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(RESEARCH ARTICLE)

Energy consumption of appliances powered by power supply of sustainable energy

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Abstract

An inverter of 2500Watts (2.5KW), 230Volts and 50Hz frequency was designed in gradual process starting from gathering of materials to testing of components and it worked efficiently as intended. The research was intended to estimate the energy consumption of appliances available for usage in homes, offices and institutions when installing solar energy system supply having at least 1500 to 2000 watts of energy after all power dissipations in order to serve as supplementary alternative energy to diesel/ generator engines. The materials used consist of solar panel, inverter, battery, which are the major quantifiable used in the research. The solar system worked effectively and add no further operational cost. Comparatively, it is very cheap to 2.5KVA petrol/diesel generator, except the initial expenses which is encountered only that once. However, its cheapness was as a result of the system needing no petrol to operate but sunlight which is natural free gift. The solar cell acted as a source of charger to the batteries and inverting the power stored using an inverter into usable power for any load/appliance. The power output was usable in one office, two classrooms and two laboratories that need required appliances that are sensitive to having sinusoidal inputs. The operation of the solar energy system was allowed for three (3) weeks as was compared to operation of petroleum by-products (domestic fuels) engines (generator) and was found to be more economical in all ramifications.

Keywords: Solar Energy; Solar Panel; Battery; Inverter; Energy Consumption; Automatic Voltage Charger Circuit; Relay; Power MOSFET

1. Introduction

The most important objective is to estimate the energy consumption of appliances available for usage in homes, offices and institutions when installing solar energy system. Other objectives of the research project are unified as to provide efficiency, steadiness in the use of power appliances to ensuring continuous availability of power supply even in the absence of the mains, thereby eliminate all suspense from mains outage during the execution of an important and urgent assignment as may be required and hence, design a simple and rugged technology that will utilize the appropriate use of laboratory or classroom or local electrical appliances.

A solar power system is one which is capable of converting the absorbed sun energy; store it in a lead acid cell to be used on the load. In this part of the world, where power supply is not effective and efficient, the use of solar power supply is of immense value and advantage considering the fact that our environment is blessed or rich in sun light. This simply means that high degrees of temperatures which is the main thing that feeds a solar power supply unit for uses. It is low in cost compared to other alternative sources of power supply in this society like the use of generators which consume fuel or diesel and are really expensive, and its life span is better and reliable when used under or within or above the stipulated rating of the solar power device. [1]

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In 2012, SwagatamMajumdar did a homemade 2000 VA power inverter circuit. He explained that making a power inverter rated above 500 VA is always difficult, mainly because of the involved transformer dimension which becomes quite huge, unmanageable and difficult to configure correctly [6]. Power inverters in the range of KVA requires huge current transferring capabilities for implementing the required operations as per the desired specifications of the unit. Transformer being the main power making component of such an inverter, requires high current handling secondary winding if the used battery voltage is at the lower side, for example 12 or 24 volts. In order to optimize the transformer at lower currents, the voltage needs to be pushed at higher levels which again becomes a problem because higher voltage means putting batteries in series. The above problems can definitely demoralize any new electronic hobbyists or anybody who might be planning to make a rather big inverter design, may be for controlling the whole house electrical. An innovative approach for making things simpler even with huge power inverter designs has been discussed which uses smaller discrete transformers with individual drivers for implementing a 2000 VA inverter circuit. He studied the circuit diagram in fig.1 below and its operations with this point: to divide the power into many different smaller transformers whose outputs can be fed to individual sockets for operating the relevant electrical appliances. This method helped him to avoid the need of hefty and complicated transformers, and the proposed design becomes feasible even for an electronic novice to understand and construct. Four IC4049s have been employed in this design. A single 4049 consists of 6 NOT gates or inverters, and so in all, the 24 of them have been used here. Two of gates are wired up for generating the basic required square wave pulses and the rest of the gates are simply held as buffers for driving the next relevant stages. Each transformer utilizes a couple of gates and the respective high current Darlington transistors which function as the driver transistors. The associated gates conduct alternately and drive the transistors in accordance. [4].

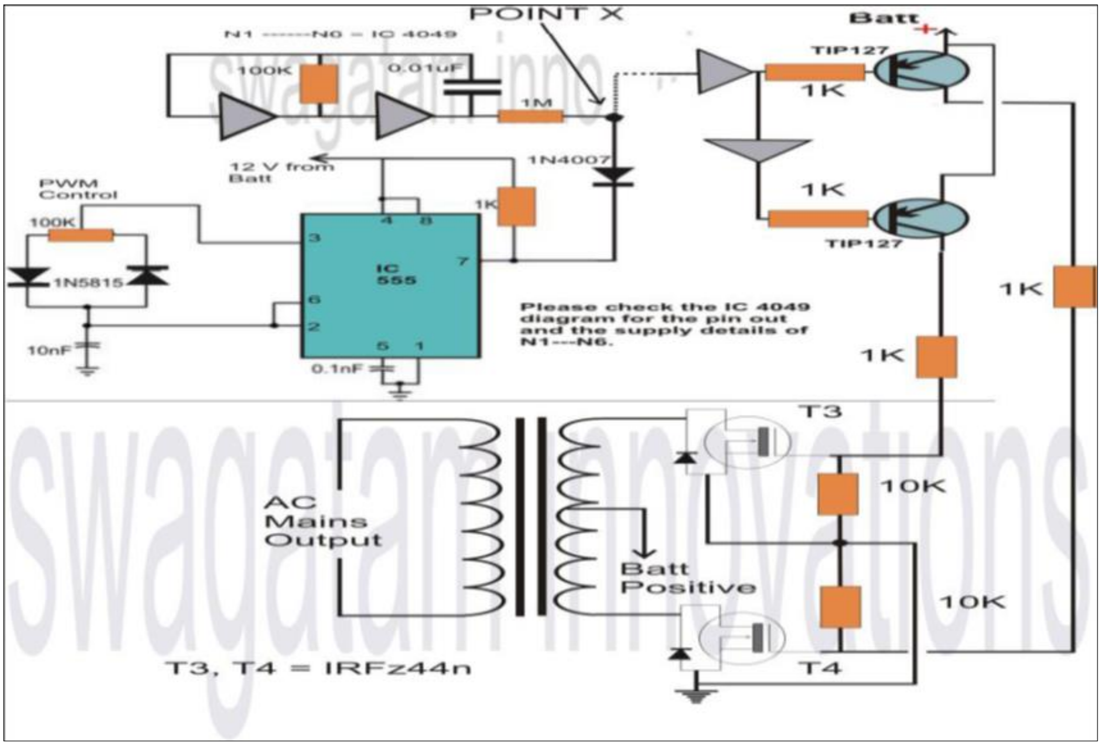

Figure 1 The circuit diagram designed by Swagatam Majumdar

The MOSFETs which are connected to the driver transistors respond to the above high current signals and start pumping the battery voltage directly into the winding of the respective transformers. Due to this, an induced high voltage AC starts flowing through the complementary output, winding of all the involved transformers, generating the required AC 220 V or 120 V at the respective outputs [8]. These voltages become available in small sockets, so only the relevant magnitude of power can be expected from each of the transformers. The 555 section takes care of the square wave output generated from the oscillator stage such that these are broken into sections and optimized for replicating a modified sine wave output. All the parts after POINT X in the circuit diagram below should be repeated for acquiring discrete power output sections, the common input of all these stages must be joined to POINT X. Each of the transformer may be rated at 200 VA, so together, 11 stages (after pointX) would provide roughly outputs up to 2000 VA. Though using many transformers instead of a single transformer might look like a small drawback, the actual need of deriving 2000 VA using ordinary parts and concepts finally becomes easily achievable from the above design. [4]

The solar inverter is a critical component in a solar energy system. It performs the conversion of the variable DC output of the Photovoltaic (PV) module(s) into a clean sinusoidal 50 or 60 Hz AC current that is then applied directly to the commercial electrical grid or to a local, off-grid electrical network [6]. A solar cell (also called photovoltaic cell) is the smallest solid-state device that converts the energy of sunlight directly into electricity through the photovoltaic effect. A Photovoltaic (PV) module is an assembly of cells in series or parallel to enlarge or increase voltage and/or current. A Panel is an assembly of modules on a structure. An Array is an assembly of panels at a site. Typically, communications capability is included so users can monitor the inverter and report on power and operating conditions, provide firmware updates and control the inverter grid connection. At the heart of the inverter is a real-time microcontroller. The controller executes the very precise algorithms required to invert the DC voltage generated by the solar module into AC. This controller is programmed to perform the control loops necessary for all the power management functions necessary including DC/DC and DC/AC. The controller also maximizes the power output from the PV through complex algorithms called maximum power point tracking (MPPT). The PV maximum output power is dependent on the operating conditions and varies from moment to moment due to temperature, shading, soilage, cloud cover, and time of day so adjusting for this maximum power point is a continuous process. For systems with battery energy storage, the controller can control the charging as well as switch over to battery power once the sun sets or cloud cover reduces the PV output power. [2]

If there is one factor that has perpetually maintained the status of Nigeria as a less developed country, it is its electricity sector. Till date, many households and businesses cannot be guaranteed of 24 hours supply of electricity from the public grid. At this stage of Nigeria's social and economic development, the country cannot deliver adequate energy to the citizens despite huge financial resources that have been expended in the sector. Rather, Nigerians have continued to rely on electricity generators for their power supply and fuel marketers are taking significant portion of households' and businesses' incomes to supply power. Noise pollution from regular humming generators have become integral part of living for many Nigerians with imaginable consequences on their health. Because of these problems, there is a need to design and construct the solar panel inverter which will complement the electricity supply from the public grid. It is less noisy and does not have any consequence(s) on human health. [3]

The solar power source makes it possible to provide a clean reliable supply of alternative electricity free of sags or surges which could be found in the line voltage frequency (50Hz). This project design aims at creating a 2500 watts power source which can be utilized as a regular power source at the laboratories, offices and classrooms. This project involves the design and construction of a 2500 Watt Solar PV (photovoltaic) system which involves a solar panel, car battery and an inverter. Furthermore, as a consumer is generating his or her own electricity they also will benefit from a reduction in their electricity bills. [7]

The significance of the project research includes: the solar inverter is the second most component of a solar PV system. It is important because it converts the raw direct current (DC) solar power that is produced by your solar panels into alternating current (AC) power that comes out of the wall sockets. Inverters also have technology that maximizes the power output of that DC energy [6]. The use of solar power has many advantages: firstly, the energy from the sun is free and readily accessible in most parts of the world, the sun will keep shining until the world ends and the silicon from which most photovoltaic cells are made is an abundant and nontoxic element (the second most abundant material in the earth's crust). Secondly, the whole energy conversion process is environmentally friendly. It produces no noise, harmful emissions or polluting gases. There is no burning of natural resources for energy which can create smoke, cause acid rain and pollute water and air. Carbon dioxide (CO_2) a leading greenhouse gas, is also produced in the case of burning fuels. Solar power uses only the power of the sun as its fuel. It creates no harmful by-product and contributes actively to the reduction of global warming. [5].

2. Methodology

2.1. Materials

The major materials include solar panel, inverter, batteries, which are the major quantifiable used in then research. The inverter components include power unit, transformer circuit, power mosfet circuit, automatic voltage charger circuit, and automatic change over (relay).

2.2. The three stages charger undergoes are as follows:

- The transformer stage
- The rectification stage
- The smoothing stage

2.2.1. The transformer

The physical behaviour of electricity is that it flows from high voltage to low voltage. We want the current to flow from the transformer to battery. If the transformer voltage is lower than battery voltage, the current will flow from the battery to transformer, which is not ideal. So to be able to charge a battery you need a voltage higher than the voltage of the battery.

The transformer has two terminals both in its input and output of 0Vac – 24Vac of the secondary part. The primary side of the transformer has a rating of 220Vac. The transformer has a calculation formula for the primary and secondary which is shown below.

Since the battery voltage is 24V. The minimum supply from the transformer would be 24V plus 10% safety.

24+ (24x0.1) =26.4V ~ 27V

V_S = 27V

The transformer of the circuit was chosen in respect to the load of the circuit. So the transformer of (24VDC) (P:48V "24-0-24" / S:220V) will be able to supply voltage to the circuit.

The main power supply in Nigeria is not always 240v and so this was taken into account.

V_P = 220V

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = K = \frac{I_S}{I_P} \text{ --------------------------------1}$$

$$K = \frac{V_P}{V_S} = \frac{220}{27} = 8.148$$

Where k = transformer constant ratio.

When the main voltage becomes 180v, the secondary voltage will be

$$V_1 = \frac{180}{K} = \frac{180}{8.148} = 22.0913V$$

Since this is the V_{rms} voltage, it will be able to supply power to the circuit efficiently due to the peak voltage,

$V_P = \sqrt{2} \times V_1 = 1.414 \times 22.0913 = 31.237V$ --------------------------------- 2

2.2.2. Rectification

A bridge rectifier is an electronic components used in converting ac voltage into dc voltage. The full-wave bridge rectifier was used, having 250V and can pass a peak current of 100A. There will be a forward voltage drop across the two diodes. Since silicon diodes were used for the bridge rectifier, the forward voltage drop is 1.4 volt.

Therefore, the rectifier voltage (V_{dc}) gotten after the bridge rectifier is calculated as:

$V_{dc} = V_p – V_d$ -------------------------------- 3

Hence, rectifier voltage for forward voltage drop of 1.4 volts becomes:

V_{dc} = 31.237– 1.4 = 29.837 ~ 29.84V.

Note: V_d is forward voltage drops across diode. The PIV rating of the diode to be used should be at least:

$PIV = V_p - V_d = 29.84V$

Therefore, PIV is far greater than the value 24, thus, making it suitable for this design.

2.2.3. Filtration

A capacitor is used to filter off the ripples before it is then connected to the battery, for the circuit to charge the battery. Next the value of the capacitance needed to minimize the voltage ripple that was to be found. The AC output from the transformer consisted of 29.84Vrms at 50Hz. The transformer will be giving a maximum current of 13.64A to charge the battery. The required minimum capacitor value was calculated using the formula:

$$C = \frac{I_{OUT}}{2 \times F \times RF \times V_{IN}} \quad \text{---------------------------- } 4$$

Where RF is ripple factor, which is calculated using the formula:

$$RF = \left\{ \left(\frac{V_{rms}}{V_{dc}} \right) \times 2 - 1 \right\} \wedge 0.5 \quad \text{-------------------------------- } 5$$

$$RF = \left\{ \left(\frac{22.0913}{29.84} \right) \times 2 - 1 \right\} \wedge 0.5 = 0.6933$$

F = Frequency = 50Hz

$$C = \frac{I_{out}}{2 \times F \times RF \times V_{IN}} = \frac{13.64}{2 \times 50 \times 0.6933 \times 29.84} = 2068.8072F$$

Hence, capacitor of 2200uF, 50v was used.

2.3. Calculation of Numbers of MOSFET Needed

The numbers of the MOSFET (N_M) required for handling a 2500VA (1800W) inverter in parallel connection depends on the Maximum Power dissipation (P_D) of the MOSFET (IRFP150M). From a data sheet the P_D of IRFP150M POWER MOSFET is 230W at 25^0c but 200W at 30^0c (IRFP150M Data Sheet in 1999).

Using 200W at 30^0c,

$$Number\ of\ Mosfet = \frac{Inverter\ wattage}{Mosfet\ wattage} = \frac{1800w}{200w} = 9$$

2.4. Procedure

An inverter of value, 2.5KW, 230Volts and 50Hz was successfully designed. Afterwards, the solar panel was placed under the sun, the peak sun radiation was on the panel surface and then 17.5 volts was observed using a multimeter. While observing the voltage, the panel was slightly adjusted and the voltage varied at an angle away from the sun and the voltage depreciated. The output from the solar panel was connected to the charge controller with respect to their polarities and when the output voltage was observed, it read 12.56 volts which was right for charging 12 volts battery. The voltage was 17.5 volts DC because the solar and the charge controller were connected without load. Then load was added to the constructed inverter which gave an output of 230 volts which was left for about 30 minutes. It was observed again and the voltage did not vary. The inverter has five LED indicators. The first indicator shows if the system is connected to the mains or not, the second indicator shows if the inverter system is switched ON or OFF, the third was used to display battery low or if the system experience any fault or not, the fourth indicator is used to show the battery full and the fifth (last) indicator is used to show if the inverter is charging or not.

The inverter also had an additional socket for plugging the inverter to mains to serve as another means to charge the batteries (two batteries connected in parallel) other than the solar system. When tested with the volt meter as it was plugged on the mains out, it read 14.4 volts which was basically because of the state of the charge level of the batteries. The batteries would normally self-discharge over time even when not used. Since the inverter included a triple cycle charger, it continued to maintain the battery with equalization charge voltage of about 12 volts just to make sure that the battery does not discharge even it was on standby mode.

3. Duration of inverter under load condition

The duration at which the inverter discharges under load condition depends on the total power of load connected to its output terminal and the power rating of the battery connected to its input terminal. It was borne in mind that total load must not exceed 1000watts.

3.1. Discharge duration

a. Battery power rating = 12volts, 65Ampere per hour at total load of 150watts;

Therefore, duration = $\frac{12*65}{150} = 5.2\ hours.$

b. Battery power rating = 12volts, 65Ampere per hour at total load of 300watts;

Therefore, duration = $\frac{12*65}{300} = 2.6\ hours.$

4. Diagram of Some Materials

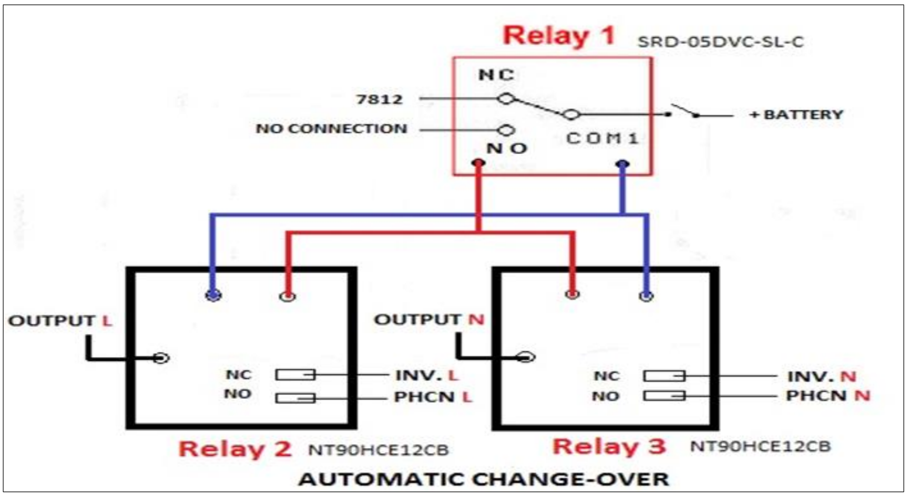

Figure 2 Circuit diagram of automatic change over

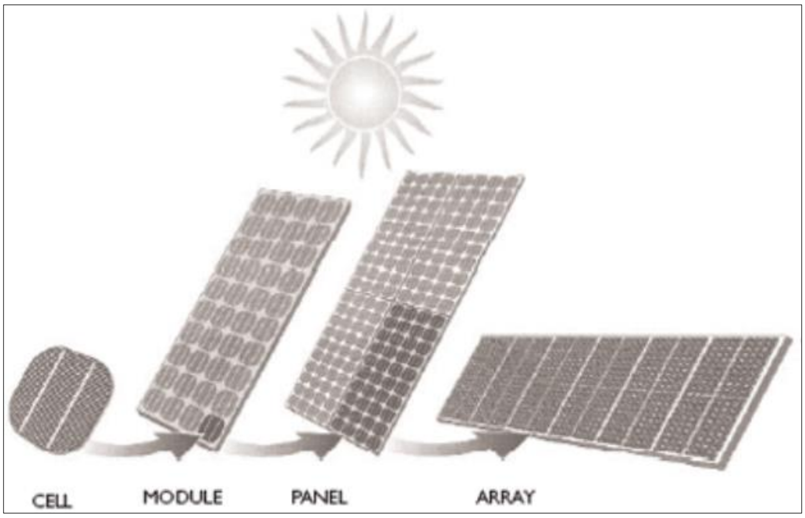

Figure 3 Cell- Module- Panel- Array

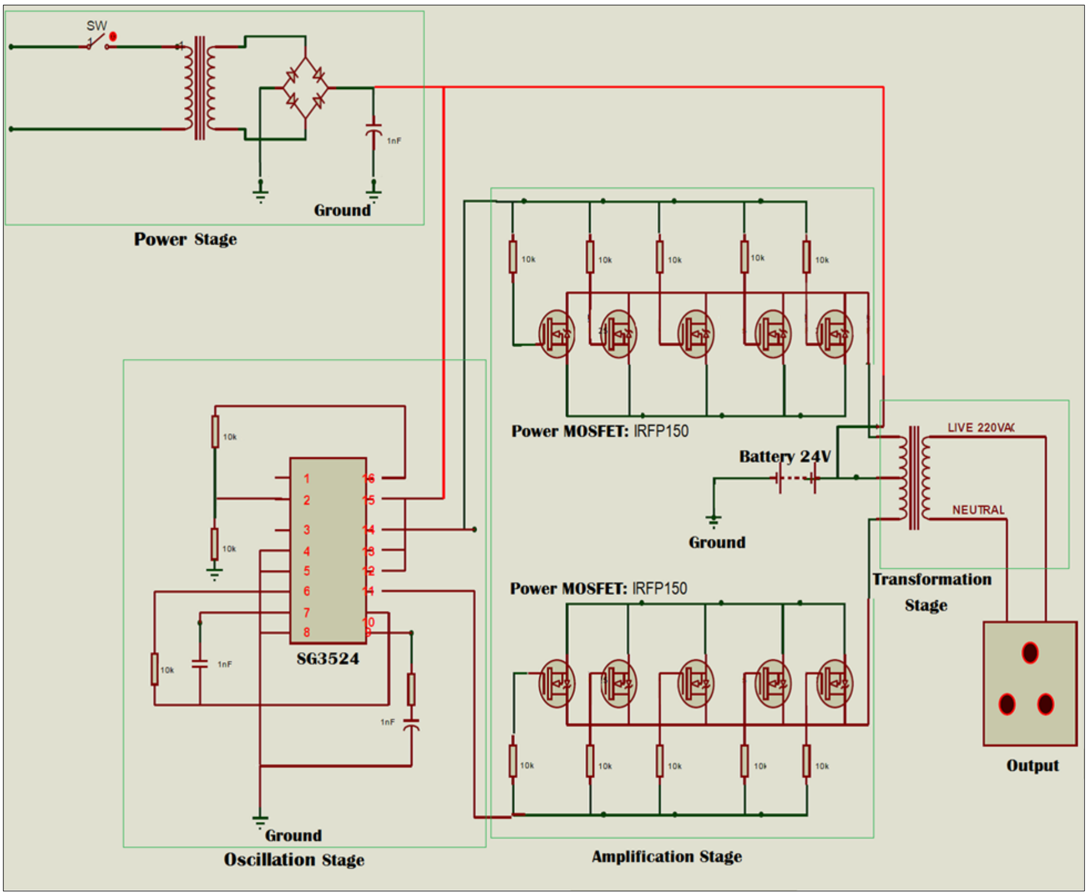

Figure 4 Inverter Circuit Diagram

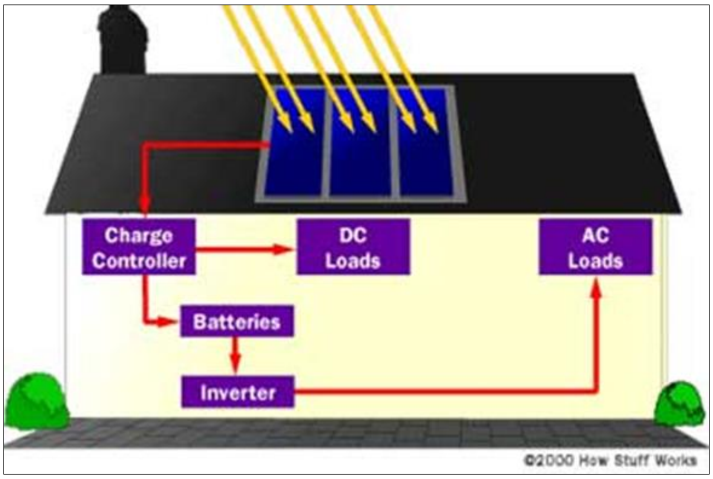

Figure 5 Diagram showing how energy of solar is radiated and how it incidents on solar panels

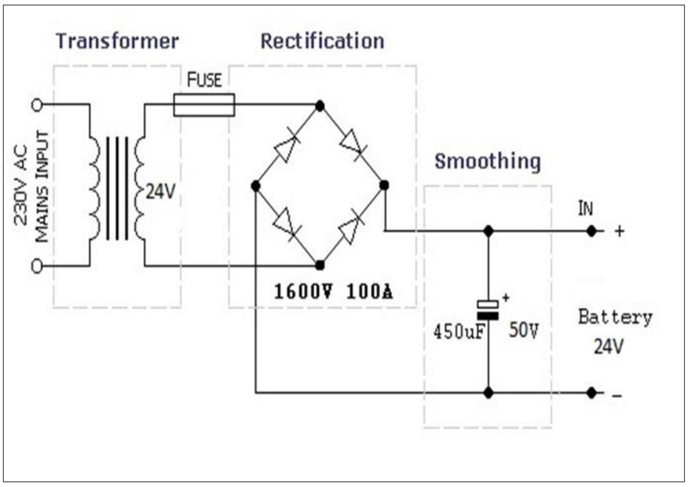

Figure 6 Charging circuit and stages of the charging

5. Results and discussion

5.1. Tabular representation of energy consumption per day

The result of this research focused on its solar calculation. Design of the solar energy system begins with the collection of detail information about electricity consuming loads or devices and their operation from the customer.

The sample of the load profile from one office, two classroom and two laboratories connected to the solar for power supply is given in the table 1 below.

Table 1 Representation of energy consumption as calculated per day

S/N	Appliance(s)	Wattage (Watt)	Quantity	Rated wattage (Watt)	Operational time (hours)	Energy/day (Watt-hours)
1	CFL Lamp	26	4	104	3	312
2	LED Bulb	18	6	108	3	324
3	Ceiling fan (ordinary)	45	13	585	9	5265
4	Laptop computer	300	1	300	7	2100
Total				1097		8001

5.2. Calculation of daily energy consumption of appliances

The data of table 1 will be used as sample data to enhance the calculation of energy consumption and make it more understandable.

Energy consumption for operating each appliance is calculated by multiplying its power rating by the time of operations.

$E_A = P_A . H_A$ --------------------------------- 6

Where:

E_A = Energy consumption of the appliance (Watt-hours)

P_A = Power rating of the appliance (Watt)

H_A = Daily operation time of the appliance (hours)

For instance, the daily energy consumed by the 26 watt CFL lamp as in table 1 for 3 hours of operation per day is:

E_L = 26 x 3 = 104 Watt hours.

So, calculating for the total number of 26W CFL Lamp (4 in number), you multiply the energy gotten by 4.

E_L = 26 x 3 x 4 = 312 Watt hours.

However, energy consumed by all the appliances is calculated as the total daily energy consumed by all the appliances by summation of all the energy consumption:

$\sum E_A = E_{A1} + E_{A2} + E_{A3} + \ldots$ ------------------------------ 7

The appliances mentioned in the table 1 above have the total daily energy requirement given by:

$\sum E_A$ = Energy/day of CFL lamp (watt-hours) + Energy/day of LED bulb (watt-hours) + Energy/day of ceiling fan (watt-hours) + Energy/day of laptop computer (watt-hours).

$\sum E_A$ = (26W x 4 x 3 hours) + (18W x 6 x 3 hours) + (45W x 13 x 9 hour) + (300W x 1 x 7 hours) = 312 W-h + 324 W-h + 5265 W-h + 2100 W-h = 8001 W-h.

In the case when power rating is not mentioned but operating voltage and current are mentioned, then we can obtain the power by multiplying rated current and voltage.

6. Conclusion

An inverter was successfully used to generate 2.5KW of alternative and supplementary energy to supplement power supply from Enugu Electricity Distribution Company (EEDC) for use in few offices, laboratories, and classrooms. The power generated was usable in one office, two classrooms and two laboratories that have appliances that are very sensitive to having sinusoidal inputs. Comparatively, it is very cheap to running of 2.5KVA petrol/diesel generator even though the initial expenses (of construction and installation) which is encountered only once is costly. The four solar panels employed were connected in series and parallel to receive solar energy from sun and the two batteries connected in parallel to produce current.

Recommendations

It is highly recommendable to subscribe to solar energy despite the initial cost of installation because its fueling is natural.

It is recommended to increase the power rating of the inverter by increasing the number of the power switching devices and the current rating of the transformer.

Crucial offices, laboratories and classrooms that need regular power supply should be powered with solar energy system.

Increasing number of batteries add to the capacity of the system to accommodate more loads.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors share same and equal interest.

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