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DESIGN AND IMPLEMENTATION OF A STAND-ALONE PHOTOVOLTAIC SYSTEM AS ALTERNATIVE POWER SOURCE FOR DEVELOPING COUNTRIES

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Abstract

In the world of today, green energy and a reduction in fossil fuel usage are being advocated. Also energy consumers look for ways of reducing cost of operating diesel generators. One way to achieve thisis by employing solar photovoltaic (PV) systems. In this study, a demonstration of installation of a stand-alone,purely DC solar (PV) home power system for low power consuming devices as alternative power source was exemplified. A prototype PV system was set up by calculating and determining total load requirement in an installation, calculating a sufficient ampere-hour to carry the load and determining a solar system capable of effectively sustaining the set-up on a continuous basis. Optimal PV sizing was carried out and adequate battery capacity determined. After the installation was carried out, tests were carried out to examine the effectiveness of the installation. It was found out that the installation can adequately replace conventional lighting systems in homes and offices and supply power to many commercial and office electrical appliances. The system consumes less electric energy as it operates on 12 V DC at all times. A form of clean energy is produced and in the long run the consumer saves a lot of resources. The system is recommended to be adopted in developing countries especially in grid-deprived areas.

Key words: renewable energy, stand alone solar PV system, dc load, green energy, state of charge.

1. Introduction

In a developing country like Nigeria, there is inadequate provision of energy and much of the available insufficient energy is wasted through many avoidable means in homes and the industries. Thus, in many rural environments power supply is being designed using distributed generation systems (DG) [1, 2, 3]. Researchers have proposed the inclusion of DG in power systems for improved reliability [4]. Photovoltaic (PV) systems have also been incorporated with DG systems to add to effectiveness and availability of power in certain instances.

Methods of reducing energy consumption and losses are currently being advocated in the power industriesall over the world. This has given birth to the development of several energy-saving measures such as the application of compact fluorescent lamps and energy-saving lamps. It also informed the application of DG and PV systems in power network. The ultimate goal of these methods is to increase energy supply while reducing the cost of production and the losses in the system.

Due to insufficient power supply, many domestic, commercial and industrial energy demand that would otherwise be provided are not met. This has resulted in loss of revenue and a lot of discomfort for electricity consumers in developing countries. Countries like Nigeria where average daily temperature may go as high as 26-39℃ in many states. A lot of hardships result due to solar heat during the day at home and in the office. In the night, many lose out on valuable rest time due to discomfort from heat. But there is solar energy in abundance in many of these countries that can be utilized positively.

In coping with the world energy crisis, specific sustainable energy systems such as the photovoltaic (PV) panel [5], the fuel cell stack [6], andbatteries of various chemistries [7] are being advocated over the years. In this study, a PV powered DC system was developed to meet certain needs in this regard.

2. The proposed dc system

The proposed DC system is a variation of renewable energy supply for developing countries. It uses solar PV system with a battery bank as a stand-alone power supply [8, 9]. It takes its source of energy as the solar energy which solar energy is harnessed through PV cells and converted into utility DC power using a solar charge controller.Thus it can be regarded as a form of DG system reducing system expansion costs, decreasing loss ofpower and reliability enhancement [3]. The difference between this system and other PV systems advocated in literature is that it does not need either an inverteror possibly a DC-DC converter [10, 11, 12] for the conversion of DC power to ahigher level of DC since its load is DC in nature. Thus, the cost of energy is minimized and the supply is easily sustained. Further, the type of load expected to be used with it is specialized energy-saving loads of purely DC loads in form of LED lamps, electronic sets, table fans, etc.

The system model is as shown in the block diagram of Figure 1. It utilizes a bank of 200Ah deep cycle batteries charged by a 200W solar PV system via a charge controller. DC energy is ultimately supplied to the purely DC load. Once the batteries become fully charged, the charge controller switches off the PV to protect the batteries. The controller also incorporates a sensing system that detects the nighttime and turn on an array of LED security lights.

The solar (PV) home power system (Figure 1) consists of the following:

- PV module
- Battery
- Controller unit

The system operates on two modes of operationnamely:

- PV charging mode during the day;
- Dark period discharging mode in the night.

During the daytime when sunlight energy is available, the PV system charges up the batteries and simultaneously supplies a steady current to the load via the charge controller. At night, the PV system is cut off and the battery takes over the supply to the load. In the morning, the loss energy in the system is replenished by the PV system.

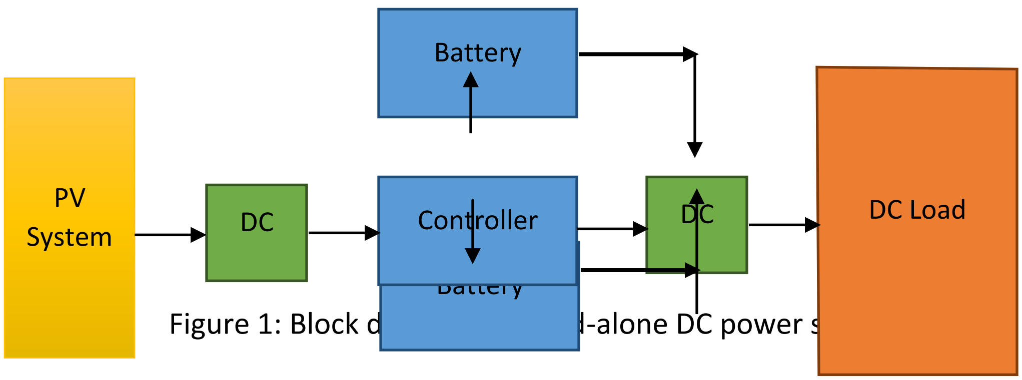

Figure 1: Block d -alone DC power s

The proposed system offers the following advantages:

- Adaptability of technology by rural masses
- Improved reliability
- Reduced emissions of hazardous gasses and pollution
- Continuous power supply
- Increased operational life
- Reduced cost and more efficient use of power.

3. Methodology

The methodology involves total power requirements determination in the proposed installation and setting up of a DC system to match the requirements. The appliances employed include LED light fixtures, electric fans, Ethernet switch, Internet protocol (IP) camera and similar DC appliances in the installation. Having determined the total load current, the cable size, battery Ampere-hour (Ah) rating and solar paned capacity to effectively charge the batteries were determined. Likewise, the appropriate solar charge controller was chosen for the charging system.

3.1 PV Module Sizing and Battery Size Determination

The empirical formula based on energy balance equation has been used to compute the optimal size ofPV module for critical load(s) as stated below:

PV Cell Rating (P_{PV}) = $\frac{P_{TL} X\ S.F}{Sun\ Hour}$ Watt(1)

where,

P_{TL}= total load energy in watt-hours (i.e. total load power over a period of 24 hours assuminghourly load power (PL) as constant;
Safety Factor (S.F) = 1.5 for cloudy weather/low sun radiation
SunHour = 11.6 hours for adopted area.

$$P_{TL}(Wh) = \sum_{0h}^{24h}(P_L)\text{Watt-hours} \qquad (2)$$

The total number of PV modules = $\frac{P_{PV}}{standard\ PV\ module\ rating}$(3)

Equation 1 – Equation 3 were employed to obtain optimal numbers of components needed for the proposed system.
To determine the battery sizing, the following equation was adopted:

Battery capacity (Ah) = $\frac{P_{TL}}{12\ V\ x\ SOC}$(4)

where,
SOC (State of Charge) of Battery = 70%.
With SOC of 70% battery capacity is 186.5 Ah.

The total power was determined as shown onTable 1 as 216.6 W and the total watt-hour demand as 1566.4 Ah. With a SOC of 70% battery capacity was determined as186.5Ah. Two units of 100Ah deep cycle battery were employed. For effective charging of the battery daily, two pieces of 100 W mono-crystalline solar panel were also chosenaccording to equation (3) producing a total of 200 W. At peak power, each of the two 100 Wsolar panels is capable of supplying about 5.71 A giving a combined total of 11.42 A current. Thus a solar charge controller of 20A was selected for the charging. When the battery is fully charged, the solar charge controller cuts-off the power from the solar panel and restores same when the battery voltage reduces to about 11.2 V.

3.2 Load Profile

The profile of the load encountered was monitored and recorded for a week and average daily energy requirement for each load was determined. The system was installed at the departmental office of the Department of Electrical Engineering, Federal Polytechnic Ilaro, (Nigeria). The loads are presented in Table 1.

Table 1: Breakdown of DC load in the proposed system

S/N	Appliance	Quantity	Total Current (A)	Total Power (W)	Average Daily power usage (hr)	Total Load(Watt-Hour)
1	LED light fixture	5	2.92	35	8	280
2	16-port Ethernet switch	2	1	12	8	96
3	DC standing fan	4	13.33	160	6	960
4	IP camera	1	0.8	9.6	24	230.4
Total			**18.04**	**216.6**	**62**	**1566.4**

The load profile for a 24-hour period is depicted on the bar chart of Figure 2. From the load consumption pattern of the Figure 2, it is seen that the power consumption increases in the morning during the working hour reaching a peak of 157.6 at the noon and continues so until 1600 hours. It is noted that there is a constant load on the system represented as the camera and the two ethernet switches. The system is capable of supplying this load demand as it is supplied from a 200 W PV module. This ensures that the load demand is met and battery continues to charge simultaneously.

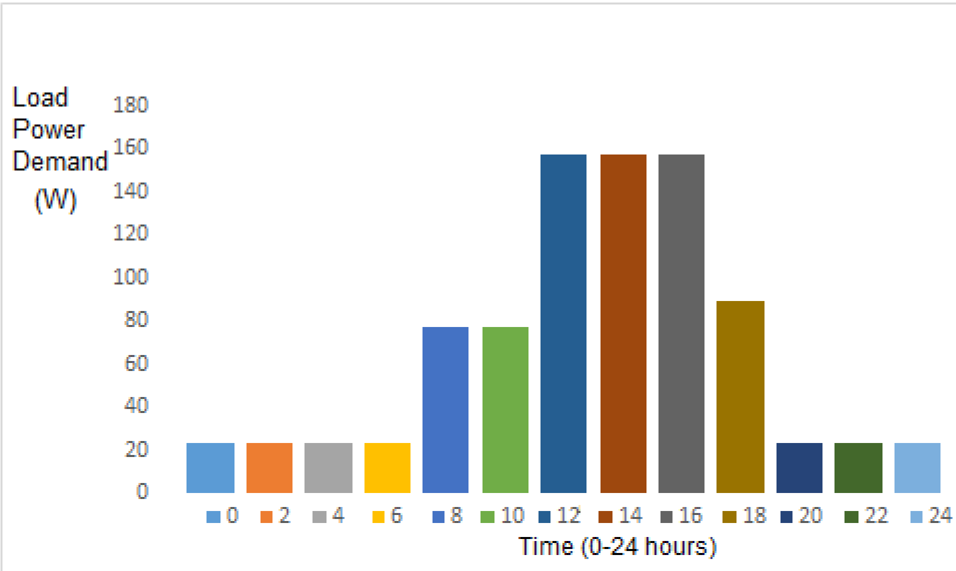

Figure 2: Load prefigure for a 24-hour period

4. Cost Evaluation of System

The cost the system is basically due the cost of installation of the PV module, charge controller and the deep cycle batteries. The system is expected to run almost free of operation and maintenance costs as it is purely based on PV system which is a renewable form of energy. For the imstallation of the system, the cost implications are as given in Table 2.

Table 2: Cost evaluation of the proposed system

S/N	Appliance	Quantity	Unit Cost (₦)	Total Cost (₦)
1.	PV Module	2	14500	29,000
2.	Charge Controller	1	5000	5,000
3.	100Ah Deep Cycle Battery	2	25000	50,000
4.	2.5 mm^2 connecting wires	1	1400	1,400
Total				**85,400**

The total cost of the system is high but this is expected due to the high cost of the PV modules and the deep cycle batteries. However, the system runs with virtually no maintenance and operation cost thus paying back the cost in the long run. It is expected to last as long as the batteries and PV modules last (typically above 5 years). In the long run, the maintenance cost shall be the cost of replacing the deep cycle batteries and the PV modules and this will not take place in the nearest future.

5. Conclusion

The study has proposed a "fuelless", fumeless, and noiseless, stand-aloneDC power specifically for lighting applications and other low power home, commercial or industrial electric power appliances in rural areas and many developing countries where electric power supply is grossly inadequate. This is a form of renewable or green energy being advocated nowadays. It was found to be effective when utilized solely for its design purpose. The system also is virtually maintenance free and runs no cost of fuel. The only expected maintenance in the long run is the battery replacement. With a choice of good deep cycle batteries, the user will enjoy the system for a number of years. Also with a good choice of solar panels, for instance, mono-crystalline panels, the charging system is expected to outlive the batteries but will eventually be replaced in about 25 years.

This system is a form of renewable energy system that can be used to substitute the insufficient grid power system in developing countries. It will also meet the lighting and similar needs in many rural areas in developing countries where power supply is irregular and at times interrupted. The system can effectively replace the AC lighting system in the developed and developing countries when adequately maintained and monitored. The system consumes less electric energy as it operates on 12 V DC at all times. When adopted, the system should be protected from overloading as the batteries installed would only cater for the intended load. For future expansions, the primary storage (batteries) can be increased in capacity by adding more batteries. This may also require that the charging capacity of the PV system should be increased by adding more solar panels.

The only limitation of the system is that it can be employed solely for small power DC loads in domestic, commercial or industrial applications. That means when utilized in the commercial centers for instance, there should also be provision for AC supply. However, when applied alone or in conjunction with AC mains, it reduces the overall cost of energy.

6.Authors' Biography

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