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Design and Implementation of a Variable D.C Voltage Generation for Daytime Application Using Solar Energy

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Abstract: *The cost of electricity bill and diesel to power generator during power outages in our institution of higher learning is on the increase. Therefore, there is a need for an alternative that is renewable and eco-friendly. This research work presents the design and implementation of a variable D.C voltage generation for daytime application using solar energy. An electronic circuit was designed to regulate the output voltage from the solar panel into the D.C voltages of 5V, 12V and 19V respectively. The result obtained from the test carried out from the system shows that the output voltages of 5V,12V and 19V were generated during peak period of 12pm to 3pm. This reduces the man hour loss and increase productivity to larger extent when put in use by the staff in the academic environment that it was designed for.*

Keywords: *Electricity, D.C Voltage, Solar Energy*,

1. Introduction

The power demand currently is far higher than the installed capacity of 6852MW while power delivered to the grid is 3,542MW on the average [1]. The gap between demand and supply is wide [2]. This reason and other issue resulted into constant power failure and erratic load scheduling which is not suitable for work and businesses and most especially in an educational institution. Even electricity uses for domestic purposes are not really being enjoyed as expected [1].

There is currently a shift to renewable energy which is clean without any side effect to the planet. The solar energy and the wind energy are leading the way into this renewable energy. This research work utilizes the solar energy for standalone electricity generation as an alternative to the constant power outages being experienced in our institution of higher learning.

D.C is fast becoming more relevant and is currently finding more application in today's world. D.C technology is superior in efficiency compared to AC., better power quality and reliability. D.C is well aligned to renewable energy which is clean and more protective of the planet and may emerge as electricity standard of the future [3].

The focus of this paper is the generation of variable D.C voltage for daytime application that interfaced with solar panels so that the power generated in D.C form is directly connected to loads. This device regulates the output voltage of the solar panels and eliminates the need for inverter and battery. This will greatly reduce the initial installation cost challenge when using solar supply by eliminating the cost of inverter and storage battery hence making this system more affordable solar system solution for daytime power usage

2. Related Works

Highlighted here are some similar works with DC Solar source along with the one presented to review their benefits. Solar calculators are earliest form of solar direct devices that has been around for quiet sometime. It was between 1976 and 1977 that three companies namely; Royal, Teal and Sharp came up with pioneer solar calculator trade named as Solar1, Photon and EL-8026 respectively. At that time, these were very expensive and less efficient; however continuing research into this achievement of solar calculator went on until the mid-1980s when cheaper and more reliable ones were produced. Today, solar calculators are everywhere well developed and far better and very efficient and also very cheap in price making it dominant in the modern market. The solar cell powered the calculator uses the solar direct to load for its operation during daytime and it's been widely used and very effective [4].

Solar Pump-Solar PV directs has successfully been applied to dc-powered solar pump. Here the solar pump is designed in such a way as to utilize the energy from the solar panel direct to power the pump for operation during the day. This development has made water available in remote areas without the conventional power. The relieve and profit to such communities has been of great benefit to humanity.

The solar pump uses dc motor powered directly by the solar PV panels. Compared to AC motors which requires greater level of control system and uses less energy because of losses during DC to AC conversion when inverter is used, the DC motors eliminates the use of inverters, simple control system and maximizes available power for its operation [5]

This paper presents the design and implementation of a variable D.C voltage generation for daytime application using solar energy.

3. Methods and Materials

The materials used in this work are: Solar panel, MC34063 IC, MOSFET, resistors, inductors, capacitors, cables, LCD. The approach on the methodology was to convert the solar panel DC voltage to variable voltages of 5V, 12V and 19V to power a fan, lightning bulb and laptop respectively.

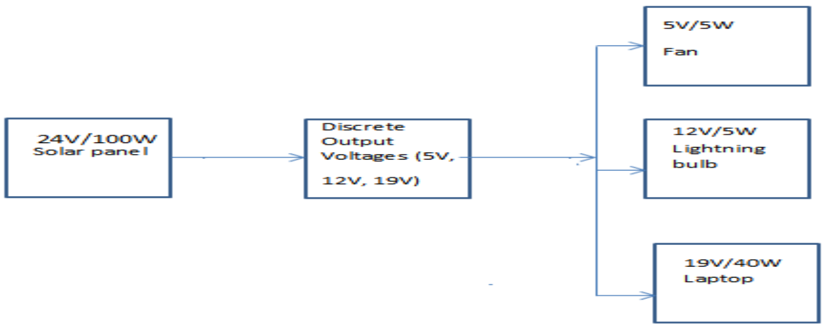

Figure1. *A Simple block diagram of the system*

3.1. Determination of Sizes of Materials Used

Most of the materials used were selected based on the circuit design and components selection using relevant calculations and approximation where necessary.

Sizing the solar panel

Lightning bulb=5W

Fan =5W

Laptop =50W

Total = (5+5+50) W (1)

Total =60W

100W solar panel was selected based on the calculated load demand from the total of all the loads. At peak operation of the solar panel, 70% of the rated power will be delivered which is sufficient for the loads.

Block Diagram of the System-Figure 1 showed the different stages of the system design involved in achieving this project to provide power during the daytime to a campus office of an institution of higher learning. The first stage is the solar panel; a 100W solar panel was computed for this research work. Specification of solar panel is very important in its selection. Generally solar panel varies in wattage and sizes and other considerations determine prices. The second stage is a discrete output voltage at three levels of 5V, 12V and 19V. The third stage is the load stage, DC loads were used for this research work since the focus and emphasis is on DC power generation direct from the solar panel. Currently DC power generations are bouncing back to greater usefulness and application in a world with increasing electronics devices and applications.

3.2. Discrete Output Voltages of 5V,12V and 19V

This block section represents the circuits for this research work, there are three circuits for three levels of voltages of 5V, 12V and 19V to power a fan, lightning bulb and a laptop respectively. These circuits are made up of buck converters which step down the 24V from the solar panel to these three

Voltage levels as stated above.

3.3. The Operation of the Buck Converter

Since a buck converter as in Figure 2 to 4 requires a Pulse Width Modulation (PWM) to switch a MOSFET and the MC34063 contain a timing circuit (internal oscillator) which is controlled by an external capacitor C_T that is connected to pin3. This capacitor C_T was used to set the frequency of the oscillator and the frequency ranges from 24 kHz - 100 kHz

$$C_T = 4 \times 10^{-5} t_{on} \quad (2)$$

Since

$$F = \frac{1}{t_{on}+t_{off}} \quad (3)$$

Assume 50% duty cycle

$$t_{on} = t_{off}$$

$$F = \frac{1}{2t_{on}} \quad (4)$$

The MC34063 also contain an internal reference voltage of 1.25V which it uses to set the output voltage, a voltage divider network that is connected to the comparator input (pin5) was used to set the voltage to 1.25V which serve as an input to the internal comparator. The output of the internal comparator is used to control the PWM in order to maintain the output voltage set. Pin 1 and 2 are the switch emitter and collector, since an N-channel MOSFET 1RF740 was used, the switch emitter (Pin2) was connected to the GRN. Pin 1 will be connected to the gate of the MOSFET, Pin 4 and 6 are the V_{cc} and the GND for the MC34063 chip. Pin 8 is the drive collector which was used to set the voltage and current for the internal switch. Pin 7 is used to sense the peak current used by the internal oscillator, a manufacturer specified resistor R3 and R1 was selected for pin7 and 8 respectively.

3.4. Discrete Output Voltage of 5V

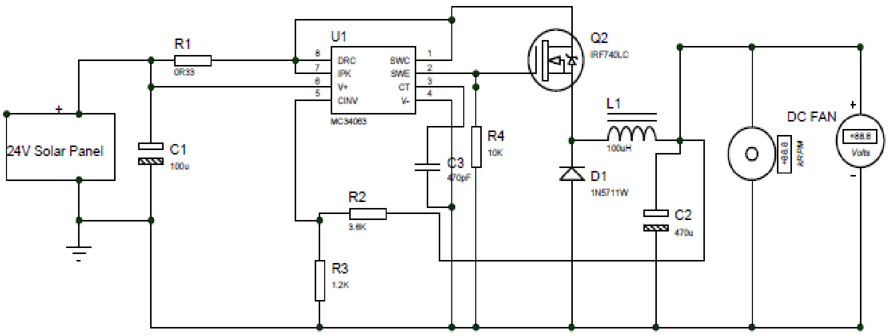

Figure2. *Circuit diagram of discrete output voltage of 5V*

The Figure 2 is the discrete output voltage of 5V it is made up of a buck converter to 5V. The following are the calculations for the 5V section of the circuit. In the design of this circuit and those of the other voltages of 12V and 19V, some calculations were made with some considerations. as follows:

Given are the following:

$V_{out} = 5V$ is the output voltage

$I_{out} = 0.896A$ is the output current of the MC34063

$f_m min = 24kHz$ is the minimum frequency

$V_{in}(\min) = 24.0V - 10\% or\ 21.6V$ is the minimum voltage

$V_{ripple(p-p)} = 20mV_{p-p}$ is the peak to peak ripple voltage

1. The ratio of switch conduction t_{on} versus diode conduction t_{off} time.

From manufacturer design calculation formula

$$\frac{t_{on}}{t_{off}} = \frac{V_{out}+V_f}{V_{in}(\min)-V_{sat}-V_{out}} \quad (5)$$

$$\frac{t_{on}}{t_{off}} = \frac{5+0.8}{21.6-0.8-5}$$

$$\frac{t_{on}}{t_{off}} = 0.37 \quad (6)$$

2. The cycle time of the LC network of Figure2 is equal to $t_{on} + t_{off}$

$$t_{on} + t_{off} = \frac{1}{f_m min} \quad (7)$$

[6]

Taking $f_m min = 24kHz$

$$t_{on} + t_{off} = \frac{1}{24\times 10^3}$$

$$t_{on} + t_{off} = 42\mu s\ per\ cycle \quad (8)$$

3. $t_{on}\ and\ t_{off}$ were calculated from the ratio of $\frac{t_{on}}{t_{off}}$ in equation (6) and the sum of $t_{on} + t_{off}$ in equation (7). By using substitution and some algebraic, an equation can be written for t_{off} in terms of $\frac{t_{on}}{t_{off}}\ and\ \ t_{on} + t_{off}$

$$t_{off} = \frac{t_{on}+t_{off}}{\left(\frac{t_{on}}{t_{off}}\right)+1} \quad (9)$$

[6]

$$t_{off} = \frac{42\mu}{0.37+1}\ s$$

$$t_{off} = 31\mu s$$

$$since\ t_{on} + t_{off} = 42\mu s$$

$$t_{on} = (42 - 31)\mu s \quad (10)$$

$$t_{on} = 11\mu s$$

4. The maximum on–time, $t_{on}(\max)$ is set by selecting a value for C_T

$$C_T = 4.0 \times 10^{-5} t_{on} \quad (11)$$

[6]

$C_T = 4.0 \times 10^{-5} (11 \times 10^{-6})$

$C_T = 440pF$

The closest standard value is 470pF therefore; this value is chosen for the value of C_T

5. The peak switch current is:

$$I_{pk(switch)} = 2I_{out} \quad (12)$$

[6]

Using $I_{out} = 0.869A$

$I_{pk(switch)} = 2(0.869)$

$I_{pk(switch)} = 1.738A$

6. With knowledge of the peak switch current and maximum on time, a minimum value of inductance can be calculated.

$$L_m min = \left(\frac{V_{in}(\min\quad) - V_{sat} - V_{out}}{I_{pk(switch)}}\right) t_{on}(\max\quad)$$

[6]

$$L_m min = \left(\frac{21.6 - 0.8 - 5}{1.738}\right) 11 \times 10^{-6} \quad (13)$$

$$L_m min = 100 \times 10^{-6}$$

$$L_m min = 100\mu H$$

7. A value for the current limit resistor, R_{sc}, can be determined by using the current level of $I\_pk(switch)$ when $V_{in} = 24V$

$$I'_{pk(switch)} = \left(\frac{V_{in} - V_{sat} - V_{out}}{L_m min}\right) t_{on}(\max\quad) \quad (14)$$

$$I'_{pk(switch)} = \left(\frac{24 - 0.8 - 5}{100 \times 10^{-6}}\right) 11 \times 10^{-6}$$

$$I'_{pk(switch)} = 2A$$

$$R_{sc} = \frac{0.33}{I'_{pk(switch)}} \quad (15)$$

[6]

$$R_{sc} = \frac{0.33}{2}$$

$$R_{sc} = 0.165\Omega$$

A standard resistor of 0.33Ω was chosen

8. A minimum value for an ideal output filter capacitor C_o in Figure 2 was obtained.

$$C_o = \frac{I_{pk(switch)}(t_{on} + t_{off})}{8V_{ripple(p-P)}}$$

[6]

$$C_o = \frac{1.738(42 \times 10^{-6})}{8(20 \times 10^{-3})} \quad (16)$$

$$C_o = 456.23\mu F$$

Standard value of 470µF is chosen

9. The nominal output voltage is programmed by the R1, R2 resistor divider. The output voltage is:

$$V_{out} = 1.25\left(\frac{R2}{R1} + 1\right)$$

[6]

The divider current can go as low as 1000 µA without affecting system performance. In selecting a minimum current divider R1 is equal to:

$$R1 = \frac{1.25}{1000\times10^{-6}} \quad (17)$$

$R1 = 1{,}250\Omega$

Rearranging the above equation so that R2 can be solved yields:

$$R2 = R1(\frac{Vout}{1.25} - 1)$$

If a standard 5% tolerance 12 k resistor is chosen for R1, R2 will also be a standard value.

$$R2 = (1.2 \times 10^4)\left(\frac{5}{1.25} - 1\right) \quad (18)$$

$R2 = 3.6K$

3.5. Discrete Output Voltage Of 12V

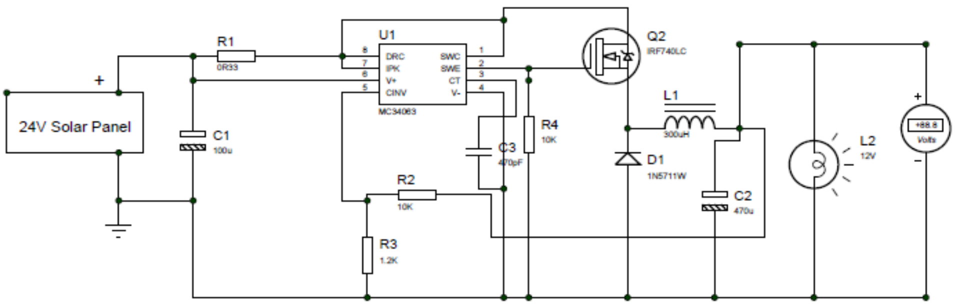

Figure3. *Circuit diagram of discrete output voltage of 12V*

Figure 3 shows the circuit diagram that was used to achieve the discrete output voltage of 12V. The following are the calculations for the 12V section of the circuit. In the design of this circuit, some calculations were made with some considerations as follows:

Considering 12V

Given are the following:

$V_{out} = 12.0V$ is output voltage

$I_{out} = 173mA$ is the output current from the MC34063

$f_m(\min) = 50kHz$ is minimum frequency taken

$V_{in}(\min) = 24 - 10\% \; or \; 21.6V$

$V_{ripple(p-p)} = 1.84mV_{p-p}$

Following the above series of calculations here are the results for 12V

$t_{off} = 8.2\mu s$

$t_{on} = 11.8\mu s$

C_T = 472pF

Using a standard 470pF capacitor

$I_{pk(switch)} = 46mA$

$L_m min = 300\mu H$

$I'_{pk(switch)} = 440mA$

$R_{sc} = 0.75\Omega$

A standard resistor of 0.33Ω was chosen

$C_o = 470.1\mu F$

9. Taking standard value for R1 and R2

R1=10kΩ

R2=1.2kΩ

3.6. Discrete Output Voltage Of 19V

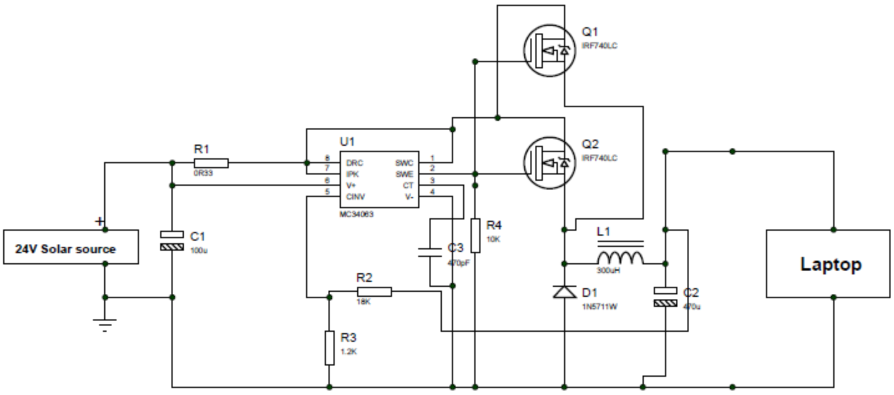

Figure4. *Circuit diagram of discrete output voltage of 19V*

This section is the buck converter of Figure 4, this gives the 19V of the discrete output voltage stage. The following are the calculations for the 19V section of the circuit. In the design of this circuit, some calculations were made with some considerations as follows:

$V_{out} = 19V$ is the output voltage

$I_{out} = 366mA$ is the output current of the MC34063

$f_m min = 80kHz$ is the minimum frequency

$V_{in}(\text{min} \quad) = 24.0V - 25\% or\ 21.6V$ is the minimum input voltage

$V_{ripple(p-p)} = 2.589mV_{p-p}$ is the peak to peak ripple voltage

Following the same calculations here are the results for 19V

$t_{off} = 1.1\mu s$

$t_{on} = 12.2\mu s$

C_T = 488pF

Using a standard 470pF capacitor

$I_{pk(switch)} = 732mA$

$L_m min = 300\mu H$

$I'_{pk(switch)} = 170mA$

$R_{sc} = 0.06\Omega$

Standard value of 0.33 Ω is chosen

$C_o = 470.04\mu F$

Taking a standard value for R1 and R2

R1=18$k\Omega$

R2=1.2kΩ

3.7. The DC Loads

There is a continuing increase in the development, production and deployment of DC devices. DC load for this work are as follows: DC bulb and DC fan and laptop which is purely a DC device usually powered by a power adapter that converts AC to DC.

3.8. Hardware Implementation of the Research Work

The Plate I shows the various components used for the hardware implementation of this research work. Plate 2 is that of the 24V/100W Solar panel DC power source.

Plate1. *Components on board for this research work*

Plate2. *24V/100W Solar Panel*

Plate3. *Box casing with components enclosed*

Plate 3 shows the eclosure box for the components used with LCD display.

4. DISCUSSION OF RESULT OF THE HARDWARE IMPLEMENTATION

The readings shown on Plate IV are 17.43V, 12.39V and 5.12V on full load which are approprite for the loads. The unit was tested on all the loads as shown in plate V and sucessfully powered them

Plate4. *LCD display for voltage and current reading*

Plate5. *The unit powered all three devices (a 19V Laptop, 12V bulb and 5V fan)*

Since the output of the solar PV depends on the varying intensity of the sun radiation various readings were taking at different time from 7.30am to 4.30pm and under different weather conditions as seen in Table 1, voltage and current readings were taking as shown. It was observed that the voltage is low in the early hour of the day and later in the day. However, during the normal sunny days(between 8am-5.30pm, the sun radiation is sufficent to operate the device with minimal variation.The readings span approximately ten days, it was discovered that best results was achieved between 10.00am to 3.00pm for most of the days when the sun radiation is good. For some days the system works well between 8.30am and 9.00am to power all the loads.

Table1. *Voltage and current readings of the Hardware implementation at different time*

Time	Input voltage	Total current	19V	12V	5V	19V current	12V current	5V current
7:30:00 AM	18.60	0.24	12.18	12.32	5.08	0.00	0.00	0.00
8:00:00 AM	26.88	0.23	21.48	12.32	5.08	0.00	0.44	0.34
8:30:00 AM	29.00	0.23	21.54	12.32	5.12	0.00	0.44	0.34
9:00:00 AM	30.78	0.66	22.71	12.25	5.12	0.00	0.43	0.33
9:30:00 AM	27.71	2.07	19.56	12.32	5.12	1.45	0.39	0.34
10:00:00 AM	27.56	2.49	19.47	12.25	5.12	1.48	0.46	0.42
10:30:00 AM	27.56	2.49	19.47	12.25	5.12	1.48	0.46	0.42
11:00:00 AM	26.88	2.56	18.90	12.32	5.12	1.56	0.47	0.30
11:30:00 AM	27.72	2.49	17.25	12.25	5.06	1.75	0.39	0.31
12:00:00 PM	26.64	2.32	18.75	12.25	5.10	1.64	0.45	0.31
12:30:00 PM	26.04	2.60	18.18	12.25	5.10	1.51	0.47	0.31
1:00:00 PM	26.24	2.31	18.36	12.25	5.10	1.63	0.45	0.31
1:30:00 PM	27.88	2.44	19.80	12.25	5.12	1.43	0.47	0.31
2:00:00 PM	26.00	2.29	17.97	12.25	5.10	1.63	0.43	0.32
2:30:00 PM	26.44	2.60	18.45	12.25	5.10	1.57	0.47	0.33
3:00:00 PM	25.92	2.31	18.03	12.25	5.10	1.62	0.46	0.32
3:30:00 PM	23.48	2.09	15.72	12.25	5.10	1.89	0.45	0.32
4:00:00 PM	25.04	2.75	17.49	12.25	5.12	1.72	0.48	0.32
4:30:00 PM	27.16	1.00	20.16	12.18	5.08	0.00	0.46	0.31

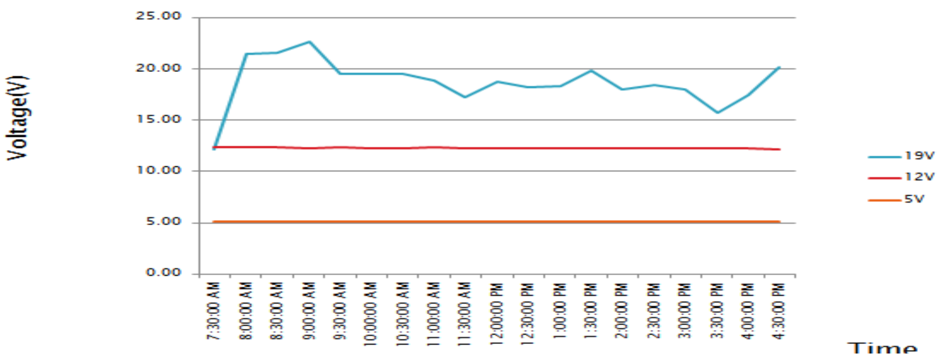

Figure8. *Graph of Voltage measured over time*

Figure 8 shows the graph of voltage measured from 7.30am to 4.30pm it reveals that the 12V and 5V output is more stable than the 19V output.

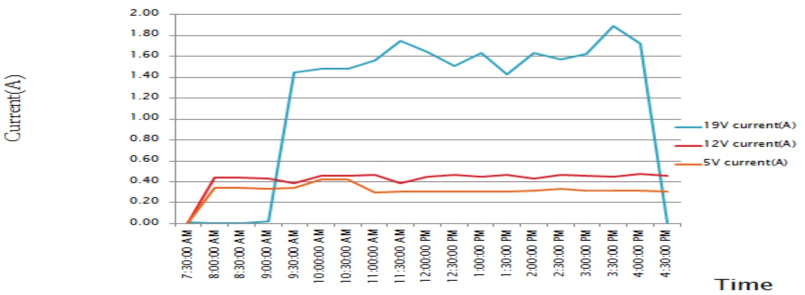

Figure9. *Graph of Current measured over Time*

Figure 9 shows the currents on all the three loads taken from 7.30am to 4.30pm, it reveals that the 19V load consume more currents compare to the other two loads that are closed.

5. Conclusion and Recommendation

In this research work "Design and implementation of a variable D.C voltage generation for daytime application are using solar energy", voltages of 5V, 12V and 19V were generated and tested to carry a fan, lightning bulb and laptop respectively. The major limitation of this research work is the amount of power it can handle; it has been designed for an average of 100W which can handle a limited number of loads. Another limitation of the work is that it is limited to 8 hours, this is because the time frame considered was that of official working hour which is from 8.00am to 4.00pm. Non-availability of components within the immediate local environment has been a great challenge for speedy execution of this project.

Despite the limitation of this research work, it has successfully been able to achieve the aim for which it was carried out. The challenge of availability of electricity for learning and research in institution of higher learning during the day has been a crucial one. The campus has only a limited power solution to key offices which are mostly administrative in nature and operation like the Senate Building, School and departmental offices. The achievement of this project work is that it has provided solution for individual staff and member of the academic community on campus which will ensure daytime uninterruptible power supply. This will eliminate man-hour loss due to power failure and make the daytime more productive. It is recommended that future work will explore higher capacity that will carry more D.C loads

Acknowledgment

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