ACADEMIC INN INTERNATIONAL

ISSN NO : 2523-1189

Journal of AGRICULTURAL AND RURAL RESEARCH

open access

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To cite the article: *Emmanuel O. Sangotayo, Oluwafemi A. Olakanye, Rasheed O. Jaiyeola, Ayodeji J. Bamidele, Oluwaseun A. Babarinde (2020), Development of stand-alone hybrid photovoltaic system for metrology laboratory in lautech Southwest Nigeria, *Journal of Agricultural and Rural Research*, 4(2): 60-77.

Link to this article:
http://aiipub.com/journals/jarr-191231-010092/

Article QR

Journal QR

DEVELOPMENT OF STAND-ALONE HYBRID PHOTOVOLTAIC SYSTEM FOR METROLOGY LABORATORY IN LAUTECH SOUTHWEST NIGERIA

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ARTICLE INFO

Article Type: Research
Received: 31, Dec. 2019.
Accepted: 25, Mar. 2020.
Published: 27, Mar. 2020.

Keywords:
PV Power System, Voltage, Temperature Gradient, Sustainable Energy

ABSTRACT

The photovoltaic power system uses the direct conversion of solar irradiance into electricity, can be used as an electrical power source for a home and farm settlement to meet its daily energy requirement. This work presents the design, installation, and testing of a hybrid standalone photovoltaic power system. The process of securing photovoltaic power involves designing, selecting, and determining specifications of different parts that are used to conform to the load estimation of 940 watts. The designed system consists of a 150 watts PV with a battery of 12 V, 100 Ah, and a 1.0 kAV inverter. The designed PV stand-alone power system was tested to study the relationship between the potential difference and the temperature distribution using extended heat transfer equipment. The set-up compr ises of PV stand-alone solar power inverter system, extended heat transfer device, and 12 channel temperature recorder to measure temperature distribution along the length of the metallic rod, Aluminum. It was deduced that voltage has a direct relationship with the temperature distribution using extended heat transfer equipment. The result reveals that the developed system powered 940 watts daily energy demand satisfactorily, and efficient utilization of renewable energy will enhance energy supply in the country.

1.INTRODUCTION

Solar energy has been judged clean, inexhaustible, unlimited, non-polluting, and reliable, require little or no maintenance and environmental friendly (Assad, 2010). Such features and attributes have attracted the energy sector to utilize renewable energy sources on a large scale. The exploitation of renewable energy resources has been at the forefront of the campaign throughout the world for the supply of an essential proportion of world energy demands (Ikuponisi, 2004). Nigeria is fortunate with plentiful renewable energy means, which includes hydroelectric, solar, wind, tidal, and biomass; there is a need to utilize these energies and to plan a new energy future for Nigeria. The government should be concerned about making renewable energy available and affordable to all. (Oyedepo, 2012).

Many indigenous researchers have examined the feasibility of renewable energy reserves in Nigeria to establish its sustainability in the country. Onyebuchi (1989) accessed the technical possibility of solar energy in Nigeria with a 5% appliance change efficiency place at 15.0×10^{14} kJ of functional strength yearly. It amounts to about 258.62 million barrels of oil equivalent yearly, which marches to the present national every twelve months of fossil fuel production in the country. This will also sum up to about 4.2×10^5 GW/h of electricity production once a year, which is about 26 times the present year electricity production of 16,000 GW/h in the country. Chineke and Igwiro (2008) presented that Nigeria obtains abundant solar energy that can be utilized efficiently with a yearly average daily solar radiation of about 5.25 kW h/m^2/day. It varies between 3.5 kW h/m^2/day at the coastal areas and 7 kW h/m^2/day at the northern boundary.

The average quantity of sunshine hours all over the country is appraised to be about 6.5 h. This yields an average yearly solar energy concentration of 1,934.5 kW h/m^2/year; as a result, a year, an average of 6,372,613 PJ/year of solar energy descends on the whole land area of Nigeria. This is about 120,000times the total yearly average electrical energy produced by the Power Holding Company of Nigeria (PHCN). The accessible solar energy means, it is about 23 times the Energy Commission of Nigeria's (ECN) prediction of the entire aggregate of energy demand for Nigeria in the year 2030 with a 10% conventional change efficiency, [ECN, 2005]. There is a necessity to strengthen the current erratic energy sector with a sustainable source of power supply through solar energy to improve the developmental trend in the country.

Rezzouk and Mellit (2015) showed that the hybrid system of PV and diesel would be sustainable than a stand-alone PV system. The latest research has led to a substantial improvement in the efficiency of the PV system to utilize clean energy. Therefore the stand-alone PV systems are becoming more global for the electrification of off-grid communities and other projects like the water pumping system (Bogno *et al*., 2018; Rahra et al., 2015 and Mohammedi *et al*., 2013)

Oladeji, *et* al (2017) proposed a cost-effective energy system for the National Centre for Hydropower Research and Development, NACHRED building utilizing solar PV to meet the indispensable electrical load demand of the building and power from the grid to supply the surplus need for air conditioner system, that the government should provide incentives to encourage the use of solar energy to power necessary electrical appliances for residential, commercial and industrial buildings. Saleh.*et al*. (2015) presented the application of the photovoltaic power system by the use of direct conversion of solar irradiance for power generation into electricity. The cost analysis and installation of a PV system were estimated, which shows that the initial investment is high but within a few years will gain a substantial dividend and has a long life span if adequately utilized.

Heat transfer and thermodynamics are fundamental and very crucial topics that deal with energy and have long been a significant part of Mechanical Engineering curricula across the globe. Heat transfer processes are experienced in a large number of engineering applications, such as solar energy systems. Thermal engineers need to comprehend the principles of heat transfer and be able to utilize the right governing equations that govern the amount of energy being used. However, the majority of students feel that these topics are difficult (Odeh and Abu-Mulaweh, 2012).

Abu-Mulaweh (2004 and 2005) described an experimental apparatus designed to demonstrate solar energy applications where needed, such as photovoltaic thermal hybrid solar collectors (Hybrid PV) system. The device developed by companies specializing in education equipment may not consider the educational objectives proposed by the faculty. These impediments forced different venues to be searched to secure instructional experimental laboratory device to show solar energy applications. It was concluded that such an apparatus could be designed, developed, and constructed in a laboratory house and farm settlement within a flexible budget.

Hybrid Photovoltaic solar collectors (Hybrid PV) are systems that convert solar radiation into both electrical and thermal energy (Charalambous *et al.*, 2007; Tonui and Tripanagnostopoulos, 2008). These sets of systems combine a photovoltaic panel, which changes solar energy into electricity, with a solar thermal collector, which traps the remaining energy and removes waste heat from the photovoltaic (PV) module (Saad and Abu-Mulaweh, 2012). The PV cells suffer from a drop-in efficiency with the rise in temperature due to an increase in PV electrical resistance. The Hybrid PV systems can be manipulated to move heat away from the PV cells, thereby cooling the cells and thus enhancing the efficiency by reducing PV electrical resistance (Duffie and Beckman, 2006).

The efficiency and output power of PV are influenced by solar irradiance, location, face angle of the PV panel, type of PV such as mono-crystalline, poly-crystalline, micro amorphous silicon, and amorphous silicon and the efficiency of the components, but the obtainable solar irradiance and location play a substantial role (Charan, *et al*., 2017). Sangotayo *et al.* (2018) presented an experimental examination of the thermal effect of photovoltaic hybrid solar cells on the electrical efficiency of the solar inverter to maintain the effectiveness of the system. It was found that the solar photovoltaic module electrical efficiency reduces as the solar radiation and ambient temperature increase due to a rise in solar cell temperature and irreversibility. The study shows that today's accessible silicon photovoltaic module takes little advantage of the exergy content of the incoming solar exergy, it helps in determining the effective performance and selecting of solar panel in Ogbomoso climatic conditions.

Daily energy demand would be fulfilled during sunshine hours by using solar energy while during night hours, when there is no sunshine, a new energy storage device is required to meet the demand. Total solar irradiance varies with time of the day, location, season, and climatic condition. Therefore, the design of the stand-alone solar system cannot have only one standard. The site, area, is a crucial factor that influences photovoltaic power system design, and its specifications vary from place to place (Abhik, 2015). Iqbal and Iqbal (2019) presented thermal modeling, sizing, and optimization of a stand-alone PV system with detailed cost calculations for a typical house of the rural area in Pakistan, The designed system consists of 5.8kW PV, eight batteries of 12V and 255 Ah, and a 1.4kW inverter, and overall costs of $9650. It was recommended that a hybrid and cheaper energy storage system would prove helpful in harnessing clean and affordable energy.

In this work, the developed standalone PV system was tested with an extended surface heat transfer equipment as a teaching aid for laboratory use in Ladoke Akintola University of Technology, LAUTECH. Ogbomoso. The photovoltaic system includes a photovoltaic panel that harnesses solar energy from the sun and incorporated with a thermal collector that is solely responsible for heat removal from the system. The hybrid PV system type is an air PV system type. The epileptic power supply is a significant concern in Nigeria as a result of this; the stand-alone hybrid photovoltaic system was developed for all equipment in the Metrology Laboratory of Mechanical Engineering, LAUTECH, Ogbomosho with total load estimation of 940 watts.

2.0 MATERIALS AND METHODS

2.1 Design Analysis and Material Used for PV System

A Hybrid Photovoltaic/Thermal (PV) collector is a fused system of a photovoltaic (PV) solar module for power propagation and a flat plate solar collector. The photovoltaic system comprises the following components;

i. Solar PV array
ii. Cables

iii. Charge controller
iv. Inverter
v. Battery
vi. Protection devices

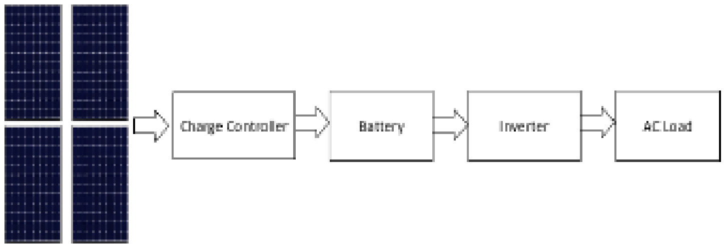

Fig. 2.1: Stand-alone Photovoltaic Components

A schematic diagram of the interconnection of a typical stand-alone photovoltaic power system is presented in Figure 2.1. The components of the system are specified depending on load requirement and radiation intensity at the site,

2.3 Factors influencing the PV System Design and Installation

PV power systems have diversity and great merits; however, it is essential to know that it has a high initial cost, which is one of the significant limitations to its existence. The following factors are considered in the design of the hybrid PV system:

2.3.1 Site Inspection and Radiation Analysis

The first and essential part of the design is the geographical location of the installation, site inspection, and radiation analysis. The radiation data of the place revealed that the amount of electrical energy that can be produced depends on the sunshine intensity in the whole year. Shadow examination determines the time persistence for which solar power falls on solar arrays. Azimuth angle and altitude angle is used to find out the sun path at that location.

2.3.2 Reasonable Load Consumption

The principle of energy conservation is applied when calculating the total average energy demand in watt-hour per day. The electrical load of a specific building determines how a PV system has to be installed, and the load is evaluated by listing all the loads and their corresponding daily hours when in use.

2.3.3 Optimizing Building Design

The optimal energy and the amount of energy that is needed to meet the required building heating, the building is provided with sufficient insulation. The southern part of the building is free from all types of solar irradiance impediments since the array is mounted towards the south for enough output of the irradiance.

2.3.4 Reliable and Energy Efficient Loads

The lighting apparatus is the compact fluorescent lamp (CFL) type referred to as energy savers to reduce energy consumption. Also, cooking and hot water devices usually are not part of a PV power system design.

2.3.5 Choice of Low- Voltage De Powered Components

Low-voltage depowered components are used wherever possible, as this will significantly reduce the capacity of the inverter and a corresponding reduction of its cost.

2.3.6 Inductive Loads Consideration

It usually has a large starting inductive current in the building, such as AC and refrigerator which must be taken into account during the design phase.

2.4 Determination of PV Size

The solar PV array is the central part of a stand-alone PV system. The PV modules are connected in series to obtain the required voltage, and it is called a PV string are then combined in parallel for the system to produce the desired current.

The following vital pieces of information are be known to determine the size of the PV which includes the DC voltage of the system (V_{dc}), the mean sun hours of the installation site per day (T_{shd}), and the daily average energy demand in watt-hours (E_d)

The required daily average energy demand (E_{rdd}) is determined for accurate PV sizing which is obtained by dividing the daily average energy demand by the product of the efficiency of all the system components as given in equation (2.1)

$$E_{rdd} = \frac{E_b}{\eta b \, \eta_i \eta c} \qquad (2.1)$$

Where ηb = battery efficiency

η_i =inverter efficiency

η_c = charge controller efficiency

The average peak power ($P_{ave,\ peak}$) is obtained by dividing the required daily average energy demand by the sunshine hour per day as expressed in equation (2.2)

$$P_{ave,peak} \frac{E_{rdd}}{T_{shd}} \qquad (2.2)$$

The number of modules (I_{dc}) which is obtained by dividing the average peak power by the system dc voltage as written in equation (2.3)

$$I_{dc} = \frac{P_{ave/\,peak}}{V_{dc}} \qquad (2.3)$$

The number of the parallel of module string (N_{sm}) is obtained by dividing the system dc voltage (V_{dc}) by the rated voltage of each module (V_{rm}) is given as system dc voltage divide by the voltage of each module as given in equation (2.4)

$$N_{sm} = \frac{V_{dc}}{V_{rm}} \qquad (2.4)$$

The numbers of the parallel of modules string (N_{pm}) can be obtained by using equation (2.5)

$$N_{pm} = \frac{I_{dc}}{I_{rm}} \qquad (2.5)$$

The total number of modules (N_{tm}) that form the array is determined by using equation (2.6)

$$N_{tm} = N_{sm} x N_{pm} \qquad (2.6)$$

2.5 Evaluation of the Charge Controller Specification

The solar charge controller is mainly sized in a way that enables it to perform its function of current control. The charge controller sizing is estimated using equations. 2.7, 2.8, and 2.9.

The required charge controller current (I_{cc}) is expressed in equation (2.7)

$$I_{rcc} = I_{sc}^{M} x N_{pm} x F_{safe} \qquad (2.7)$$

Where I_{sc}^{M} = the short circuit current of the selected module.

The required number of the charge controller, N_{cc} is obtained using equation (2.8)

$$N_{cc} = \frac{I_{rcc}}{I_{cc}} \qquad (2.8)$$

The total cost of the charge controller is obtained in the equation (2.9)

$$T_{cc} = N_{cc} * C \qquad (2.9)$$

Where C= cost of each charge controller

2.6 Evaluation of the Inverter Capacity

Solar PV system delivers Dc voltage and power, and an inverter changes DC power to AC power. An inverter is rated by its output power (P_{KVA}) and DC input voltage (V_{dc}). The consumption of power in the appliance can be classified into two categories: resistive power (P_{res}), such as in light, heater, and iron, and inductive power (P_{ind}), such as in fan, motor, etc. The power (P_{inv}) delivered by the inverter is given in equation (2.10)

$$P_{inv} = 1.25(TP + 3.5 x P_{ind}) \qquad (2.10)$$

Where, P_{inv} = the power of the inverter

TP = power of all loads running $(P_{res} + P_{ind})$

P_{ind} = Power of all inductive loads simultaneously with large surge current

The power rating of the inverter (P_{output}) is the real power that is delivered by the inverter as output, and it is given by the power factor (PF) in equation (2.11)

$$PF = \frac{D}{P} \qquad (2.11)$$

Where D is Delivery real power and P is the power rating of the inverter

The real power is the power consumed for work on the load (P_{inv}); it is estimated using equation (2.12). The value of PF is mostly taken as 0.8 for most of the inverter.

$$P_{KVA} = \frac{P_{inv}}{PF} \tag{2.12}$$

2.7 Determination of battery capacity

The battery is designed to store enough energy to operate all loads in all the season of the year and in the night, cloudy, rainy and dusty of the month. Battery storage is calculated in Ah (ampere-hour) unit.

The charge storage capacity is significant in the energy storage capacity of the battery bank, (B_{Ah}) is evaluated by the daily energy requirement and number of days for backup power (N_{bachup}) using the equation (2.13), and the energy of the inverter is determined using equation (2.14)

$$B_{Ah} = \frac{E_{i\ nv} x N_{backup}}{V_{dc} DoD}(AHr) \tag{2.13}$$

where $E_{inv} =$ the energy of the inverter $\left(\frac{E_d}{\eta_i}\right)$ (2.14)

N_{backup} = Number of days for backup power

DoD =Depth of discharge of the battery, it is the percentage of charge that is the energy of the battery that can be allowed for running the load.

The C-rating is an essential part of selecting a battery. It indicates the optimum charging and discharging rate of a battery. The number of cells connected in series (N_{Bs}) is obtained using the equation (2.15)

$$N_{Bs} = \frac{V_{dc}}{V_b} \tag{2.15}$$

Where V_{dc} and V_b are system DC voltage and individual battery voltage

The number of batteries connected in parallel (N_{Bp}) can be obtained using equation (2.16),

$$N_{Bp} = \frac{B_{Ah}}{C_b} \tag{2.16}$$

The total number of cells (N_{TB}) are obtained using the equation (2.17)

$$N_{TB} = N_{Bp} x N_{Bs} \tag{2.17}$$

The battery efficiency (ηb) is 85% for a lead-acid battery, then the energy required (E_{Bat}) from the solar PV array to charge the battery bank is determined using equation (2.18):

$$E_{Bat} = \frac{V_{dc} B_{Ah}}{\eta b} \qquad (2.18)$$

Dc able sizing

The correct size and type of cable selected for wiring the PV components together determine the effectiveness of the PV system. There are two types of DC cable: PV array to bank and charge controller cable also inverter to distribution board system of the Laboratory cable

PV array to battery and charge controller - The wire is selected based on the current between the array and the battery bank. The cable is based on the maximum continuous input current from Inverter, and it is obtained using equation (2.19).

$$I_{oi} = \frac{P_i}{V_{oi} x Pf} \qquad (2.19)$$

Where I_{oi} = Current at the inverter output

V_{oi} = Inverter output voltage

P_i = Power rating of the inverter

P_f = Power factor

3.0 DESIGN SPECIFICATION OF THE PV COMPONENTS FOR METROLOGY LABORATORY AT LAUTECH, OGBOMOSO

Nigeria is located between latitude, 9.08^{o}N, and longitude, 8.7^{o}Ewith a total area of 923,768 square kilometres. The country is situated between the equator and the tropic of cancer. The weather condition can be characterized into the wet season and dry season. The scope of this work is limited to Ogbomoso, Oyo State South West Nigeria located at the latitude 8.1^{o}N, longitude 4.02^{o}E, and an altitude of 347m above the sea level.

Load Profile of the Laboratory

The load profile is determined by itemizing and summing up the power rating and hour of use of all the appliances in the laboratory to obtain the total average energy requirement in watt-hours. It is based on hours of usage per day. An estimation of the demand needed for the laboratory is presented in Table (3.1).

3.1 Inverter Specification and Sizing

The inverter is specified according to the resistive load and inductive load requirements of the laboratory. The summary of the inverter sizing procedure and its cost estimate are presented in Table 3.2. The inverter of 1000 VA capacity is used. The inverter with power rating is sourced from the manufacturer at a reasonable cost.

3.2 Battery Specification and Sizing

The battery bank size is calculated based on the energy storage requirement by using eqns. 2.11 to 2.16. The summary of the battery sizing procedures is presented in Table 3.3.

Table 3.1: Total Energy Requirement and Power Rating of the Lab.

S/N	Appliance	Qty	Power Rating (Watt)	Hour of use per day	Energy per day

1	Inverted Metallurgical Microscope – Illumination, Halogen Lamb, Adjustable brightness (6 volt/20 watts)	1	20	4	80
2	Upright Metallurgical Microscope (LABOVISION) (6 volt/20 watts)	1	20	4	80
3	Upright Metallurgical Reflected/ Transmitted Microscope – Illumination, Halogen Lamb, (12 volt/50 watts)	1	50	4	200
4	Heat Transfer Equipment for measuring temperature	1	60	4	240
5	Computer	1	65	4	260
7	Energy Saving Bulb	1	15	4	60
8	Mobile	2	2.5	4	20
	Total Energy Demand.				940

Table 3.2: Inverter Specification and Sizing Inverter 1KVA (1kva inverter. 1batt. System)

Parameters	Calculated Values	Source
Inductive Load (P_{ind})	119.86 W	Table 2
Resistive Load (P_{res})	820.18 W	Table 2
Total continuous output power (TP)	940 W	Table 2
Efficiency (η_b)	70%	Battery datasheet
Efficiency (η_c)	68%	Controller datasheet
Efficiency (η_{inv})	90%	Inverter datasheet
Input power to the inverter (TP1)	1.04 kW	Refer to "(Eqn.2.10)"
Input Dc Voltage(V_{dc})	12V	Inverter datasheet
Input Dc current to the inverter(I_{dc})	13 A	Refer to "(Eqn.2.3)"
Total inverter power(P_{inv1})	1.7 kW	Refer to "(Eqn.2.10)"
Power factor(PF)	0.8	Inverter datasheet
KVA rating(P_{KVA})	2.12 kW	Refer to "(Eqn.2.12)"
Inverter cost	N60,000	Market price
Output AC voltage	240V	Inverter datasheet

Table 3.3: Battery specification and Sizing KPH 100-/12AH

Parameter	Calculated Values	Source
Usage/day	7hrs	Taken
Autonomy (N_{backup})	3 Days	Taken
The depth of discharge (DoD)	80%	Battery datasheet
The required capacity of the battery (B_{Ah})	100Ah	Battery datasheet
Battery bank operating voltage (V_{dc})	12 V	Battery datasheet
Each battery voltage	12V	Battery datasheet
No. of battery in series(N_{BS})	1	Refer to "(Eqn.2.15)"
No. of parallel (N_{BP})	1.6	Refer to "(Eqn.2.16)"
Total no of battery required (N_{TB})	1.23	Refer to "(Eqn.2.17)"
C-rating	C-10	Battery datasheet
The energy required to charge the battery (E_{Bat})	4.8 KW	Refer to "(Eqn.2.18)"

Cost of each battery	N60,000	Market price

3.3 PV Specification and Sizing

PV array is designed based on the energy required to charge the battery bank by using equations 2.1 to 2.3. The number of series and parallel modules is determined to give the array size by using equations 2.4 to 2.6. The summary of the PV array sizing presented in Table 3.4.

Table 3.4.: PV Specification and Sizing

Parameter	Calculated values	Source
Daily Average Required Energy (E_d)	940 W	Table 2
Required Energy demand (E_{rrd})	1.3KWh/day	Refer to "(Eqn.2.1)"
System Voltage (V_{dc})	24V	PV datasheet
Maximum voltage (V_{max})	26.2V	PV datasheet
Maximum current (I_{max})	7.63A	PV datasheet
Isc	6.39A	PV datasheet
Total PV array capacity	345WP	PV datasheet
Average Peak Power ($P_{ave,\ peak}$)	260 W	Refer to "(Eqn.2.2)"
Total dc Current (I_{dc})	10.8 A	Refer to "(Eqn.2.3)"
No. of modules in series (N_{SM})	1	Refer to "(Eqn.2.4)"
No. of modules in parallel (N_{PM})	1.4	Refer to "(Eqn.2.5)"
Total No module in the array (N_{tm})	1.4	Refer to "(Eqn.2.6)"
Average sunshine hour (Tsh)	5hrs	The chosen location, Ogbomoso
Cost of each module (M_{cost})	N30,000	Market price

3.4 Charge Controller Specification and Sizing

Sizing a suitable charge controller begins with estimating the required total current that the controller can withstand. The total number of charge controllers are calculated using equations. 2.7, 2.8, and 2.9. The summary of the Charge Controller sizing specification and its cost estimate are presented in Table 3.5.

3.5 Cable specification and Sizing

In a PV system, the selection of suitable cable is a significant aspect of the design. In this design, flexible copper cable is chosen based on the designed current for the laboratory as presented in Table 3.6

Table 3.5: Charge Controller Specification and Sizing

Parameter	Calculated values	Source
System rated voltage	12V/24V	Charge controller data sheet
System rated current	20A	Charge controller data sheet
Required charge controller current (Icc)	11.18 A	Refer to "(Eqn.2.**7**)"
Require a number of charge controller (Ncc)	1	Refer to "(Eqn.2.8)"
Cost of each charge controller (Cccost)	N 10,000	Market price

Table 3.6: DC Cable Specification and Sizing.

Parameter	Calculated Value	Source and selected cable
PV array to Battery Bank via Charge Controller	11.18A	Refer to "(Eqn.2.7)". 3X35mm^2 insulated flexible copper cable

Inverter to DB system of the Lab	2.8039A	Refer to "(Eqn.2.8)" 3X4mm^2 flexible copper cable

3.6 Summary of the PV System and Cost Estimation

Solar PV modules and the associated components designed for the setup of a standard and complete stand-alone power system for the Metrology Laboratory in LAUTECH MECH ENGRG DEPT, OGBOMOSO. The components used for the system and its costs are presented in Table 3.7. The total estimated cost of the designed stand-alone PV power system is ₦ 190,000.00.

Table 3.7: Summary of the PV System and Cost Estimation

S/N	Component	Qty	Model	Power Rating (W/Ah)	Voltage (V)	Current (A)	Unit price (₦)	Total price (₦)
1	Solar module	1		150W	26.2	7.63	35,000	35,000
2	Battery	1		100Ah	12	-	60,000	60,000
3	Charge Controller	1		-	24	60	10,000	10,000
4	Inverter	1		1000W	24/240	-	60,000	60,000
5	Cables	10 -yards	3X35mm^2 3x4mm^2				500	5,000
	Miscellaneous							10,000
	Labour							10,000
	Total							190,000

The system of the photovoltaic source of energy, which uses a stand-alone PV solar system is an environmental emission-free, clean and efficient energy source. This system is envisaged for use in an area where the constant power supply is needed and in rural, remote areas such as farm settlements where the national grid system is not accessible or available. The geographical location of Ogbomoso is characterized into the wet and dry season with an average solar irradiance of 7.2 kWh/m^2/day and 11.3 kWh/m^2/day respectively which if efficiently tapped is enough to provide an alternative, clean and environmentally friendly energy source. The photographs of the devices available in the Laboratory are shown in Plate 3.1-3.9

4.0 RESULT AND DISCUSSIONS

The result reveals that the designed PV system sustains and powered 940 watts daily energy demand satisfactorily for the Metrology Laboratory.

The effect of potential difference on temperature distribution along rod

Figure 4.1 presents the variation of temperature distribution along the length, 40 cm of the metallic rod, Aluminum against time at 50 volts. It shows the heat rises faster at point 0cm because it is the heating source and kept on growing. It displays a slight change on the temperatures at points 10cm, 20cm and 40cm along the length of the metallic conductor rod for 6 minutes.

Figure 4.2 presents the variation of temperature distribution along the length, 40 cm of the metallic rod, Aluminum against time at 100 volts. It shows that the heat gradually extended to other ends of the on the metallic conductor rod along the length of 40 cm. The hotness of the rod kept increasing as time is growing for 6 minutes.

Figure 4.3 presents the variation of temperature distribution along metallic rod against time at 150 volts and Figure 4.4 presents the changes in temperature distribution along metallic rod against time at 200 volts for the time of 6 minutes. Figures 4.3 and 4.4 also display that the heat gradually extended to other ends of the metallic conductor along the length of 40 cm with higher values of temperature as the voltage is increased. The degree of hotness of the rod kept increasing as time is growing for 6 minutes.

Figure 4.1 to 4.4 displayed that as potential difference increase from 50 volts to 200 volts the temperature gradients increase accordingly. It is deduced from Figure 4.1 to 4.4 that temperature gradient has a direct relationship with a potential difference (Voltage) along the metallic conductor rod using an extended heat transfer equipment in the Laboratory.

Figure 4.5presents temperature distribution at the point of heating. x = 0 cm for 6 minutes for different voltages of 50, 100 and 150 volts and Figure 4.6 presents temperature distribution at the end of the length of 40 cm for 6 minutes for different voltages of 50, 100 and 150 volts. Figures 4.5 and 4.6 display clearly the effect of voltage changes on temperature distributions along the metallic conductor, Aluminum. It reveals that as the voltage increases, the degree of hotness increases along the length of the metallic conductor rod.

Figure 4.7 presents temperature distribution against distance at the various potential differences, voltages of 50, 100, 150 and 200 Volts. It shows that the temperature gradient reduces as the length of the rod increases. It obeys the Fourier law of conduction that the temperature distribution along a metallic conductor is inversely proportional to the length of the rod.

Plate 3.1: Inverted and Reflected

Plate 3.2: Extended Heat Transfer Equipment

Plate 3.3: Solar Charging Controller

Plate 3.4: 1.0 kVA Inverter

Plate 3.7: Multimeter

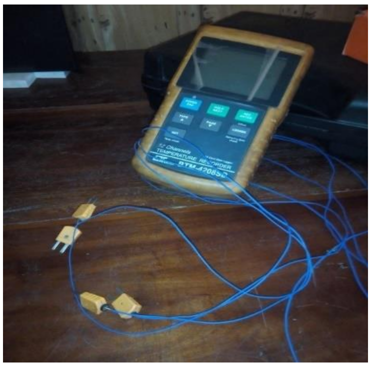

Plate 3.8: 12 Channels Temperature

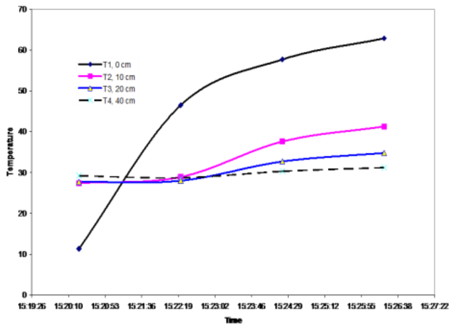

Fig. 4.1: Graph of temperature distribution along rod against time at 50 Volts

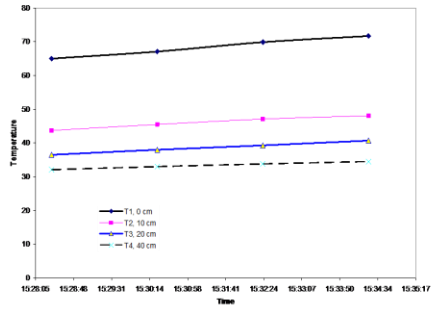

Fig.4.2: Graph of temperature distribution along rod against time at 100 Volts

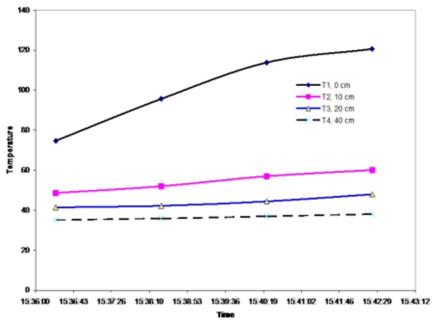

Fig. 4.3: Graph of temperature distribution along rod against time at 150 Volts

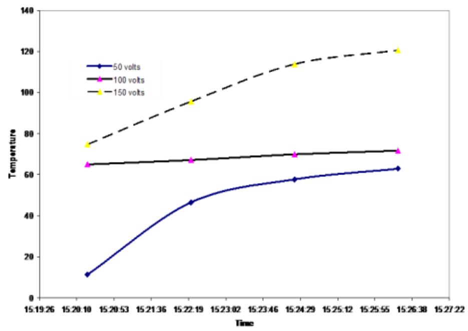

Fig. 4.4: Graph of temperature distribution along rod against time at 200 Volts

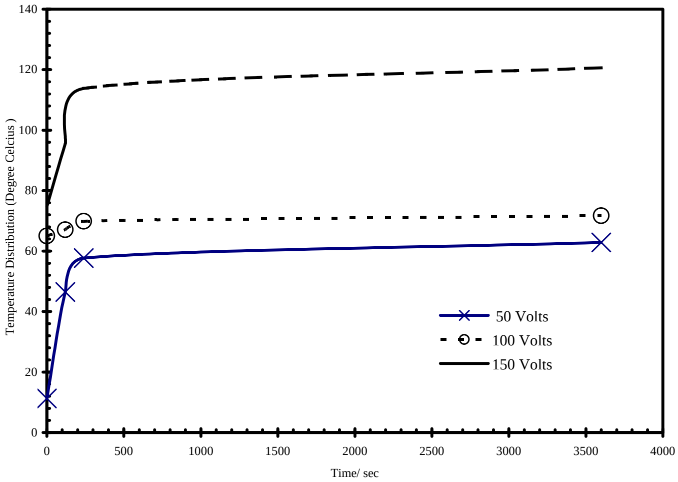

Figure 4.5 Temperature Distribution against Time at X = 0 cm

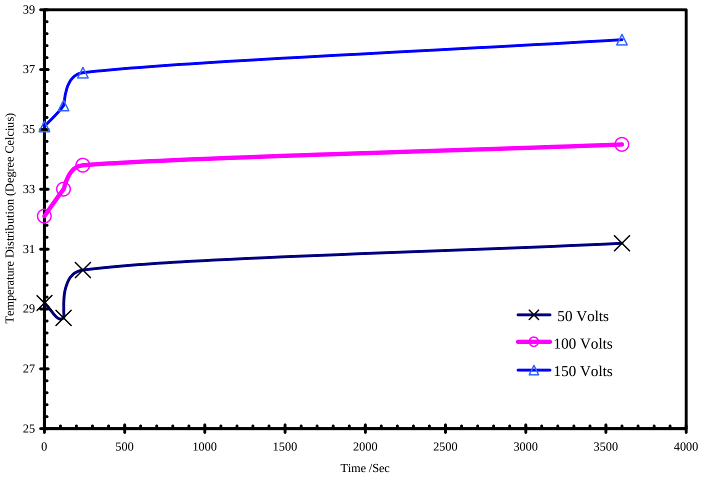

Figure 4.6 Temperature Distribution against Time at X = 40 cm

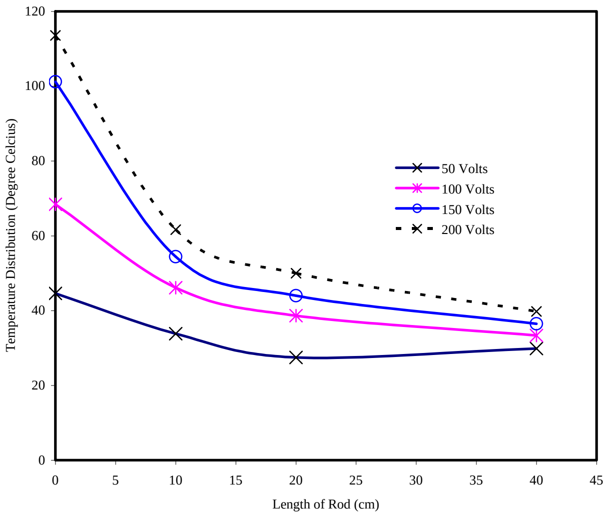

Figure 4.7 Temperature Distribution against Distance at different Potential Differences

5.0 CONCLUSIONS

The designed system of the photovoltaic source of energy, which uses a stand-alone PV solar system to provide daily energy needs, is an environmental emission-free, clean and efficient energy source. This system is foreseen for use in an area where the constant power supply is needed, in rural, remote areas such as farm settlements where the national grid system is not accessible or available. It is good enough to provide the energy requirement of the Lab; it's beneficial and suitable for a long term investment. The cost estimate of the complete stand-alone PV system, which includes design, control devices, and labour has also been provided. The result reveals that the system sustains and powered 940 watts daily energy demand satisfactorily, that efficient utilization and promotion of renewable energy resources in the energy sector will enhance sustainability and improvement of the security for energy supply in the country. It was deduced that voltage has a direct relationship with the temperature distribution using extended heat transfer equipment. It obeys the Fourier law of conduction that the temperature distribution along a metallic conductor is inversely proportional to the length of the rod. It is recommended that the Government should be involved in providing financial support for the procurement and installation of the PV system which will make it a popular choice and appropriate energy source to reduce the effect of the high capital intensive nature of this alternative and renewable source of energy.

Symbols

η_{energy} Energy Efficiency
V_{oc} Open circuit voltage, V
V Voltage, V
V_{mp} Voltage at the maximum power point, V
I_{mp} Current at the maximum power point, A
I_{sc} Short circuit current, A
I Current, A
I_1 light generated current, A
I_o saturation current density, A
F_F Fill factor
Q Charge of the electron, eV
R_s Series resistance, Ohm
A Surface area of the module, m^2
G Global irradiance, W/m^2
K Boltzmann constant, J/K
P_{el} Electrical power, W
P_{max} Maximum power, W
E_{xin} Input exergy, W
Ex_{loss} Exergy loss, W
Ex_{out} Output exergy, W
$Ex_{thermal}$ Thermal exergy, W
$Ex_{electrical}$ Electrical exergy, W
T Temperature, K
T_a Ambient temperature, K
T_s Surface temperature of the sun, K

T_m Module temperature, K

T_{sky} Sky temperature, K

Q Heat emitted to the surrounding, W

U Overall heat loss coefficient, W/m^2-K

h_{conv} Convective heat transfer coefficient, W/m^2-K

h_{rad} Radiative heat transfer coefficient, W/m^2-K

V_w Wind velocity, m/sec

σ Stefan Boltzmann's constant, W/m^2-K^4

ε Emissivity of the module

NOCT Nominal operating cell temperature, ^{o} C

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