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DEVELOPMENT OF A DYNAMIC AC/DC (HYBRID) ELECTRIC POWER DISTRIBUTION BOARD

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ABSTRACT

The lack of utility power supply in Nigeria for many hours on daily basis has made individuals and organizations seek alternative power supplies in form of generating sets and solar system. A solar photovoltaic(PV) system can be utilised to supply DC power to low power-consuming devices such aslamps in a building while other devices are AC-operated.Utilising AC power and DC in the same building requires a mains distribution fuse board to distribute AC and DC power simultaneously. An AC/DC distribution fuse board has been designed to have two power inputs: 220 V mains supplying an 8-way set of circuit breakers protected by a 60 A MCB and a 12 V DC from solar PV system protected by DC circuit breakers. The consumer unit has a rectification section where 220 V AC is converted to 12 V DC to supply power to a DC illumination system. An automatic selection of DC supply to the lighting circuits was provided with a 220 V, 10 A, AC relay. When mains is available, it supplies power to the lighting circuits and all other AC devices and when not available, the PV system takes over the supply to the lighting circuits only.

KEYWORDS: *AC/DC Consumer Unit, DC Illumination System, LED Lamps, Power Failure, Solar Photovoltaic System*

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INTRODUCTION

The provision of electrical energy is insufficient in many developing countries.According to the International Energy Agency, 1.2 billion people are without access to electricity and more than 2.7 billion people rely on the traditional use of biomass for cooking, which causes harmful indoor air pollution [1]. The lack of utility power supply for many hours on daily basis has made individuals and organizations seek alternative power supplies [2]in form of generators and bank of batteries connected to inverters.

Another alternative power supply is the solar photovoltaic (PV) system. Deep cycle batteries charged by a solar PV system are capable of supplying moderate power to low power-consuming devices such as the illumination system in a building. When such a setup is operated as a fully DC system, power consumption is reduced. Modern illumination systems use 220 V to operate incandescent lamps which are giving way to compact fluorescent (energy-saving) lamps (CFLs). The CFLs save up to 80% energy in the illumination systems. This can be saved further by replacing them with DC (battery-operated) light-emitting diode (LED). The LED 7 W, 10 W, or 20 W lamps can produce approximately the same lumen output that 40 W, 60 W, or 100 W CFL lamps respectively produce.

Such LED lamps are operated as DC devices from 12 V batteries. This can reduce greatly the power consumption in domestic, commercial and industrial illumination systems and reduce the cost of electricity as an average household dedicates about 5% of its energy budget to lighting [3]. In addition, the LED lamps though more expensive, have a better lifespan compared to either the incandescent or CFL lamps [4]. Also, operating the LED lamps as a fully DC system reduces the cost of installation of inverters incurred in solar PV system using inverters. Many individuals and corporate organizations are now employing this alternative system of illumination.

Due to incessant utility power failure, most households in Nigeria sleep in darkness at night. It is said that only the under-developed African continent remains dark in the aerial view at night [5,6]. This is owing to insufficient grid-supplied electrical energy. Interestingly, Africa is blessed with enormous solar irradiation [7,8] better than many other continents and the solar DC illumination system can be employed in dealing with the challenge of darkness at night. Romisher, (2015)[9] opines that solar electricity is one of five innovations to electrify Africa. The potential of renewable energy technologies (RETs) in meeting energy needs where conventional energy supply options have failed has been established in the literature[10,11].

Many outlets−residential, commercial and industrial−that have employed the DC illumination system do so at an additional cost of re-wiring their buildings as the existing distribution fuse boards cannot accommodate the solar DC illumination system. A hybrid power supply system is required to address the problem. Indeed, hybrid energy systems have been recommended for modern applications and their advantages accessed in literature [12,13]. They have been found to be effective, durable, robust, resilient, safe, marketable, affordable, have low maintenance and operating costs and environmentally friendly.Employing the DC illumination system comes with the challenge of re-wiring the building and the inability to supply the illumination system from the mains supply.

There are various structures and current rating of the distribution fuse board (consumer unit) available in the market which is a device that contains fuses or circuit breakers[14]used to supply power to different parts of a building [15,16]. The various power ratings include 32 A, 60 A, 100 A, 150 A and even higher ratings. Modern wiring of buildings is designed to work with AC power and a consumer unit is used to divide electrical power fed into subsidiary circuits while providing a protective fuse or circuit breaker [17]for each circuit in a common enclosure. Usually, this device is made for the distribution of AC power to a building but there are also available DC distribution boards in the market for special applications. Lately though, other DC appliances have been introduced into the market needing DC power supply at home.. This paper describes the design of a hybrid distribution fuse board that will accommodate the utility power and the solar DC illumination system.

The consumer unit is capable of taking supply from both mains and a DC source and distribute these as required in a building.

DESIGN CONSIDERATIONS AND CONSTRUCTION

Proposed Criteria for the Consumer Unit

As shown in Figure 1, the wiring for both all AC loads and DC loads come from the dynamic hybrid consumer unit. To achieve this requires certain considerations in the overal design.

The consumer unit should conform to BS EN 61439-3 standard for low-voltage switchgear and control gear assemblies [18]. It should also conform to IET Wiring Regulations, BS 7671:2018 which requires that consumer units in domestic (household) premises be manufactured from non-combustible material [19]. It should be capable of selecting from different inputs to power the DC lighting circuits. The illumination system should be given priority by the design. When the mains supply fails, the DC system takes over the supply to the lighting circuits automatically without a break. Thus, it is aimed to design a power distribution fuse board that maintains DC power supply to lighting circuits always from DC input and AC input and AC supply to other loads with the following specifications:

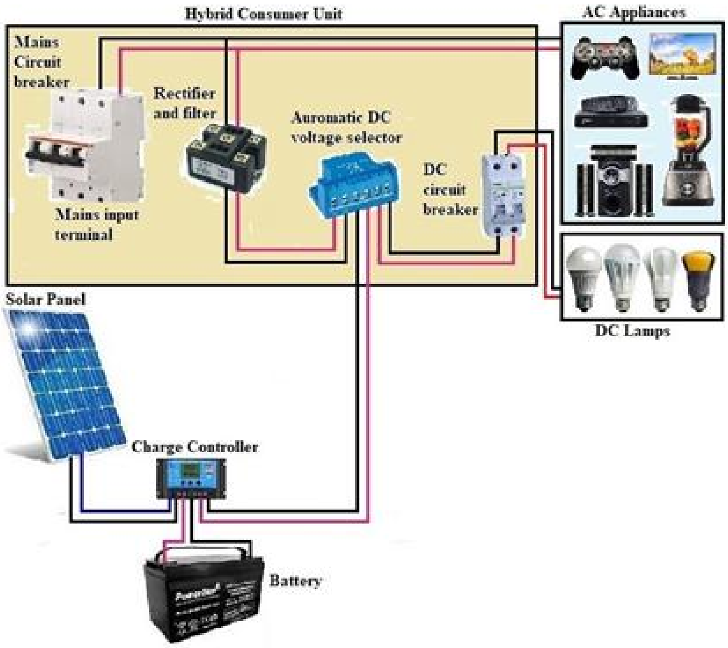

Figure 1: Wiring Diagram of the Hybrid Consumer Unit Supplying AC and DC Loads [20].

Power Rating

60 A AC.

10 A DC.

Input

230 V AC mains. Mains supply powers both lighting circuits and AC outlets when available.

12 V DC battery supply. Supplies only lighting circuits.

Output

230 V AC for all socket outlets.

12 V DC for all lighting point. All lamps work as DC lamps.

Protection

60 A circuit breaker for overall protection.

AC miniature circuit breakers for all AC loads.

DC circuit breakers for lighting circuit.

Switching

Automatic changeover between rectified DC and battery supply to lighting circuit.

Manual switching of circuit breakers.

Manual change-over from mains supply and generating set.

Enclosure

The enclosure must satisfy the BS EN 61439-3 standard which stipulates that the enclosure must be manufactured from non-combustible material[18].

Determination of Circuit Breaker and Relay Ratings

Choices of circuit breaker rating are determined as follows:

The consumer unit is to serve a small home apartment. Considering the possible appliances in the apartment the value of the mains AC circuit breaker was determined according to eqn. (1)[21–23].

$$MCB = \text{No. of devices x wattage x demand factor/rated voltage} \quad (1)$$

Where

MCB = miniature circuit breaker

Demand factor = the ratio of the maximum demand during an assigned period upon an electric-power system to the load actually connected during that time expressed usually in per cent.

A demand factor of 0.6 for non-continuous loads such as television set, cable TV decoder, blender, air conditioner, etc. and 1.35 for continuous loads such as refrigerator were applied.Thus, a 60 A circuit breaker was selected for the AC mains circuit breaker.

The lighting circuit on the average would serve up to 24 lamps in the building. If each lamp is rated 5W DC on the average, the current consumption is determined as thus:

$$P = VI \quad (2)$$

Where

P = lamp rated power

V = supply voltage

I = lamp current.

$$\therefore I = P/V$$

Total expected current passing through the circuit breaker, $I = \sum_0^n P/V$.

For a total of 24 lamps and average of 5W each supplied from 12 V DC, $I = 5x\ 24/12\ A$.

$$I = 10\ A.$$

Thus, a DC circuit breaker of 20 A was selected to accommodate a 100% future additions.

- For the other possible DC appliances, common DC loads range from 5 W for table-top fan to 36 Wforceiling fan.Using a demand factor of 0.6, a 20 A DC circuit breaker was selected for theseloads.
- Considering the DC lighting circuit total possible current of 10 A, a 16 A DC relay was utilised as the automatic switching device. It switches the input power from battery input to the rectified DC when mains supply is available.

Overall Design

An electric power distribution system having sections for both AC and DC inputs was designed. The block diagram given in Figure 2 describes the design of the hybrid power distribution board. The consumer unit was designed to have two power inputs namely 220 V mains supplying an 8-way set of circuit breakers protected by a 60 A-mains circuit breaker and 12 V DC from solar PV system protected by DC circuit breakers. It was designed to have a rectification section where 220 V AC is converted to 12 V DC which supplied the DC illumination system. The 8-way system of sub-circuits protected with circuit breakers supply power to various AC circuits and appliances. The DC section has circuit breakers controlling the DC illumination system and any other DC appliance in the building. The DC section was protected with 5 A, 10 A and 20 A circuit breakers. At the same time, a redundant system of circuit breakers was provided to accommodate future expansion. Voltage measurement was incorporated into the DC circuit through a digital DC voltage meter showing the measurement on the front panel. All component parts are enclosed in a rigid metallic case fitted with a door and locking mechanism that can be opened to access the components parts.

To ensure the usability of the AC supply when available in DC form to power the illumination system, a rectification system converting the mains power to DC for illumination circuits in the building was incorporated into the consumer unit. To ensure a longer lifespan of the battery input, a control operation giving priority to the rectified DC input to be fed to the illumination system whenever mains power is available is applied. This control operation was achieved by means of a 220 V, 20 A, AC relay incorporated into the consumer unit that ensures that power is available at all times to the illumination circuits. By connecting the battery input to the NC contact and the rectified DC input from mains to the NO contact of the relay, mains input when available energises the relay ensuring that supply power is taken away from the battery supply and the supply is switched to the rectified DC input. When the rectified DC input is unavailable, the battery supply is switched on supplying power to the lighting circuits. In this way, whether the mains is available or not, the hybrid distribution board ensured that the DC illumination system is powered with a DC supply at all times, day and night. The inner construction of the consumer unit is shown in Figure 3.

CONSTRUCTION AND TESTING

A rigid metallic case was used to house the various component parts of the hybrid consumer unit as shown in Figure 3. The upper section of the case houses the DC section while the lower part contains the AC section. The component modules are firmly screwed to the base of the casing.

A prototype three-bedroom apartment was constructed on a wooden panel (Figure 4). The hybrid distribution system was installed on it to represent consumer unit in a building. Power was connected from three different sources namely: a generating set, a deep cycle battery charged by a solar panel and from mains, for the purpose of testing and demonstration. An external change-over switch was used to select AC supply from either mains or generating set to the building. When a generating set (or an inverter) is employed to power the building, its supply shall be taken in as mains via

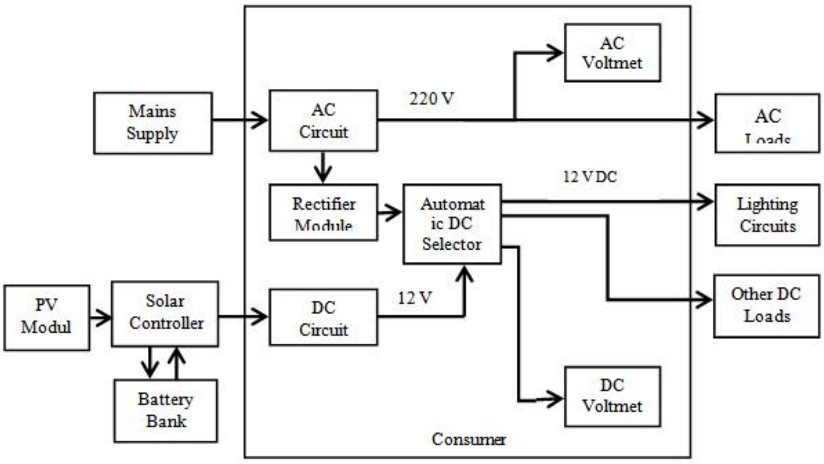

Figure 2: Block Diagram of the Hybrid Consumer Unit with Supply Input and Output.

Figure 3: Hybrid Consumer Unit Showing Inner Construction.

the change-over switch. A generating set (or inverter) shall be employed for limited hours as the illumination system shall have its alternative power source from the PV renewable energy system, especially during the night. The voltages (AC and DC) values of the consumer unit are displayed by the AC and DC voltage measurement meters attached to the front panel.

Figure 4 shows the hybrid distribution fuse board was tested using the prototype three-bedroom apartment constructed and supplied from two different power supply inputs namely mains and the PV system. The operation was tested for correct priority placed on each of the two sources of power by causing a manual interrupt in each of the power supplies in turn. The hybrid consumer unit always automatically route the mains input supply to the illumination system when available and ensured power was supplied to the lighting circuits at all times.

CONCLUSIONS

In this study, a hybrid (AC/DC) consumer unit was developed and tested. It is based on two sources of power supplies namely mains for supplying power to all AC appliances in AC form and capable of supplying DC energy to lighting circuits as rectified DC; and DC from a solar PV system backed by a deep cycle battery supplying power to lighting circuitsand few DC appliances. The combined energy sources enable the hybrid consumer unit to supply power to the DC

Figure 4: Hybrid Consumer Unit Supplying Power to the Prototype Three-Bedroom Apartment.

lighting circuits always and supply AC power to all other loads in a building when AC is available. When compared to the regular consumer unit, it is more dynamic as it can take power from two different sources namely mains and PV system and capable of supplying power in two different forms (AC and DC). The mains supply is 220 V while the DC supply is implemented from mains as rectified and filtered DC 12 V and DC supply from a deep cycle battery. The hybrid consumer unit is designed for domestic electrical installation but can be adapted to commercial buildings and industrial applications. It can help in ensuring that electric lighting is always available in an installation and reduce energy consumption thereby resulting in energy efficiency.

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