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Design and Performance Evaluation of DC - DC Stepup Sepic Converter for Photovoltaic Based off Grid Application

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Abstract: Solar energy resourses is abundantly available but its exploitation through PV system is not economically feasible. In order to optimize the power output, an electronics device should be integrated with solar PV system. A high classical classical single ended primary inductor converter SEPIC converter for renewable energy applications was designed, constructed and experimentally tested. The voltage multiplier cell (consists of two diodes and two capacitors) was incorporated with SEPIC to design a DC – DC boost converter for PV application. The new converter can improve the capacity of 10 V DC input to output 60 V DC, the design circuit will boost input voltage and maintain a constant voltage output. The performance of the proposed topology was authenticated and the result achieved from the implemented prototype are in good agreement with the design strategies. The effects of input parameters such as sun radiation and useful power input on PV system and DC-DC converter outputs were investigated. Results confirmed that the DC-DC converter was perfectly designed using Multisim software and accurately constructed, when integrated with solar PV system under no load and on load conditions.

Keywords: DC-DC Converter, Photovoltaic (PV), Single Switch, High Step-Up Voltage Gain, Duty Cycle.

1. INTRODUCTION

Today's global energy stock primarily comes from fossil fuels such as coal, oil and natural gas which was key sources of greenhouse fumes. The Earth's climate will be compromised if we prolong relying on these fuels without scalable replacement[7]. Due to demeaningavailability of fossil fuel, an increase in energy demand and current restrictions

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integrated to reduce the CO2 emission in almost all the countries, the power industries and researchers concentrates on a renewable energy based power generation.
The renewable energy sources like solar and wind energy will lead the power demand in upcoming years, out of all renewable energy sources, solar energy has gained much more attention due to its availability, cleanness, inexhaustibly in nature, free of charge, less ecological pollution and with modular character which allows construction of the solar array at different power levels [9][6].

Solar energy is one of the most underutilized among them, the experimenting the solar panelsand photovoltaic cell are extremely important, This implies that solar photovoltaic (PV) has a great capacity for a variable energy economy, and the further development of PV panels technology becomes very critical for it to become a major electricity and energy resources[7]. One of the predominant element of solar panels is having low dc power which is not suitable for direct utilization by inverters [12]. Generally, PV criteria are connected in series in order to achieve highvoltage values**.** In a photovoltaic (PV) system, the most visible part of the system is the PV panels. Panels can be mounted in open fields and building rooftops, and nowadays, PV cells are being integrated into the building materials themselves[7]. The PV cells convert solar energy into electric energyIn order to overcome potential instability issues,recent research has begun to focus on making the PV system more intelligent unit.

A solar power meter (pyranometer) has been used to measure the direct sun radiation in W/m^2. A solar module consists of several interconnected solar cells, these interconnected solar cells embedded between two glass plates to protect from the bad weather. The photons from solar radiation are being converted by the use of solar PV panels [11]. The amount of sun radiation (W/m^2) directly striking the surface of the PV modules of given specifications (m^2) is refers as theuseful power input and is evaluated using equation 1.

$$Pinput = S \times A \quad (1)$$

Power input = sun radiation in W/m^2 * Area of the PV module in m^2=Watt
The Solar PV module is a device that harnessed sun radiation and converts it into electricity through the principles of photovoltaic effect. The magnitude of the power output from the solar PV module duly depends on the intensity of solar radiation available at the location where it has been installed. The measured voltage and current output from the PV panel are usually used in eqn 2 to determine the total power output generated by the PV module.

$$P = I0Vo \quad (2)$$

DC-DC Converter Evaluation Parameters
The determination of the efficiency of electronics devices for interfacing renewable energy systems is a very crucial issue. Therefore, it is an important consideration with any device design or implementation in renewable energy applications. The fact that the cost for energy may be higher than conventionally produced electricity, minimizing loss is of even greater importance. Therefore, the efficiency of the DC-DC SEPIC converter is obtained by usingeqn(3) [12][13].

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$$\cap = \frac{pout}{pin} = \frac{I_c max \times Vmax}{pin} \quad 3$$

$$\text{Efficiency} = \frac{pout}{pin} \times 100\% \quad 4$$

A research on different literature reviews on DC-DC converters for PV applications reveals thatmany conventional and artificial methods have been proposed for boosting low voltage generatedby PV panels. [10] Reported an integrated double boost-sepic DC-DC converter for fuel cell andPV applications. But, the topology has a large duty-cycle which caused too much stress withinthe components and besides, the topology looks too expensive. The topology reported in [8], hashigh gain and low duty-cycle but its switching voltage is equals to twice the input voltagewhich isnot expected to make the switch works properly and resulted in high stress within thecomponents. A single ended primary inductor converter (SEPIC) with voltage multiplier cellpresented by [12], showed some improvements, but exhibit a bit high duty cycle value and littlestress across the semiconductor devices. [4] Reported A multi-port DC-DC converter for hybrid energy system with 4 independent switches, though the converter can works in 3-different modes, but three switches for a single converter is deemed too much and the voltage transfer ratio isrelatively low also. [8] Proposed a topology with higher voltage transfer ratio and low duty-cycle. But the converter are; a clamping strategy was employed which increase the number of components and there is complexity in terms of stress and positioning of the multiplier cell used. To overcome this challenges a profitable DC-DC Converter is used to convert low voltage to high voltage. In this work, a classical boost converter was combined with a voltage multiplier cell to designa DC-DC boost converter for PV applications. The proposed converter implored a single switch for switching control. The advantages of the topology are: it is being cheap, light,presenting less stress across the semiconductor devices, and high voltage gain. This DC converterwill boost any input DC voltage of 10 V to an output of 60V DC voltage as shown in Fig 1.Verification performance of the converter was done using an experimental prototypecircuit in thelaboratory.

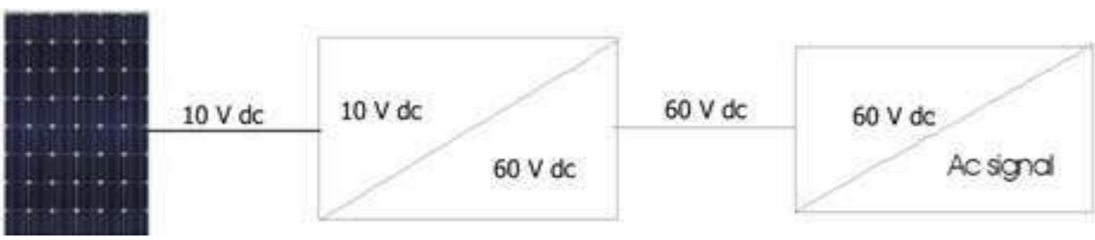

Fig 1.Graphical representation of the proposed converter system.

Materials

The materials used for the design, construction and performance analysis of DC-DC SEPIC

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Converter for solar PV systems

Instrument Used
The measuring instrument used for the DC-DC SEPIC converter performance investigation is short-listed in Table 1.

Table 1: Measuring Instruments

Instrument	Specifications
Pyronometer	TES 1333R Data logging Solar power meter
Multimeter	DT9205A, DT-830D and DT9201A (0 – 120 V)
Oscilloscope	CA6620 20MHz
Variable power supply	MCR – 303A DC POWER SUPPLY

Electronics Components Used
The actual sizes of the electronics components for the designed SEPIC DC-DC converter based on simulation are shortlisted in Table 2 (selected from datasheet);

Table 2: Actual components specifications used for the designed circuit topology of DC-DC SEPIC converter

s/no	Equipments		Specifications
1	Input voltage Vin		10DC voltage
2	Inductor L1		10µH
3	Signal generator (MOSFET)		IRFZ44
4	Inductor L2		250µH
5	Diodes D1		MUR110
6	Diodes D2		MUR110
7	Diodes D3		MUR110
8	Capacitor C1		2.2µF
9	Capacitor C2		2.2µF
10	Capacitor C3		2.2µF
11	Output Voltage Vout		60 DC voltage

2. METHODS

The methods Adopted for the design, construction and performance investigations of the DC-DC SEPIC Converter are presented in this unit.
The proposed circuit diagram of the DC-DC SEPIC converter consists of a power input source, 2 Inductors, and 1 signal generator, 3 diodes, 3 capacitors and the load. Figure 2 present a circuit diagram of the proposed SEPIC converter as

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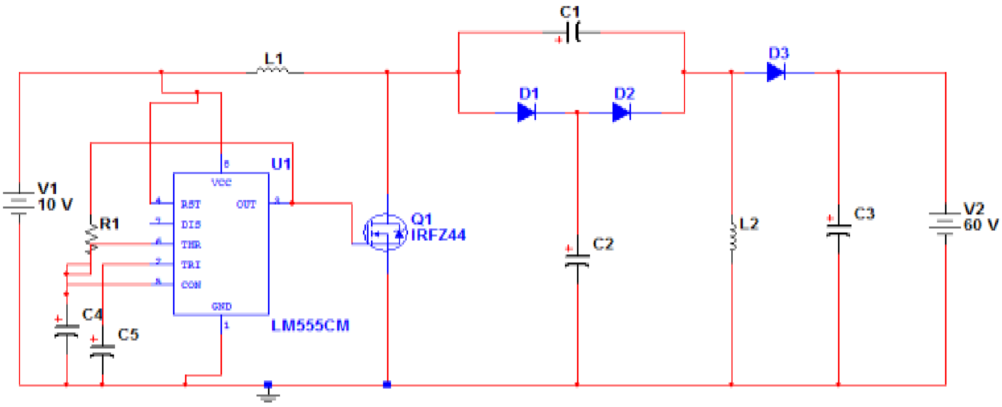

Fig 2: The Proposed DC-DC SEPIC Converter Topology

Methods
Design Equation
The proposed components sizing for the DC-DC SEPIC converter design involved thevoltage ratings and specifications of all the electronics components as indicated in Figure 2 The proposedesign equations was used to calculate the parameters mention in Table 1
From fig:
From the figure. 2 above, it can be seen that, the proposed converter is a product of two classical boost converter. Therefore, the numerical analysis can be obtained from the circuit above (fig. 2) as:

$$Vin = VL1 \quad (1)$$

$$V_{C3} = V_{output} = V_{C1} + V_{C2} \quad (2)$$

$$Vind = (VC2 - Vin)(1 - d) \quad (3)$$

$$Vind = VC2 - V0d - Vin + Vind \quad (4)$$

$$V0 - V0d - Vin = 0 \quad (5)$$

$$V = \left(\frac{Vin}{1-d}\right) \quad (6)$$

$$\frac{V0}{vin} = \left(\frac{1}{1-d}\right) \quad (8)$$

$C1$, $C2$, $D1$& $D2$ are representing voltage daubler, and M is representing the number doubler circuit used. Hence in this project one voltage doubler circuit is used and therefore

M = 1Now equation will take the form

$$\frac{V0}{} = \left(\frac{M+1}{}\right)$$

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9
V_{in} $1-d$

here $\frac{V_0}{V_{in}}$ are voltage gain, M is the number of voltage multiplier cell used and V_o voltage output

$$\frac{V_0}{V_{in}} = \left(\frac{2}{1-d}\right) \quad 10$$

In terms of duty cycle equation 9 will take the form

$$V_0 - 2V_{in} = V_{od} \quad 11$$

The value of duty-cycle of the switching signal will be calculated using, equation (12)

$$\partial = \frac{V_o - V_{in}(m+1)}{V_o} \quad 12$$

In terms of voltage stress on switch, the voltage stress of the components will be calculated using, equation (13)

$$V_{switch} = v_{in}\left(\frac{1}{(1-6)}\right) \quad 13$$

Where V_{in} is the voltage input, and ∂ *is the duty cycle*

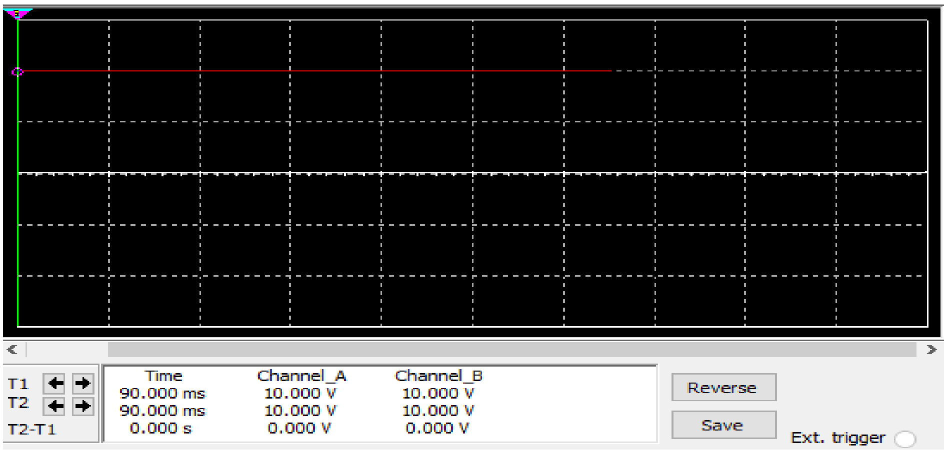

Fig 3: Input and output voltage values across the Inductor L1

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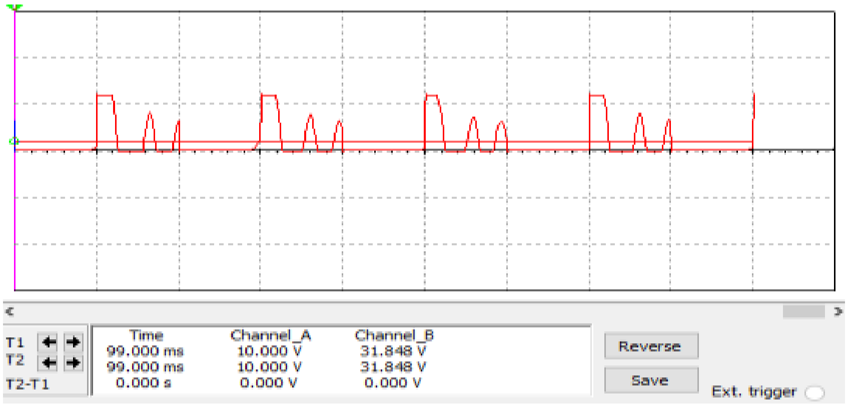

Fig 4: input and output voltage values across the switch

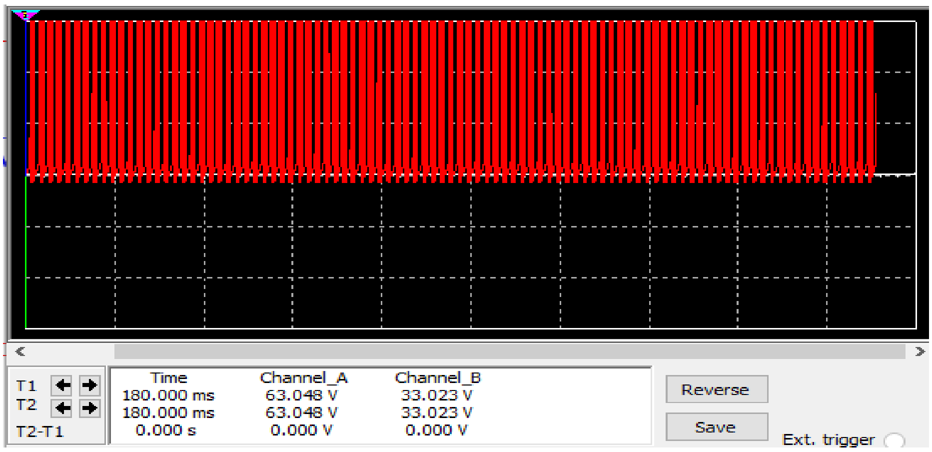

Fig 5: Input and output Voltages across the Capacitor C1(Voltage Doubler Output)

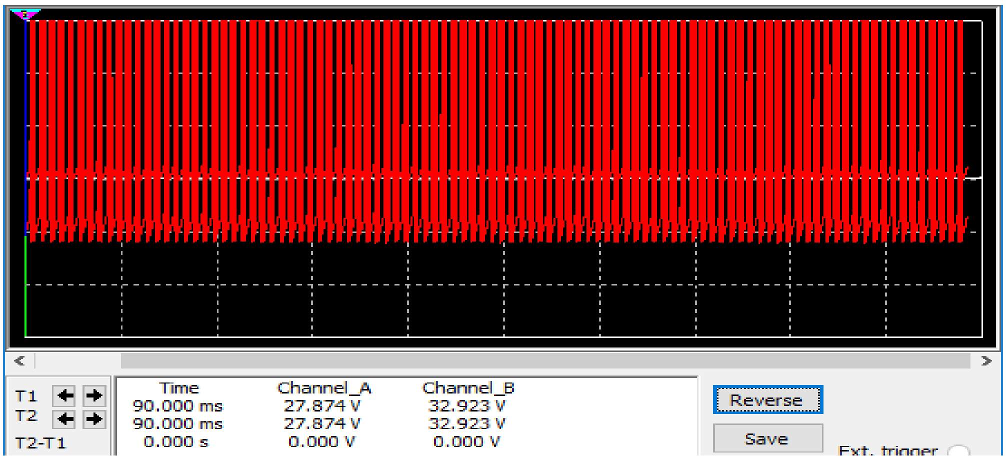

Fig 6: Input and output voltage values across the Capacitor C2

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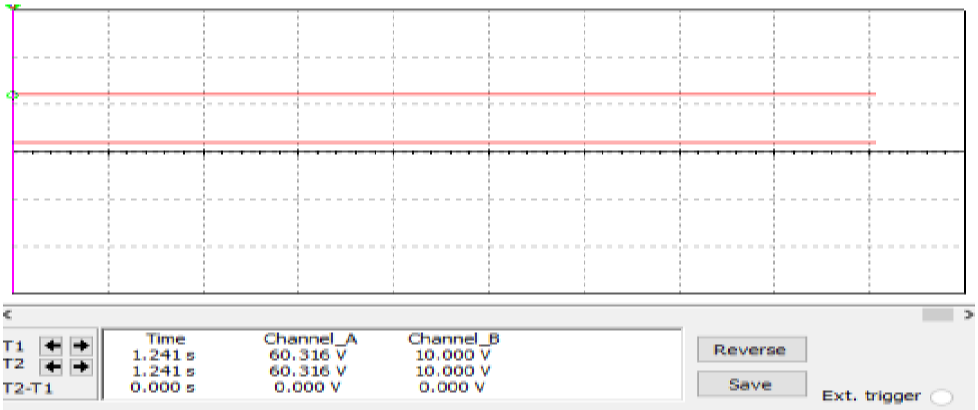

Fig 7: Input and output voltage values across the Inductor L2

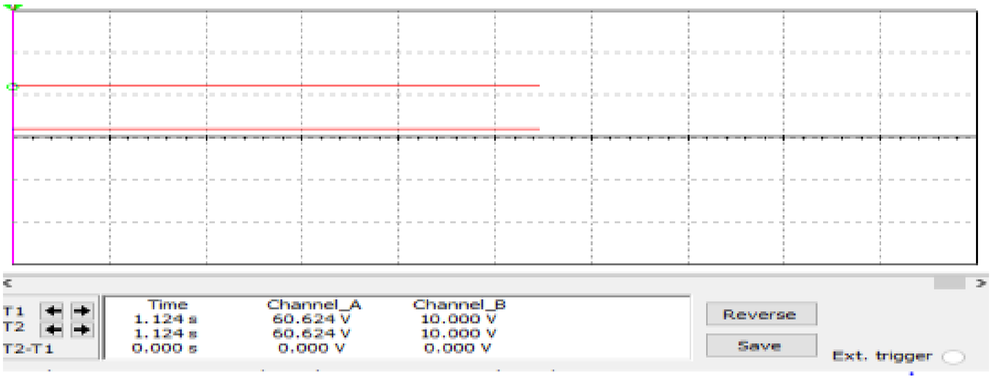

Fig 8: Input and output Voltage values across the Capacitor C1

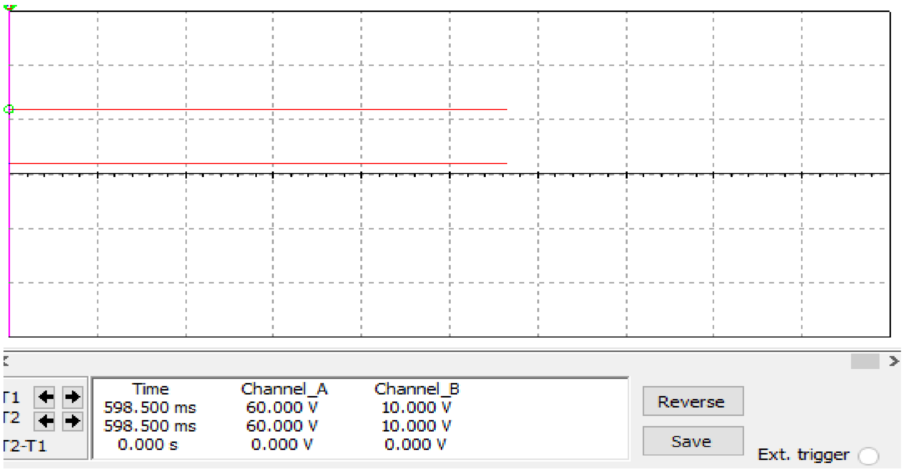

Fig 9: Input and Output voltage values across the Capacitor C3(output voltages)

3. RESULTS AND DISCUSSION

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Simulation results

The simulation was conducted with 10 V input and 60 V output voltage, the simulation was conducted several times under varying time conditions. In each case, the output voltage was recorded and the average voltage was evaluated, the input and output volues were showed infigure 10;

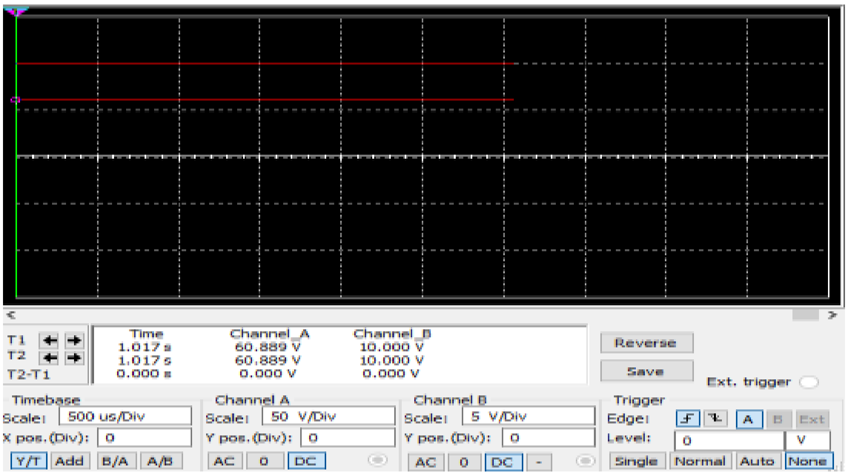

Fig 10 Complete circuit simulations results via multisim

Construction of DC-DC SEPIC converter

The components and tools listed in Tables 1 and 2 were assembled and trouble Shouted totest their functions, hardware test was monitored through the oscilloscope before construction The output voltage with the respect to time and its amplitude was monitored and recorded from the oscilloscope. The Constructed DC-DC SEPIC converter is shown in Figure 11;

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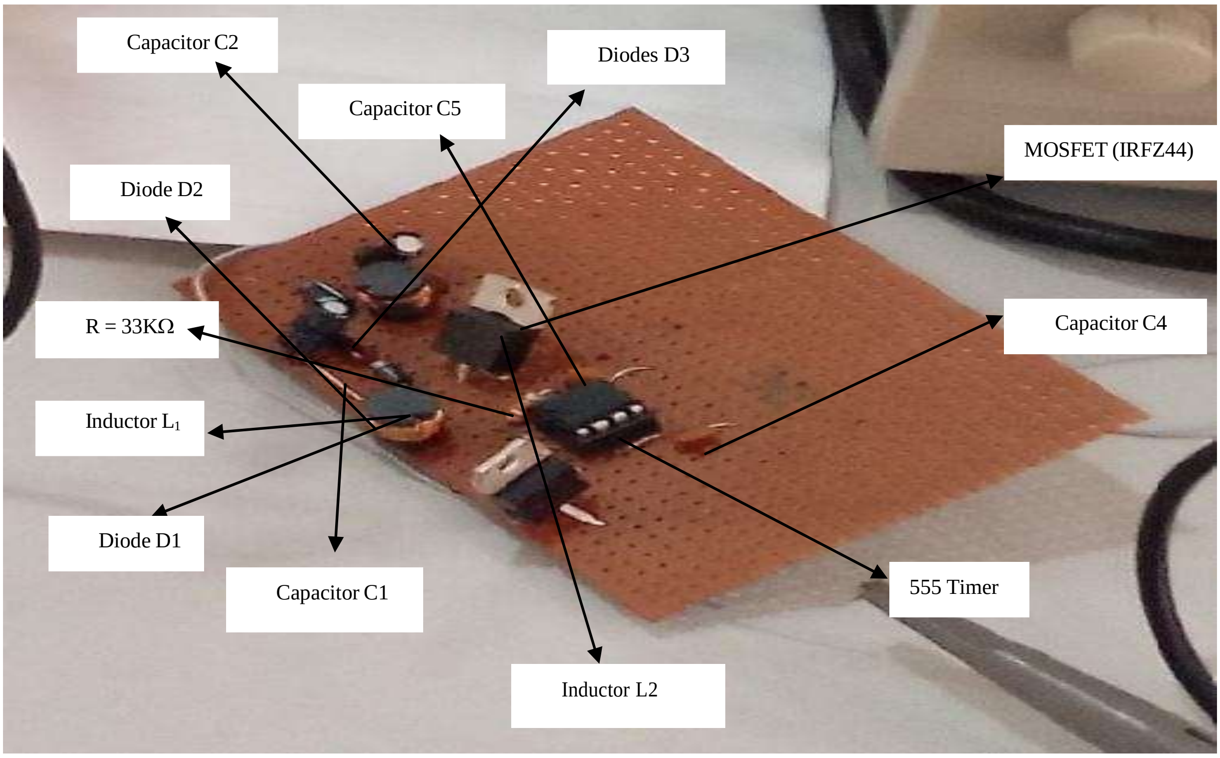

Fig 11. Constructed DC-DC SEPIC Converter

Experimental Tests

The outputs of the PV module were connected to the two digital multimeters which serve as the input voltage to the converter and were measured and recorded. The direct sun radiation striking the surface area of the PV module has been measured simultaneously with the input and output voltages at intervals of 10 minutes.These data were collected for 10 days and average hourly results were obtained.The experimental set up of DC-DC SEPIC converter consisting of stands tools, PV module, constructed system and two Multimetersare shown figure 12;

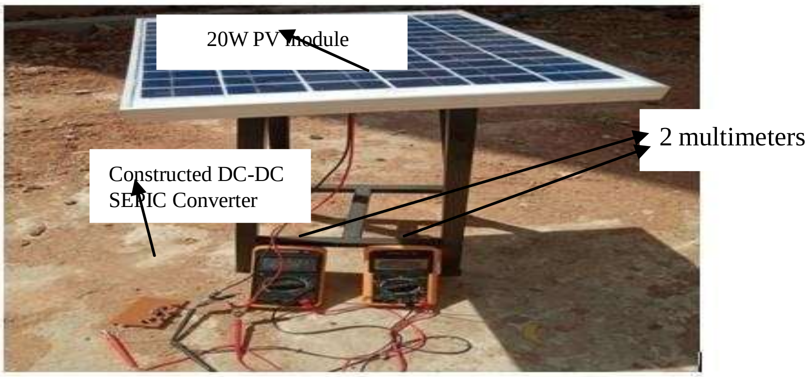

Fig 12: Experimental set up of DC-DC Converter under no load

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The constructed DC-DC SEPIC converter was placed in Plate 3.5 consisting of load, PV module, constructed system and 2 Multimeters were presented.

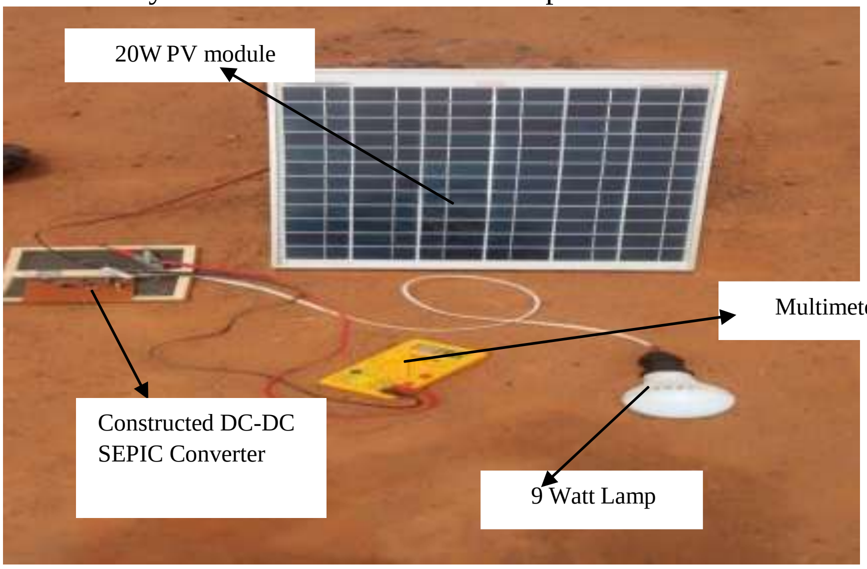

Fig 13: Experimental set up of DC-DC converter on load condition

Experimental Test Results for the DC-DC SEPIC Converter

Figure 14: presents a graph of the correlation between the useful solar power input and Solar PV power output under no-load conditions. Solar PV modules generated 13.91 W when the useful solar power input has the maximum value of 159.4 W. However, the solar PV module power output has reduced to a lower value of 4.58 W at 5:00 pm while the useful solar power input was

70.68 W. This indicated that the solar PV module power output depends dully on the useful solar power input.

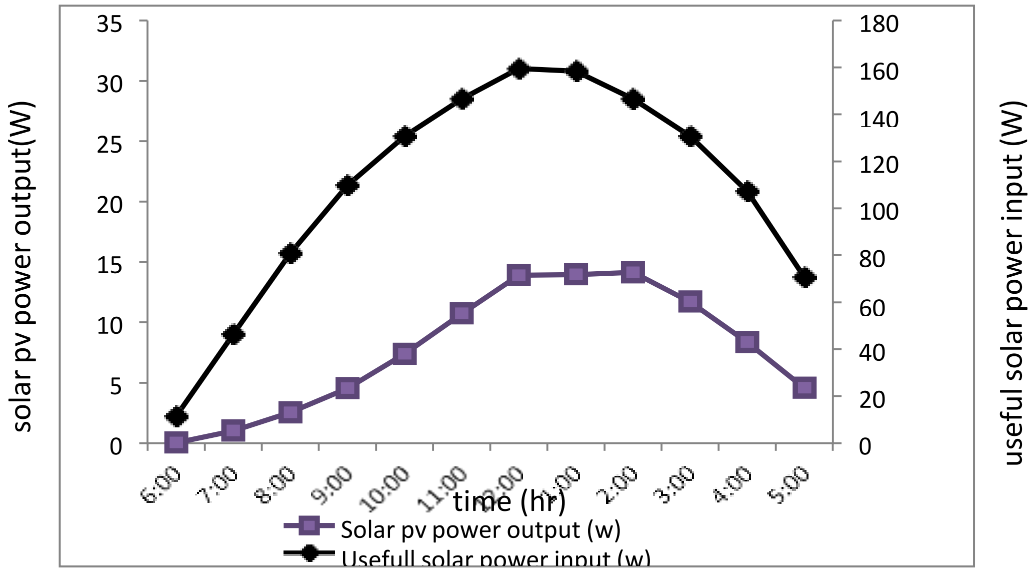

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Fig 14: Graph of correlation between the Solar PV power output and useful solar powerinput under no load condition

The correlation between the useful solar power input and Solar PV power output on load conditionis presented in Figure 15; The results show that a maximum value of solar PV module power output of 14.15 W was observed at around 12:00 pm, when the useful power input was maximum at 160.53 W. These indicated the PV module power output depends on the useful power input as they followed the same trend in the graph.

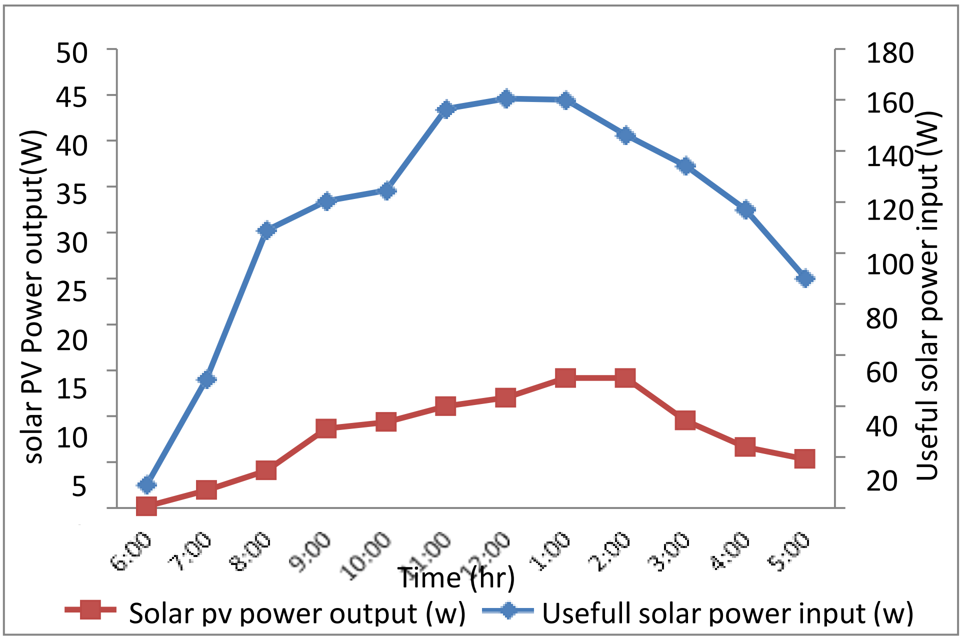

Fig 15: Graph of correlation between the Solar PV power output against useful solar power input on load condition

Figure 16 presents a graph of the correlation between the useful solar power input and Solar PV module efficiency under no-load and on load conditions. The result shows that at maximum value of useful solar power input of 159.58 W around 12:00 pm, the Solar PV module efficiency of 8.78
% was obtained this shows that correlation existed between useful power input and PV efficiency under no load condition. However, at 1:00 pm, both the efficiency and useful power input have increased to 8.8 % and 160.03 W respectively on load condition. figure 17 indicated the correlation between the useful power input and efficiency of the PV module but the input power was not always i

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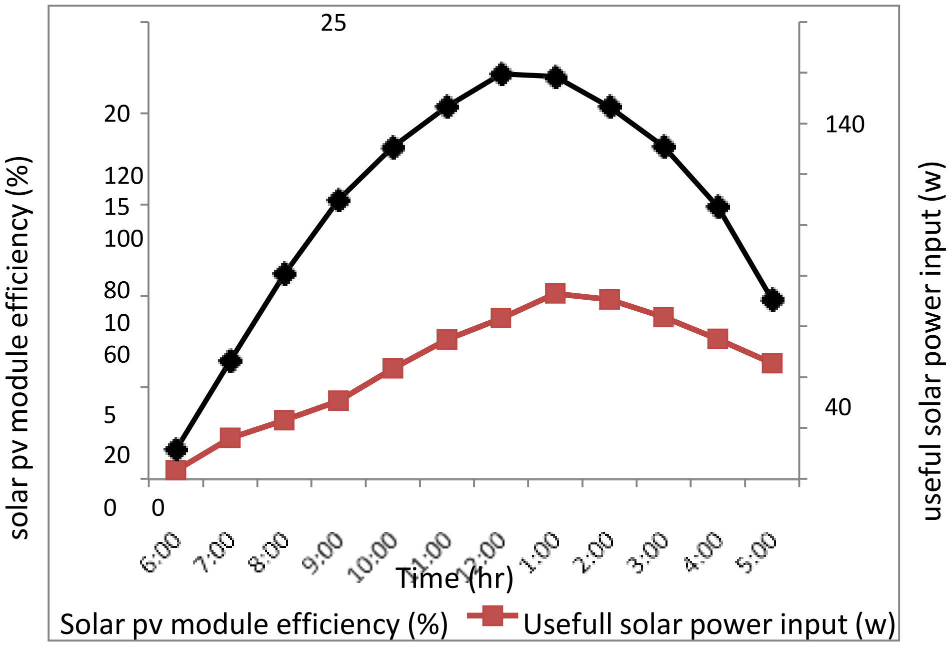

Fig 16: Graph of correlation between the Solar PV module efficiency and useful solarpower inputunder no-load condition

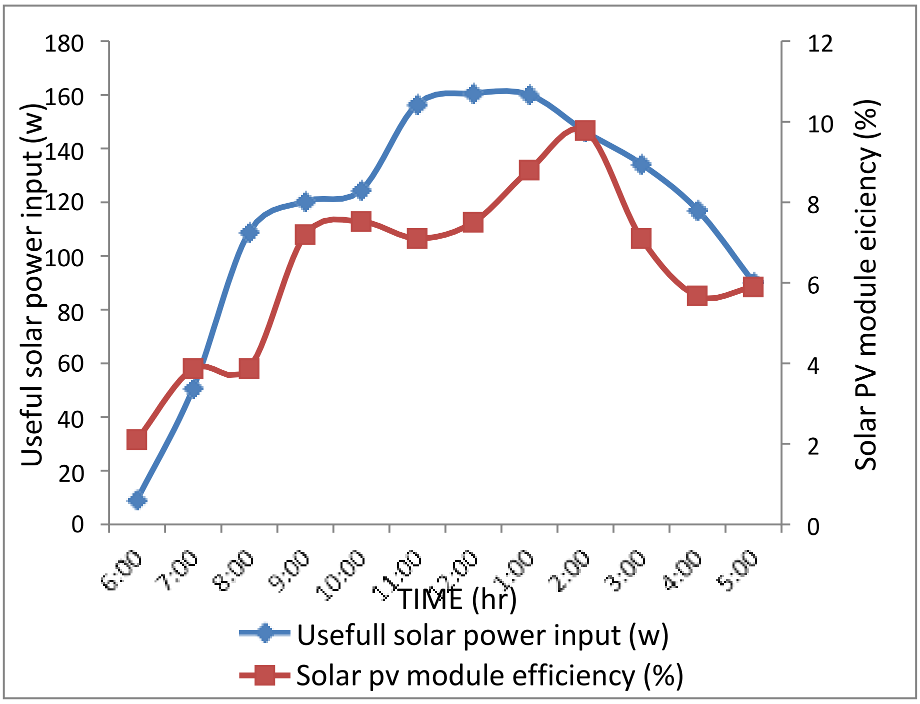

Fig 17: Graph of correlation between the Solar PV module efficiency and useful solarpower input on load condition

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Figure (18 & 19) Presents three-axis graph of correlations between the DC-DC converter output and PV Module output voltages against use solar power input under no-load and on load condition. The useful solar power input at 1:00 pm reached a maximum value of 159.48 W which leads the DC-DC converter and PV module output voltages to increase to their maximum valuesof 28.72 V and 14.26 V under no load condition respectively. Moreover, it has further being observed that at maximum value useful solar power input of 160.53 W,the PV module and the DC-DC converter outputs voltages have increases to a maximum values of 14.15 V and 38.1 V on load condition respectively at 12:00 pm. This indicated that the voltage outputs from the PV Module and the DC-DC converter dully depends on solar useful power input. As a results of this, the graphs followed the same trend under no load andon load condition.

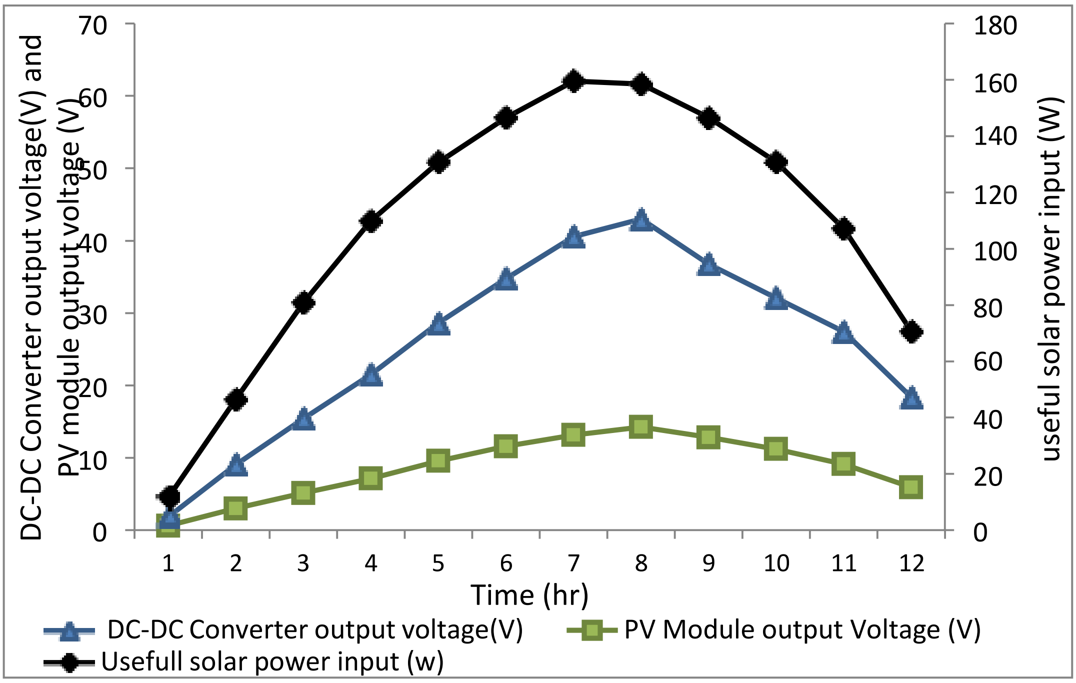

Fig 18: Graphs of correlations between the DC-DC converter output voltage and PVModule outputvoltage against useful solar power input under no load.

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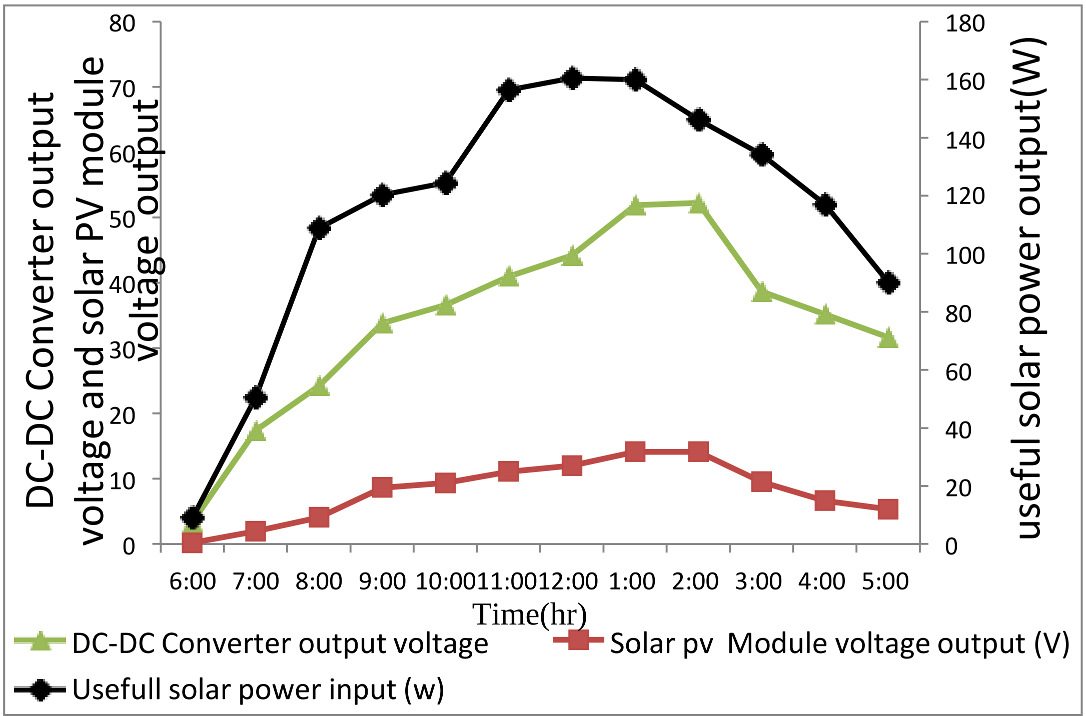

Fig 19: Graphs of correlations between the DC-DC converter output voltage, PV Modulevoltageoutput and useful solar power input on load condition.

4. DISCUSSIONS

By considering the correlation between solar PV power outputs and useful power inputs as presented in Figures 14 and 15 under no load and on load conditions, the result indicated that the PV module with 0.1645 m^2 dimension captured maximum useful power input of 159.48 W and generaed 13.91 W under no load conditions. While, under load condition , the PV module harnessed 160.53 W to generate 14.15 W as shown in Figure 16. These proof that the PV power output has dully depend on the useful power input which inturns depends on the intensity of sun radiation.
Furthermore, The correlation between the useful solar power inputs and solar PV module efficiencies under no load and load conditions presented in Figure 16 and 17 proved the inverse proportionality between the input power and efficiency. When system was under no load condition, the graphs followed the same trend showing that the efficiency dully increaseswith the decrease in the power input. However, the efficiency was found to be inversely proportional to thepower input only if the percentage increase between any two (2) points on the input power is greater than that between the output power.
Moreover, the result presented from Figures 18 and 19 comfirmed the existence of correlation between the DC-DC converter and PV module output voltages with useul power input under no- load and on load conditions. The graphs from both conditions followed the same trends and thus, the DC-DC converter was able to optimized 14.2 V from PV module to 28.72 V which is 50.3 % under no load condition, while under load condition it has been optimized from 14.15 V to 38.1V which 62.8 %. These indicated that the DC-DC converter

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output responded more to the useful power inpu when load is connected. This showed that the converter enhanced 77.17 % of the predicted gain when load was connected.

5. CONCLUSIONS

The 10 V / 60 V DC-DC SEPIC Converter has been designed, constructed and experimentally tested by integrating it with 20 W solar PV module under no load and on load conditions. The sun radiation has imfluence on the useful power input, PV module power output and the efficiency of the solar PV module. The efficiency of the PV module is proportional to the power output but inversely proportional to the power input only if the increase on the input side is greater than that on the output. The DC-DC converter output voltage responded more to the useful power input when load was connected and hence itdully depends on the PV module efficiency. The DC-DC converter as experimentally tested has achieved 88.98 % and 77.17 % onder no load and on load condition of the predicted percentage voltage regulation and voltage gain respectively. The statistical analysis proved that the data obtained were accurate and accepted the model with limited standad mean errorsand minimal mean paired differences. Thereore, the SEPIC DC-DC converter could be a technically and econonics feasible for integration with solar PV system for energy optimization.

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