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Development, Demonstration and Compatibility Test of DC Photovoltaic Power Supply to Conventional Household Appliances

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Abstract*: This research examines the feasibility of Direct Current (DC) circuits using solar photovoltaic (PV) arrays, with battery back-up for domestic appliances and lighting systems that are traditionally powered by centralized Alternating Current (AC) grid. PV power generation and storage are often DC in nature, the process of conversion from DC to AC is faced with more cost and additional power conversion losses. This research provides a demonstrative approach to determine the suitability of avoiding AC (by using DC) power supply on modern appliances, as well as using a single unified DC voltage for a wide range of home appliances. For this purpose, a 100wp/240V PV DC powered distribution system was developed and implemented to power a load of 60W. The study was conducted through the compatibility test of resistive load, and modern switch mode power supply (SMPS) household appliances on DC supplies. Test conducted included using the system for 5,475 hours, on existing loads to determine the long the effect on the devices. Results obtained from test conducted, within their specified operating voltage range of devices (100-230V) were also analyzed and showed that, heating devices and most appliances using SMPS can operate effectively and safely over a long period of time with DC power supply without the need for any circuit modification.

Keywords: ***Modern household appliance, Alternating Current (AC), Direct Current (DC), Switch mode power supply (SMPS), Photovoltaic power generation, high-voltage direct current (HVDC).***

I. INTRODUCTION

Nineteenth-century electric distribution system relied on direct current (DC) power generation, delivery, and use. This pioneering system, however, turned out to be impractical and uneconomical, largely because in the 19th century, DC power generation was limited to a relatively low voltage potential and DC power could not be transmitted beyond a mile. Although high-voltage direct current (HVDC) is now a viable means of long-distance power transmission and is used in nearly a 100 applications worldwide.

Today, the fact is that many domestic loads, such as computers, consumer electronics, and LED lighting, use DC power internally. Most of the DC voltages are at different voltages ranging from 3V to 35V DC, and this has led to a proliferation of power supplies that convert from AC to various DC voltages. In addition this has led some analysts to propose the use of building-level DC distribution to reduce the cost and improve the efficiencies of power conversion (Babyak, 2006). Fortunately the demand to improve on the performance of most power supply system has become increasingly subject to new energy efficiency standards, and has lead to the development of Switch Mode Power Supplies (SMPS), which typically consist of input rectifiers, inverter, chopper controller and filters circuits and is represented by Fig. 1. (Mammano, 2007).

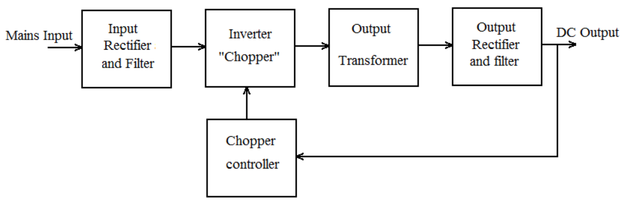

Figure 1: Block Diagram of Switch Mode Power Supplies

Studies showed that SMPS designed for AC inputs can equally operate from a DC supply, because the DC would pass through the rectifier unchanged (George, 2006). In view of the improvement in efficiencies of power supplies due to the introduction of SMPS; efforts to encourage greater overall efficiency in the use of primary energy, increase supply reliability, and lowering greenhouse gas emissions has become the growing concerns.

Solar photovoltaic (PV) and fuel cells which inherently produce DC power are becoming common. This has led some analysts to propose the use of building DC distribution to reduce the cost and improve the efficiencies of power conversion (Babyak, 2006). In this research, the use of DC distribution system for domestic appliances, lighting systems, especially with DC light-emitting diodes (LEDs) and Compact fluorescent lamps(CFL), to reduce cost and improve system efficiency by using solar panels and batteries, while eliminating the need for inverters is presented.

II. LITERATURE REVIEW

Much previous research has focused on DC distribution system design, the economics and feasibility of DC in specific applications, and the integration of DC building circuits with photovoltaic and fuel cells (Kaipia *et al.* 2006; Nilsson and Sannino, 2004; Sannino *et al.* 2003; George, 2006; Paajanen, *et al*., 2009). Initial engineering-economic analysis of a DC distribution system to residential customers shows that medium voltage DC (± 750 V) may have lower total costs than 400 V AC due to lower capital costs and outage repair costs (Kaipia *et al.* 2006). However, medium and low-voltage DC distribution systems have higher energy losses on scales of more than a few kilometers (Kaipia *et al.* 2006; Nilsson and Sannino, 2004). Sannino *et al.* (2003) have shown that 326 V DC distributions is feasible and more efficient than 48 V DC for a mid-size building, Paajanen, *et al*., (2009) stated that all the DC voltage levels of 220 V, 440 V and 750 V are standardized and are recommended DC voltage levels, however, 220 V is more appropriate because it is the established voltage level in most countries. Using 220 Vdc with for short distances of 50m as in this work guarantees electric compatibility with most devices and provide fewer losses; hence this is applied in this study.

Brinda, *et al.*, (2009) reported that, Pratt *et al. (*2007), Ton *et al. (*2008), Jancauskas and Guthrie (1995), Yamashita *et al.* (1999) and Belady, (2007) see DC circuits as cost-effective in applications where energy storage serves as auxiliary power plant to systems and that in these applications, greater power conversion efficiency can be achieved with DC by eliminating the DC to AC invertion between building circuits and batteries. DC distribution might also be economical in the face of environmental or other policy mandates; resulting in the adoption of solar PV or fuel cells.

Jimenez, (2005); (2002) report that, by eliminating the inverter, using DC distribution with PV systems can reduce PV system capital costs by up to 25%. Advocates point to greater efficiency and reliability from a DC power delivery system, indicating that eliminating the need for multiple conversions could potentially prevent energy losses of up to 35% and could also potentially translate into lower maintenance requirements. Laboratory tests at Electric Power Research Institute (EPRI) in 2002 demonstrated that many domestic devices use SMPS and can readily accept DC power (George, 2006), although additional testing was recommended, to determine the effect of DC power on the long-term operation of such equipment.

Advances in technology and literatures suggest that there are significant opportunities for certain DC-based applications, and promising benefits in terms of energy savings and increased reliability. Additional research, development and demonstration are needed to make DC systems viable.

III. METHODOLOGY

DC building distribution circuits are feasible with existing power supply and are cheaper than AC if used to power building lighting systems. This study addresses its stability, efficiency and suitability for one year running with an average of nine hours a day (5,475 hours), in a domestic building with an existing load. While these analyses is limited to lighting, heating and switch mode power supply loads, the approach is to determine the require materials for a standalone solar system for the DC distributed generation and energy storage. The study also compared the efficiency of the system against a standard AC source with input voltage variation using a resistive load.

SYSTEM DEVELOPMENT

A stand-alone PV system was developed to provide the required power in this work. The development was based on the PV sizing and usage of the load and the battery bank. A charge controller was included in the system, to stop overcharging, of the batteries can be damaged during times of low or no load usage or long periods of full sun. Therefore, a solar battery charger was used to protect the battery.

A. SIZING OF THE PV SYSTEM

The PV modules sizing for a stand-alone PV system was carried out such that the energy output of the PV panels and the storage capacity of the batteries should be within the required period. To determine the amount of energy required equation 1 was used; considering a constant electrical load energy demand (E_L) operating at a Voltage of 240 Vdc, Maximum current = 0.25 A_{dc}, Estimated operating time = 15 h. The sizing of PV module is calculated based on (Zahran et al., 1996; Zahran et al., 2006) as follows:

$$Ppv = \frac{Pl(T_N + K_2T_D)}{K_1K_2T_D}$$

$$Ppv = \frac{60(7+0.75\times 8)}{1\times 0.75\times 8}$$

$$Ppv = 130Wp$$

where: P_L is the load power, T_N & T_D are the night and daylight periods, K_1 is the direct energy transfer path efficiency, K_2 is the stored energy transfer path efficiency.

Four available 50W/150V solar panels were connected in series parallel mode to provide a 100Wp at 300V as shown in Fig. 2, which is a mono-crystalline silicon solar cell module.

B. SIZING OF BATTERY BANK

The battery bank was sized to be able to store power for one day of autonomy during cloudy weather. As the battery size is determined from the following equation for the power demanded is 60 W, Therefore, for 15 h operation time. Load energy (EL) = 60 * 15 = 900 Wh .

$$WH = \frac{(N_C E_L)}{DOD\eta_B\eta_{sys}}$$

Where, where, EL is the Load energy,

DOD =maximum depth of discharge (0.75%)

η_B=Battery efficiency (0.85%)

η_{sys}=Battery efficiency (0.85%)

$$WH = \frac{(1 \times 900)}{0.75 \times 0.85 \times 0.85}$$

$$WH = 1660Wh$$

$$AH = \frac{1660}{240}$$

$$AH = 6.9Ah$$

Although, the sizing result of the battery bank is 6.9 Ah, in this work 20 pieces of the available 12V FP deep cycle lead acid battery type with storage capacity of 7 Ah each were used.

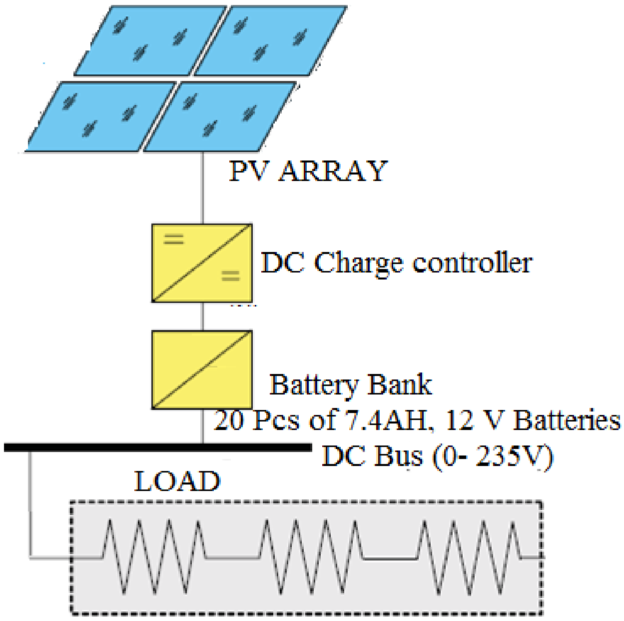

Figure 2: Developed System.

IV. RESULTS

The implemented system was tested, to see the performances of various loads, at the specified input voltage range on their name plates. The polarities of the D.C supply polarities was interchanged with the live as positive and live as negative, and performance of the various loads monitored as presented in Table 1. The efficiency characteristic of a soldering iron (resistive load) was determined and presented as in Fig 3, while images of television, led bulb lights and CFL lights powered by the DC system are shown in Fig. 4-6.

S/No	Appliance	Power pack	Live to Positive	Live to Negative
1	LED Television	SMPS	Operational	Operational
2	DVD player	SMPS	Operational	Operational
3	Decoder	SMPS	Operational	Operational
4	Led lamps	SMPS	Operational	Operational
5	CFL bulbs	SMPS	Operational	Operational
6	Printer	SMPS	Operational	Operational
7	Computer	SMPS	Operational	Operational
8	Laptop	SMPS	Operational	Operational
9	Soldering Iron	Resistive	Operational	Operational
10	Standing Fan	Inductive	None-Operational	None-Operational

Table 1: Polarity and Compatibility Test

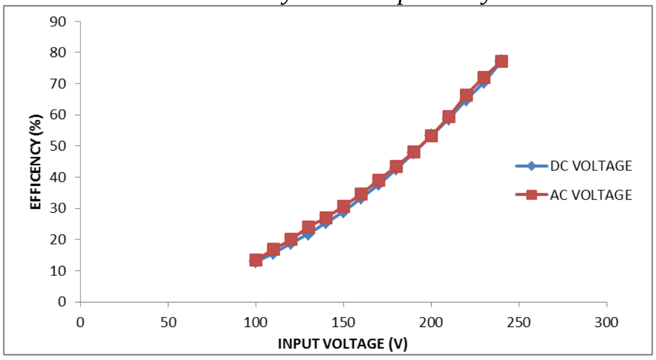

Figure 3: Efficiency Characteristic of Resistive load

Figure 4: Television Powered by DC Power Supply.

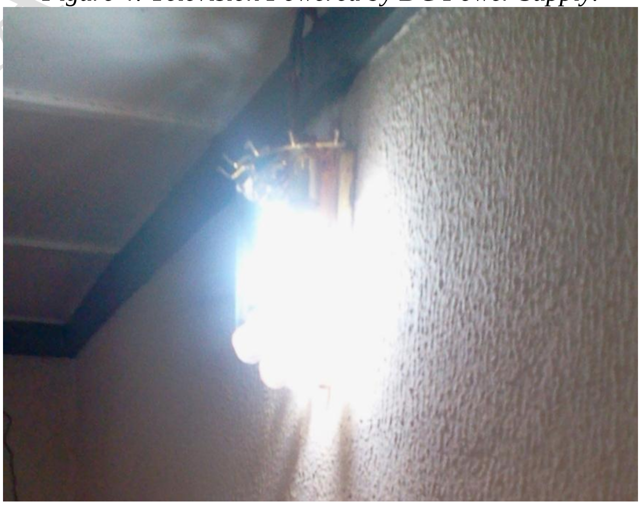

Figure 5: LED lamp Powered by DC Power Supply

Figure 6: CFL lamp Powered by DC Power Supply

V. ANALYSIS OF RESULTS

Results obtained in Table 1, showed that polarity reversal does not affect the performance and operation of the various loads even as the input voltage varied from 100V to 230Vdc. All the SMPS loads provide a fairly constant load to variation in input voltage and operated satisfactorily, while inductive loads did not operate completely as shown in Table 1. The result shown in fig 3 further showed that resistive load (soldering iron) has a fairly linear power consumption with efficiency varying from 13% to 77.2% for DC, and 13% to 77.2 for AC, as the input voltage changes from 100V to 230V; this showed that same efficiency is obtainable with the AC system as with DC system. The television image shown in Fig. 4 was sharp, bright and stable, and none of this parameter varied with changes in input voltage; this shows the stability of power provided by the SMPS, and the harmonic free nature of DC supply. The lights shown in Fig. 5, and 6 provided by the LED and CFL lamps were very stable and bright and also the brightness does not vary with variation in the input voltage as the current consumption remains 0.024Amps for the CFL lamp.

VI. CONCLUSION

This research has demonstrated that DC power delivery systems in our homes could offer the potential for improvements in energy-delivery efficiency, reliability, power quality, and cost of operation as compared to traditional power systems. In this work, DC supplied home appliance is suggested by Compatibility test using existing standards AC appliance. Overall performance of DC supplied home appliance was tested under the actual experimental test condition for 5,475 hours and it was however observed that connector/ contact problem can be dangerous but the quality of TV image, and brightness of lighting is quite commendable. Therefore, it is expected that this informative demonstrative results can be utilized for the DC home appliance in near future on existing standards AC appliance.

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