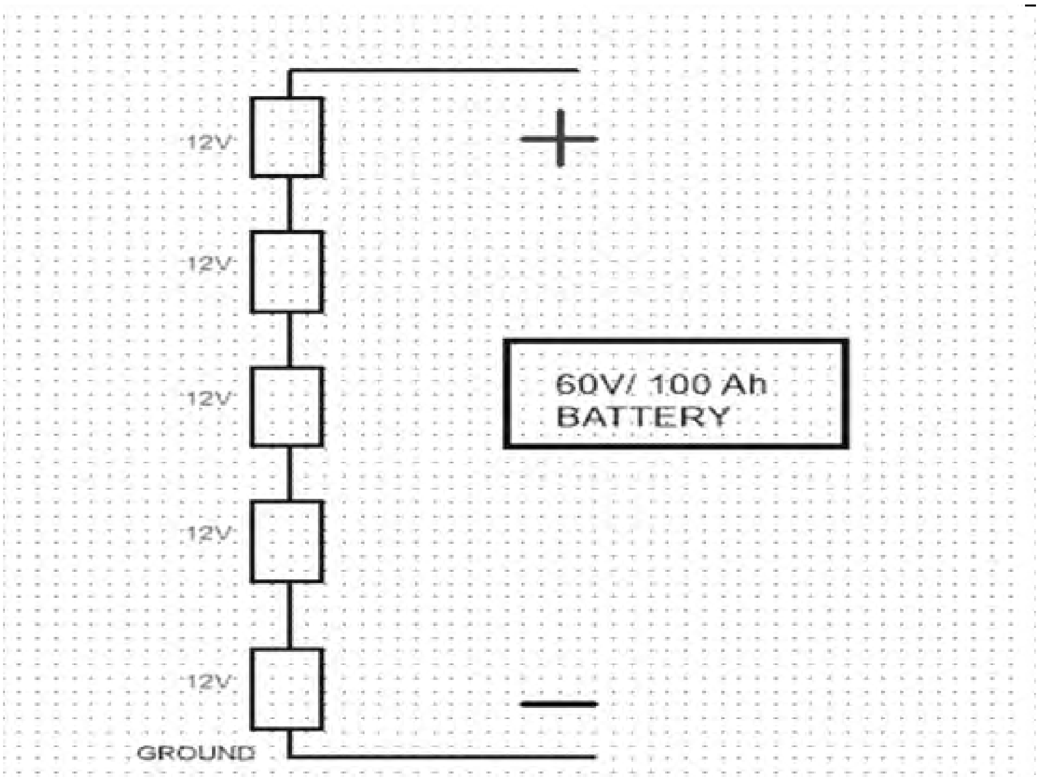

Figure battery bank configuration

5.5.2Battery management system (BMS)

The battery management system is the technology used in the battery to monitor, protect, estimate the state of health (SoH), state of charge (SoC), controlling the overcharge/over-discharge of a battery and maximize the performance of a battery (Mohammed et al.,2014). BMS help to match the battery pack, increase the energy release performance and prolong the life span (Yan et al., 2019). It also has the capability of reporting to the user the state condition of a battery via Bluetooth, for example, when using smartphone or external devices, for example, buzzer, screen display. The battery management system is; therefore, it aims to ensure that the variation of voltage between the cell in the battery pack is minimized. In brief, the essential three functions of a battery management system, ensuring that the life span of a battery is achieved, provides it protection from being damage and system optimization. Rahimi et al. 2013 suggest seven features of BMS for these three functions to be achieved and agreed by many authors as shown in the figure below (Faiz 2017)

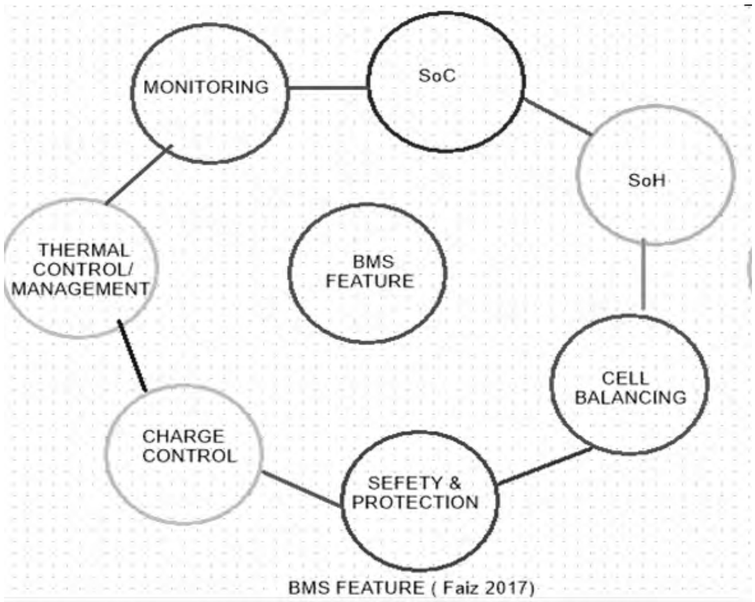

Figure features of battery management system

Furthermore, the battery management system should able to control all role of the energy storage system (ESS), communicate to the user all conditions of the battery component as well as for Data acquisition function (Rezal et al. 2014). Below is the connection of BMS to the battery bank for excellent utilization in the scheme.

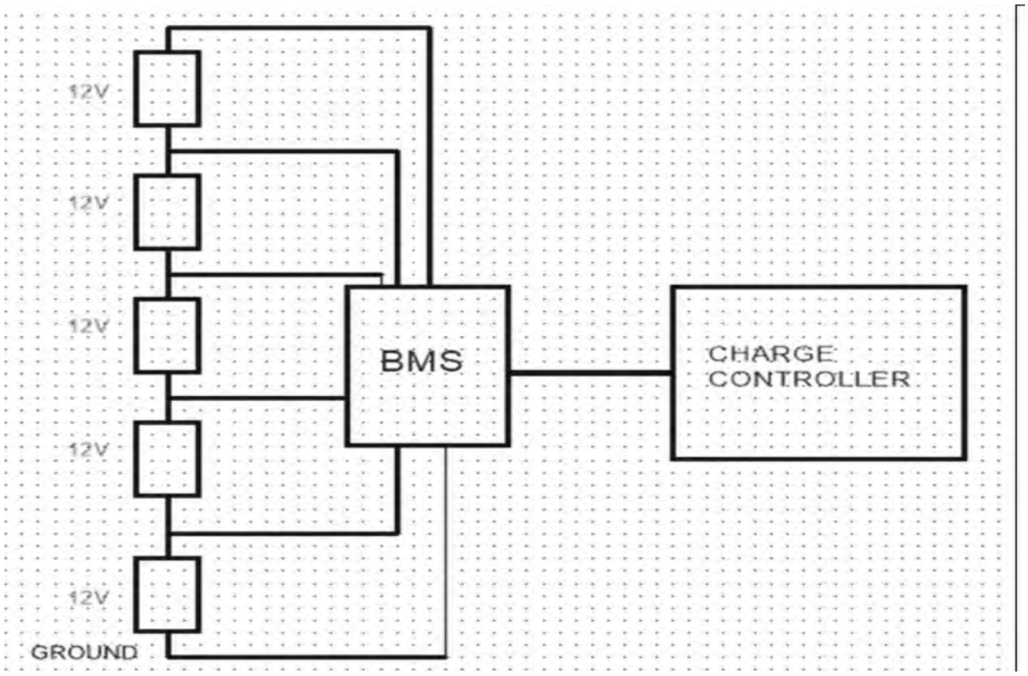

Figure Wiring diagram of BMS to the battery bank

6. TransformerlessInverter

Avoidance of galvanic isolation, cost, complexity and weight; the transformerless inverter has this feature and considered in the design. Meanwhile, its boosting capability and delivering low voltage THD make it more desirable for the scheme. It has two modes of operation each mode has boost capacitor, boost inductor and two switches, i.e. MOSFET. Note that both the parameters have the same value in order to obtain equal positive and negative cycle of the sinusoidal waveform. Switch one and two for positive half cycle, switch three and four for the negative half cycle. The 200 ohms resistor is connected to the load shown in figure (16).

6.1 Transformerless Inverter sizing

The total power of the load requirement determines the size of an inverter; thus, from table (5) the total power is 2.2KW, which is 2.2KVA at unity power factor. Applying scale factor of 1.3, the 3KVA is recommended

7.1Pumping machine (submersible) sizing

Sizing of a machine is essential; it helps recognise the amount of water flow rate in gallon per minute or litres per minute, size of a tank as well as deepness of a well. Moreover, the capacity of a machine that will supply normal water can be calculated with the aid of such parameters.

So, HP = Q x H / (3,960 GPM per foot x efficiency

Where, HP is machine in horsepower

Q = water flow rate per minute

H = Hight of a tank in feet

thus, the dwellers are expected to utilize 450 gallon (2046L) per day.

Thus, the size of machine should be, 40 x 100/ (3,960 GPM per foot x 0.85 = 1.2 HP

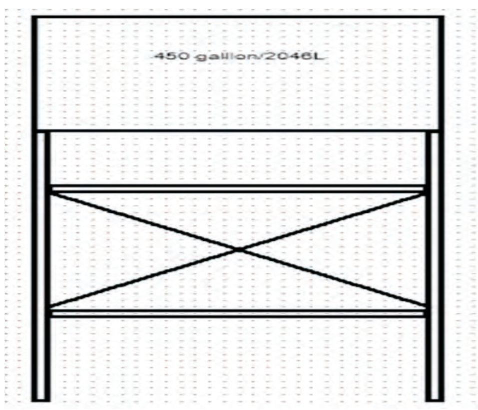

Figure Storage tank for the rural dwellers

8.Simulation of DC-DC converter and transformerless inverter

Simulation of a PV module is essential in order to observe the behavior of short circuit voltage, open circuit current, and maximum power point (MPP) at varied irradiance and temperature because they are dependent on varied weather condition (Martin 2014). Martin also highlighted that PV solar cell module is the minimal value from 0.5V to 0.6V but can be arranged in series to obtain the desired voltage. Meanwhile, solar PV panel produces nonlinear characteristic (Sahu et al., 2014), it is necessary to simulate and observe the effect of varying whether condition affecting the photovoltaic panel. Two techniques are typically employed for PV simulation; single diode model and double diode model (Ranita et all 2017). Single diode model will be considered for I-V and P-V characteristic. Following is the mathematical formula and circuit diagram for the single diode model

8.1 dc-dc open loop boost converter

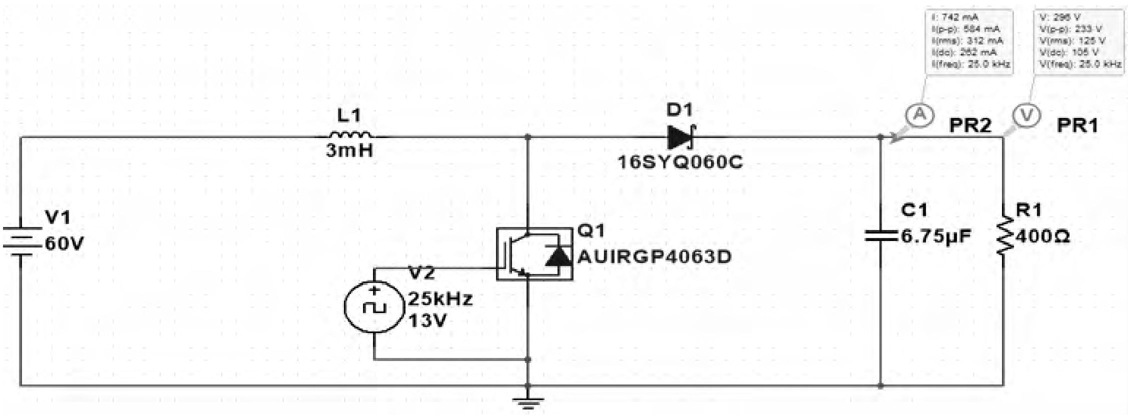

Figure 12 open loop Boost converter simulation

The figure (12) shows the simulated result of the boost converter; the voltage is raised from 60V DC to 230V DC at 0.75% duty cycle.

8.1 Simulation of the close loop DC-DC boost converter

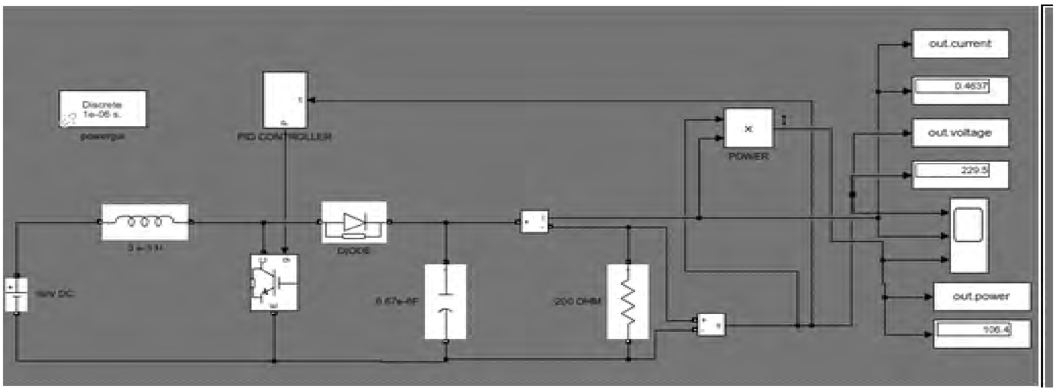

Figure 13 closed loop DC-DC boost converter/ PID controller

The figure (13) above is the boost converter with the PID controller that maintains the output at 230V DC even the input increases or decreases; note that the PID controller can serve as maximum power point tracker (MPPT) because it can maintain desired output power of the DC-DC converter.

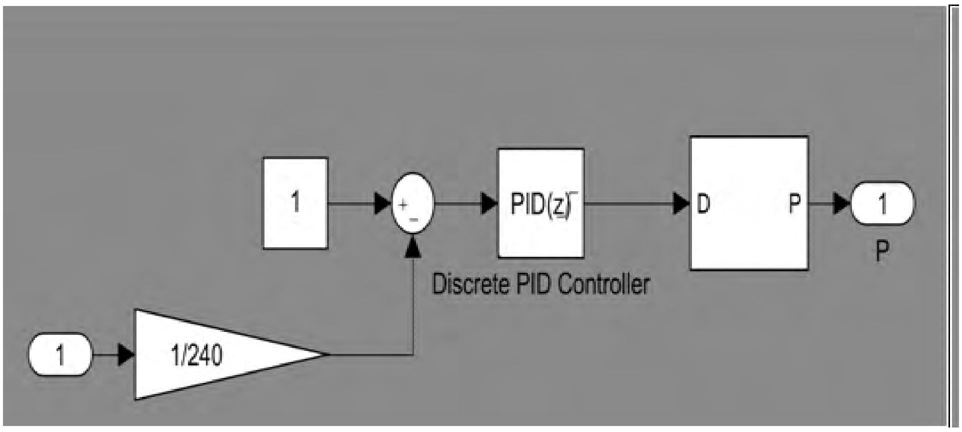

Figure 14 subsystem of PID controller

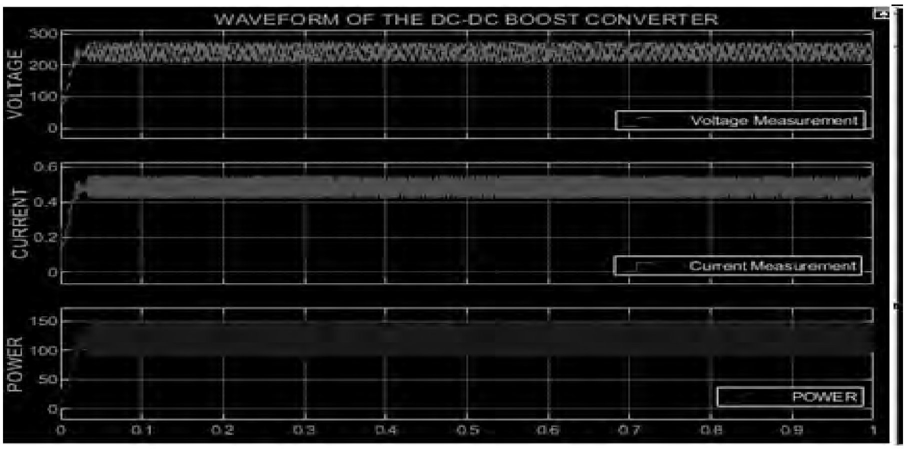

Figure 15 waveform of the closed loop boost converter

The figure (15) shows the waveform of the closed loop boost converter, the waveform depicts the good result.

8.1 Transformerless Inverter simulation

The figure (16) shows the simulation diagram of an inverter; the boost output voltage of the converter 230V DC delivered to the input of an inverter in order to obtain 240v AC. The figure (18) presents the expected Waveform of the model. Furthermore, transformerless H-bridge inverter had chosen in the design in order to neglect the bulky design in the system and to reduce the total harmonic distortion (THD).

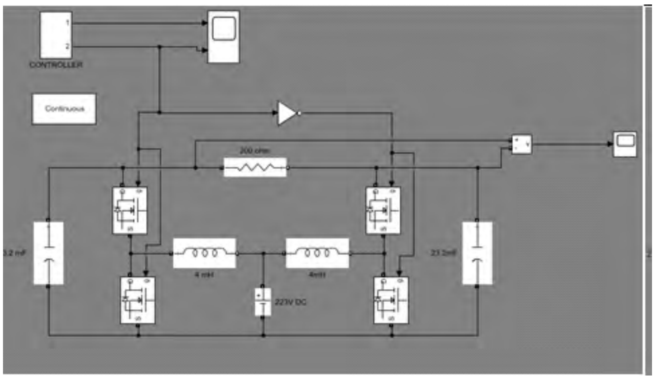

Figure 16Simulation diagram of the inverter

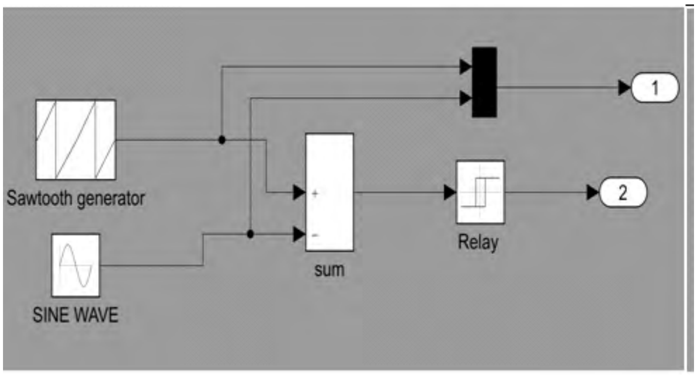

Figure 17 subsystem of the H-bridge transformerless inverter

S/N	DISCRIPTION	VALUE
1	Boost capacitor	23.2mF
2	Inductor	4mH
3	Load resistor	-
4	MOSFET	

Table parameters used for the inverter design

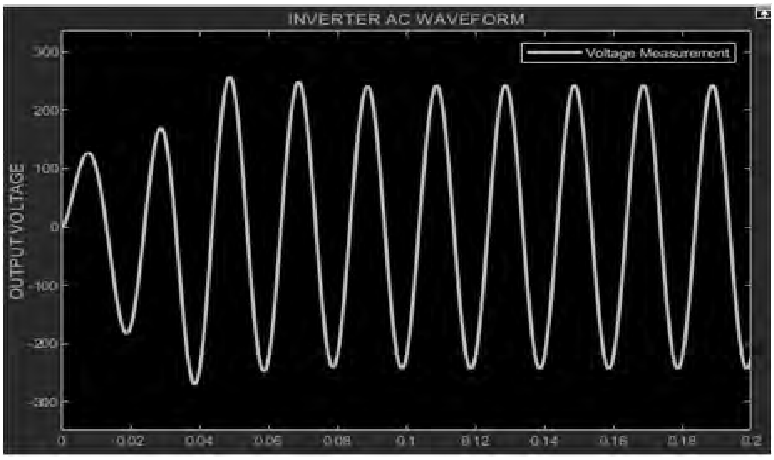

Figure 18 AC waveform of the inverter

The design and the simulation depict the validity of the scheme for optimum performance; thus, the objective of the project is achieved. Meanwhile, the scheme would be incorporate with the smart system to avoid energy waste when there is no activity.

8 Smart technology

Smart technology plays a significant role in energy saving in a home; it is ensuring that energy is not waste when not required. Different smart technology is available in the market, for example, a smart plug, smart light and occupant sensor. However, this smart system had designed with complexity like Zigbee, Z-wave that often require expensive gateway (Igor et al. 2015). Interestingly, Bluetooth low energy (BLE) smart technology had arrived that has inbuilt Bluetooth it bypasses gateway for its operation; it has direct communication with smartphone or tablets to a device. Note that the smartphone or tablets do not have Zigbee application or Z-wave application, which make them complicated by incorporating gateway for its operation and note that gateway without redundancy if failed, will bring the whole system maloperation. Thus, its complexity and cost in the market do not yield a favorable state and as well a reliable operation in home automation usage.

8.1 Selection of smart system for home automation

Considering the different system of smart technology architecture; the BLE smart system is required because now a day, it is the recent technology that widely used for home automation. Therefore, the BLE smart plug, photosensor, and occupancy sensor had selected to control the socket outlet and lighting. Meanwhile, the occupancy sensor is of two types. i.e. infrared sensor and ultrasonic sensor (Lwin et al. 2017); the former is selected to turn ON indoor luminaries when the movement is detected and automatically turn OFF the light when activities not detected. Also, the photosensor is selected for outdoor lighting control during night hours. The following figures are respectively infrared sensor, BLE smart plug and photosensor.

Figure 19 photo sensor

Figure 20 infrared sensor

Figure 21 BLE smart plug

9.2 Home energy management algorithm for smart plug

In the design, the smart plug had assigned to control different appliance; however, this machine has a different time constraint. Therefore, the algorithm had proposed to the controller to turn off the appliance if the specified duration elapsed. Following is the algorithms and the flow chart of the system.

Algorithms

Step1: start

Step 2: smart plug

Step 3: set the time constraint of the appliance

Step 4: read the time constraint of the appliance

Step 5: is the duration reach?

Step 6: yes, OFF the appliance

Step 7: No, go back to step 4

Step 8: End

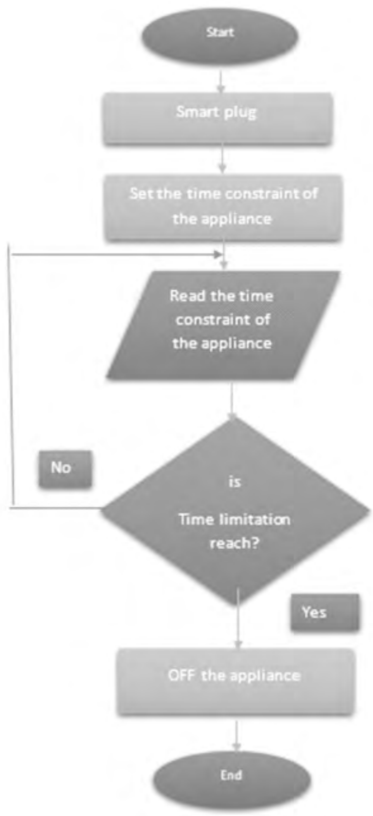

Figure 22 flow chart of home appliance schedule

9.3 Home management algorithm for lighting system

Algorithm

Step 1: start

Step 2: read motion sensor signal

Step 3: is motion detected?

Step 4: No, OFF the light

Step 5: yes, ON the light

Step 6: wait for three minutes

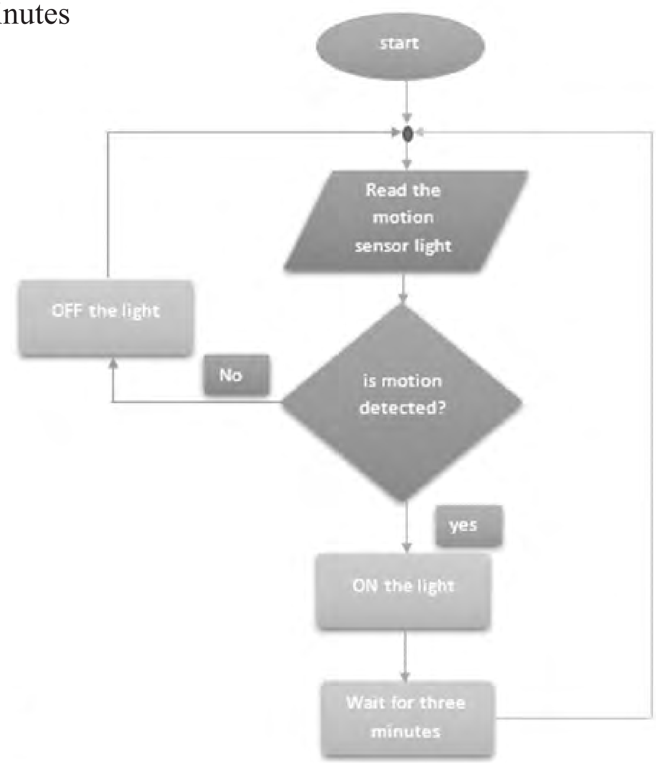

Figure 23 Flow chart of occupant sensor for lighting

S/N	LOAD	Start time	End time	Duration	Remark
1	Energy saving bulb	19:00	00:00	5 hours	Everyday
2	Refrigeration	00:00	15:00	16 hours	Everyday
3	Television	18:00	00:00	7 hours	Everyday
4	Satellite receiver	18:00	00:00	7 hours	Everyday
5	Ceiling fan	17:00	8:00	15hours	Everyday
6	AC submersible machine	7:00	8:00	1 hours	Everyday
7	Boiler	_	_	1 hour	Everyday

Table time schedule for home appliance

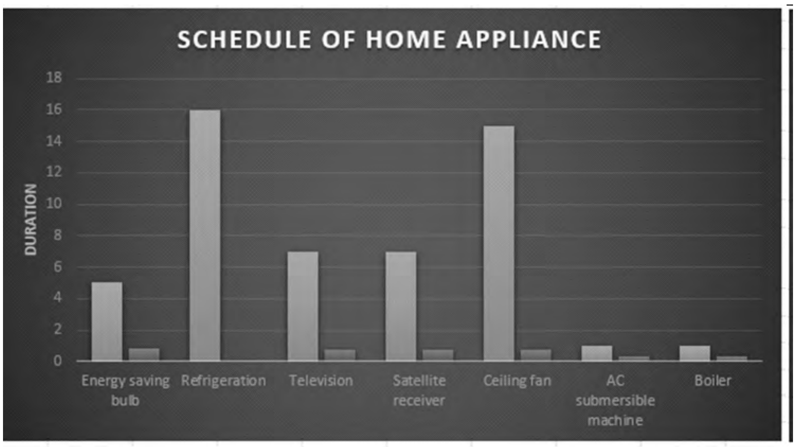

Figure 24 Bar chart graph of the time schedule

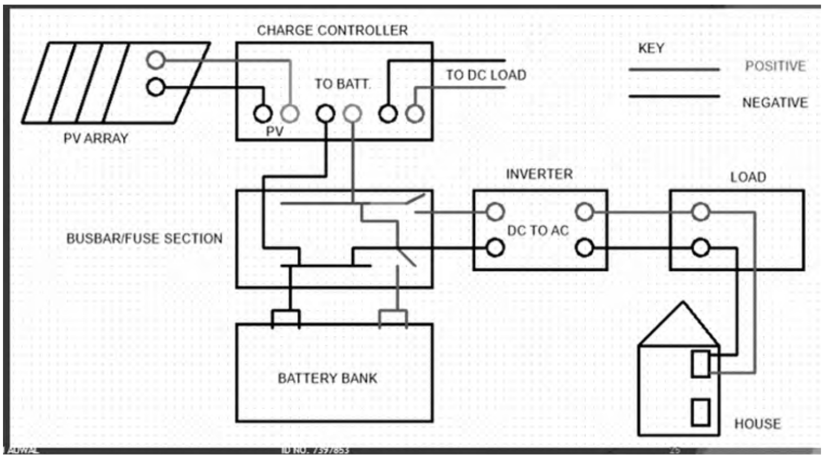

Figure 25 complete diagram of the scheme

8 Implementation and testing

The model had implemented in the MATLAB/Simulink R2020a and NI Multism; the software helps in designing and simulating main components in the scheme. In the meantime, the simulated components give the required result for accomplishment. Moreover, the tested components are shown in figure 15 and figure 18, which shows that the scheme would perform as required.

9 Conclusions

This research designs the stand-alone solar system for rural electrification; the objective of the report was to develop a solar energy system that will meet the minimum demand of the rural dwellers. So that, hygienic drinking water, a communication satellite, education, security is provided and to mitigate social vices affecting the area.

The minimum energy needed for the inhabitant had predicted in kilojoules; the PV array, DC-DC boost converter and transformerless inverter was then design and simulated to examine the soundness of the intention, which yielded perfect result presented in the figure (15 & 18). The closed-loop boost converter is connected to the output of a PV array to extract the maximum power; the output of the closed-loop dc-dc boost converter or usually called a charge controller is connected to the input of the transformerless inverter to transform it to pure sinusoidal AC voltage for the AC appliances usage. Battery management system (BMS) is incorporated into the model to ensure that the battery does not overcharge/over-discharge, battery equalization and for prolonging the life of a battery bank. Smart technology that will transform the scheme to self-regulation had also selected for socket and luminaries in order to ensure energy saving.

9.1 Future Work

The design had achieved with excellent performance; thus, the scheme shall be turned into fully functional stand-alone solar energy. Meanwhile, the installation cost shall be examined in a homer software, and the hybrid of solar energy and wind energy would also be studied to observe the cost disparity. The noise found at the output of the converter will also be addressed in future work, because the ripples will cause heat to the circuit components and distortion. Integration of the converter with the transformerless inverter in the simulator to prove their matching is another challenge that will be deal with, due to time constraint not achieved.

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