



A Conventional Double Boost Converter with Voltage Multiplier Cell for Photovoltaic (PV) Applications

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ABSTRACT

A double boost converter integrated with voltage multiplier cell for photovoltaic (PV) application and other renewables that requires DC-DC step-up control is presented in this work. The new topology was constructed using two conventional boost converters incorporated with voltage multiplier cell and it adopts only one active power switch. The merits of the converter are higher voltage transfer ratio can be obtained at the expense of low duty-cycle and voltage stress across the semiconductor devices is reduced to minimum. The operating principle and steady-state analysis of all the active components of the reported converter were analyzed and presented in details. The simulation and theoretical analysis was done using 10 V DC input and 115 V DC output. Laboratory prototype of the proposed circuit was developed and tested with PV panel.

Keywords: DC-DC Converter, Photovoltaic(PV) panel, Voltage transfer ratio, Voltage stress, Duty-cycle

INTRODUCTION

Nowadays, fossil fuel dependency is increasingly becoming low due to the availability of renewable energy resources (Turksoy *et al.*, 2018). Renewables are natural, never-ending and cost free resources (Kaouane *et al.*, 2016) and the most abundants among them is solar power (Zeb *et al.*, 2018). Photovoltaic (PV) system is the most promising solar power generation system which allow direct access to energy without much compromise to the environments (Gopi and Sreejith, 2018). PV panels can be used for grid and off-grid systems (Zeb *et al.*, 2018). Low sunshines Bayat *et al.*, (2019), large physical area are some of the biggest factors that affects the performance of PV panels (Gopi and Sreejith, 2018). There are two stages associated with PV system based electricity generation, DC-DC and DC-AC (Tian *et al.*, 2019). In the former stage, a power converter can be used to step-up a low DC voltage generated from the PV panels to a desired level for DC-load lines or a battery (Bayat *et al.*, 2019). While in the later, a simple inverter is required (Saravanan and Babu, 2017). The major problem associated with PV panels is low voltage generation which is why they are connected in series for a better performances (Kordetoodeshki and Hassanzadeh, 2018). But this connection usually occupies a whole rooftops for off-grid connections or very large physical area and number of PV panels for the construction of solar farm for big industries or island applications. To minimise these environmental threat, a simple DC-DC power converter should be adopted.

DC-DC converter can be placed in between the PV panel and load lines (Tewari and Sreedevi, 2018), it can also serve as an impedance matching unit to the PV panels (Ave, 2018). Different approaches were made in designing both isolated and non-isolated types of DC-DC power converter. But, voltage stress, large duty-cycle, cost, high weight and low voltage transfer ratio are some of the persistent problems (Fernão *et al.*, 2017). The isolated converters requires the use of transformers and only by adjusting the turn's ratio of the transformer, a higher voltage transfer ratio can be achieved. Example of these converters are forward, push-pull and flyback converters among others (Imam *et al.*, 2019). Non-isolated

converters are transformerless (Dileep and Singh, 2017), and their examples includes: classical boost converter, cuk, sepic and zeta (Gopi and Sreejith, 2018; Ahmad *et al.*, 2019)). Sepic converter generates higher voltage transfer ratio at the expense of large duty-cycle and a bit stress across the components (Kanimozhi *et al.*, 2017). Zeta converter shows some promising, but its ability to operate in two different modes (Buck-boost) is the reason why it requires two much components (Bayat *et al.*, 2019).

To minimise the aforementioned problems, different steps were taken by reseachers in designing power converter. An integrated double boost-sepic DC-DC converter for fuel cell and PV applications (Sabzali *et al.* 2014) has a large duty-cycle which caused too much stress within the components and besides, the topology looks too expensive due to much components used but a fixed and low duty-cycle value is adopted in the present study. A multi-port DC-DC converter for hybrid energy system reported by Faraji *et al.* (2019) contains 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 is relatively low also which is not in the present study. Nakpin and Khwan-On (2016) proposed a topology with higher voltage transfer ratio and low duty-cycle using only by employing clamping strategy which add to the much number of components and complexity in terms of stress and positioning of the multiplier cell used when compared with the present study. A quadratic boost combined with voltage multiplier cell was studied by Navamani *et al.* (2016) and the results obtained shows some improvements. But, the voltage transfer ratio is deemed low for such an application compared to the present study. A boost was combined with its inverted type to study a two-phase structure as a battery-powered front-end interface for automotive audio amplifiers in (Faraji *et al.*, 2019), though, the reported topology exhibits low duty-cycle but the voltage transfer ratio was relatively too low and it employs double switches with add to its complexity both in terms of cost and operation compared to the present study. In this paper we used, Fernão *et al.* (2017) a classical boost converter combined with self-lift cuk converter, but the topology there has low voltage transfer

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ratio and a bit high duty-cycle compared to the present study.

In this paper, an integrated non-isolated double boost converter incorporated with voltage multiplier cell using one single switch is proposed for PV and other renewables applications. The advantage of this converter is it requires only one active switch to obtain a higher voltage transfer

ratio with very low duty-cycle. The steady-state analysis of all the active components and operation principle under continue conduction mode (CCM) of the proposed converter are discussed in details. A laboratory prototype was prepared and tested with PV panel in order to validate the simulation analysis of the proposed converter. The results obtained are in good agreements.

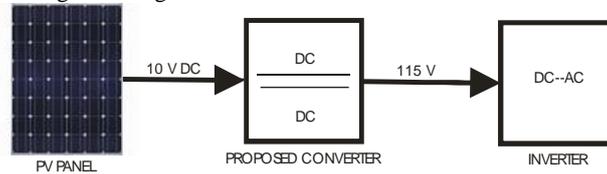


Figure 1: Architectural design of the system.

MATERIALS AND METHODS

Materials

The components used in this study are ideal because they were selected from the datasheets. The components are: 4-Capacitors C_1, C_2, C_3, C_4 , 4-Diodes D_1, D_2, D_3, D_4 , 7807 IC, 2-inductors L_1, L_2 , Dx9 USB Socket, PV panel, TPS 3371 and inductor L_3 as a filter to reduce the ripples within the voltage multiplier cell. All the components were purchased from MICA & SONS electronics Ltd, Kano, and the PV panel was purchased from Chiboy Computer Limited in 70, 70, Emir Yahaya Road, Minanata, Sokoto South, Sokoto State, Nigeria.

Methodology

In this study, two approaches were adopted; simulation and experiment. As it can be seen, The proposed topology consists of two classical boost converter attached with the main power switch which is a modification to the method adopted in Sabzali *et al.* (2014) where the SEPIC used there has now been replaced with voltage multiplier cell which reduces the complexity and add to the voltage transfer ratio of the present study. This approach is similar to the method adopted in Huzaifa *et al.* (2019) but the modification here involves the addition of voltage multiplier cell (which consists capacitors C_1, C_2 , Diodes D_1, D_2 .) which reduces the complexity within the components.

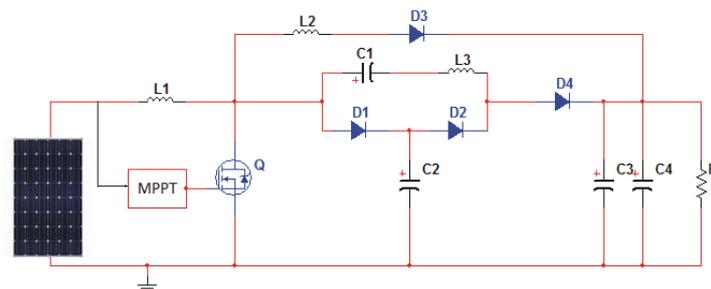


Figure 2a: Proposed Topology with PV panel.

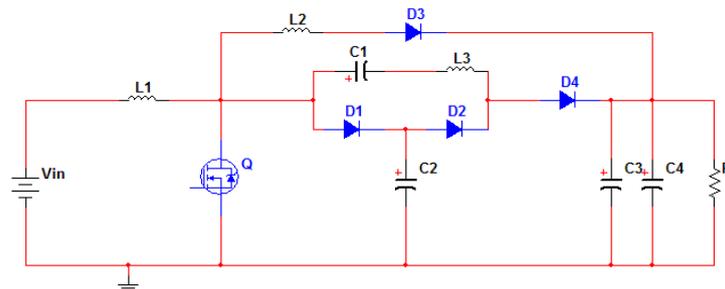


Figure 2b: Proposed Circuit Diagram.

The working principle of the proposed converter is divided into following modes:

Mode 1: When switch Q_1 is turned ON, diode D_3 is reversed bias and diodes D_1, D_2 and D_4 are forward biased. Inductor L_1 stores energy supplied by the PV panel and L_2 stores energy from the switch. Capacitor C_1 will charge and combine its stored energy with the discharged energy

from C_1 and deliver it to C_3 then, to the C_4 . The energy in C_3 will decrease while that of C_4 will increase.

Mode 2: When switch Q_1 is turned off, diodes D_1, D_2 and D_4 are reversed bias and diode D_3 . The energy generated from the PV panel will be stored to inductors L_1, L_2 and capacitors C_1, C_2 . Energy in C_3 will increase and discharge to C_4 . But the energy across C_4 will decrease.

Theoretical Analysis

This section deal with the steady-state analysis of all the active components of the proposed topology in CCM. Both the components were selected from the datasheet thus, they were considered ideal.

Voltage Transfer Ratio

This is the ratio between output voltage and input voltage. The higher the ratio the better the efficiency of the converter. It is as follows:

$$v_{in} = v_{L1} \tag{1}$$

When switch Q is ON-state,

$$v_{C2} = v_Q = v_{L2} \tag{2}$$

Capacitor C₁ will combine the energy stored in C₂ and deliver it to C₃.

That is to say,

$$v_{C3} = v_{L2} = v_{C1} \tag{3}$$

Or,
$$v_{C3} = v_{L2} = 2v_{C2} \tag{4}$$

Therefore,

$$v_{C4} = 2v_{C3} \tag{5}$$

Then, applying the switching signal to the power switch of the converter as in Rashid, (2001) the relationship between the input and output of the converter will take the form;

$$v_{in}dT = (v_o - v_{in})(1 - d)T \tag{6}$$

$$v_{in}dT = (v_o - v_{in})(T - dT) \tag{7}$$

$$v_{in}dT = v_oT - v_o dT - v_{in}T + v_{in}dT \tag{8}$$

$$v_{in}dT - v_{in}dT = v_oT - v_o dT - v_{in}T \tag{9}$$

Equation (9) reduces to:

$$\frac{v_o}{v_{in}} = \frac{1}{(1-d)} \tag{10}$$

(m represent the number of multiplier cell used, and it can be seen clearly from Fig. 2b that; m = 1), Therefore, equation (10) will take the form:

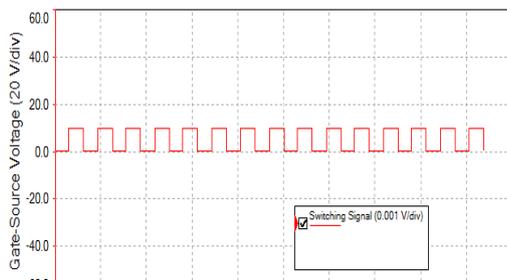


Figure 3: Switching signal

$$\frac{v_o}{v_{in}} = \frac{2}{(1-d)} = 11.11 \tag{11}$$

Equation (11) means that, voltage transfer ratio can be expressed in terms of duty-cycle.

Duty-cycle

The duty-cycle is the measure of ON-time to OFF-time in pulse signal used in making the switch (Q) and it is always less than or equal to 1 (unity). The voltage transfer ratio value of any converter depends on its duty-cycle. The duty-cycle value of the proposed converter can be obtained from equation (11) above as:

$$2v_{in} = v_o - v_o d \tag{12}$$

$$d = \frac{v_o - 2v_{in}}{v_o} = 0.82 \tag{13}$$

Voltage Stress

Voltage stress is a stress that resulted when a voltage pass through a device (active). Half of the output voltage is expected to cross each components except the output components (D₃ & D₄). Anything less or much of that can be considered as a stress

Hence, from equation (10) above.

$$v_Q = \frac{1}{(1-d)} v_{in} = 55.60 \tag{15}$$

RESULTS

All the components used in this work were ideal selected based on their operational capacity from datasheet. Their individual values are tabulated in Table 1. After the realization of the new circuit in Fig. 2b, multism version 13.0 was used to run the simulation. The parameters observed during the simulation, and their values are recorded in Table 2. The simulation analysis are depicted in Figures 3- 9. Digital multimeters were used to view the experimental output and the values are shown in Table 3. Comparisons with previous studies are presented in Table 4.

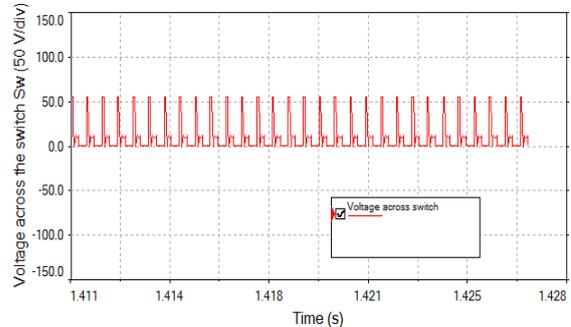


Figure 4: Voltage across the switch (Sw).

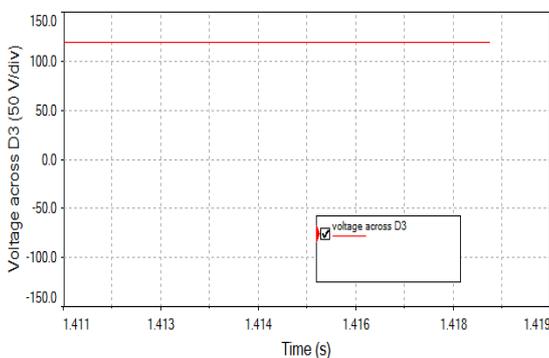


Figure 5: Voltage across diode D₃.

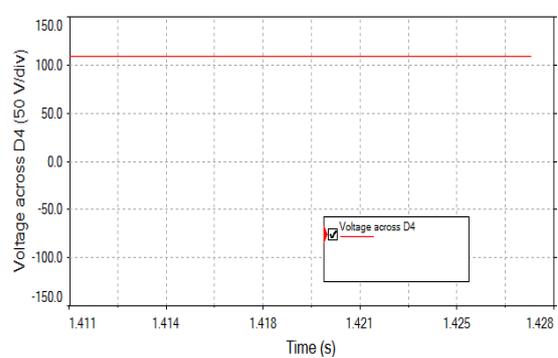


Figure 6: Voltage across diode D₄

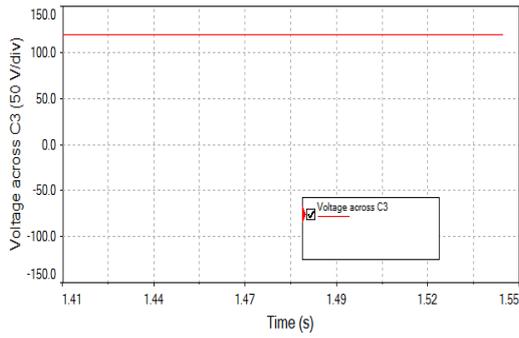


Figure 7: Voltage across C3

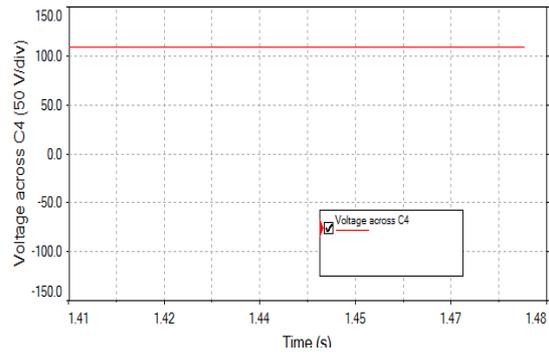


Figure 8: Voltage across C4

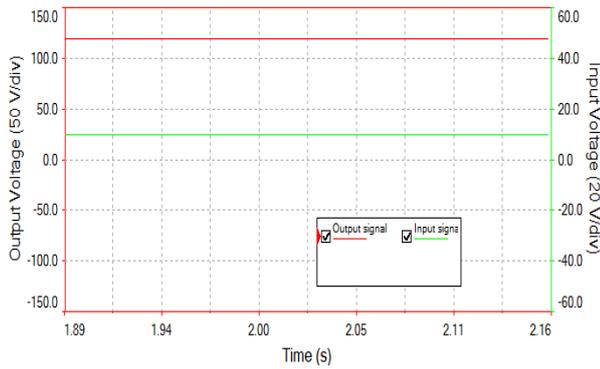


Figure 9: Input and output signal obtained from the circuit



Figure 10: Experimental set-up of the DC-DC converter with PV panel.

Table 1: Components used in designing the proposed converter selected from data-sheet.

Parameters	Value
$L_1 = L_2$	250 μ H
$C_1 = C_2$	22 μ F
$D_1 = D_2 = D_3 = D_0$	MUR420
$C_3 = C_4$	220 μ F
Power switch (Sw)	IRFZ48N
Filter inductor	10 μ H

Table 2: List of parameters and their values measured from simulation

PARAMETER	VALUES
Input DC voltage	10 V
Output DC voltage	115 V
Switching frequency	3 KHz
Duty-cycle	0.82
Voltage transfer ratio	11.11
Voltage stress	55.60 V

Table 3: List of parameters and their values measured from experiment

PARAMETER	VALUES
Input DC voltage	10 V
Output DC voltage	110 V
Switching frequency	3 KHz
Duty-cycle	0.81
Voltage transfer ratio	11.0
Voltage stress	52.6 V

Table 4: Comparison between present study and other integration methods in literature

DC-DC converters	Methods	Voltage transfer ratio
(Sabzali <i>et al.</i> , 2014)	Double boost integrated with SEPIC	10
(Fernão <i>et al.</i> , 2017)	Double boost converters (HYBRID)	6.6
(Pires <i>et al.</i> , 2016)	Boost integrated with Cuk converter	5.6
(Navamani <i>et al.</i> , 2016)	Quadratic boost integrated with voltage multiplier cell	8
(Mitra and Rout., 2017)	Extended boost converter	10
Proposed work	Double boost integrated with voltage multiplier cell	11.11

DISCUSSION

Simulation

The results obtained from simulation are depicted in figures 3,4,5,6,7,8 and 9 and table 2 represents the value of individual parameter obtained. Fig. 3 represents the switching signal obtained and that means a duty-cycle is exactly equals to the evaluated value in equation (13). This value is below the reported one in Fernão *et al.* (2017); Tewari and Sreedevi, (2018) ; Saravanan and Babu (2017)). Voltages across each semiconductor components are presented in figures 4,5,6,7 and 8. The voltage across the power switch is expected to be equals to average value of the DC output voltage. And it can be seen from the figure 4 that the signal obtained is half the output DC value and this conform with the value in equation (15). this means the stress has now been reduced to minimum. D₃ and D₄ were considered as an output diodes, so there values are equals to the DC output voltage. Output and input signals are in figure 9 which represent the voltage transfer ratio and the results conform with the value in equation (11) which is higher than that of Fernão *et al.* (2017) ; Tewari and Sreedevi,(2018); Saravanan and Babu, (2017).

Experiment

Experimental analysis was carried out to validate the theoretical and simulation analysis. The components contained in figure (2) was arranged on TPS trainer (3371) and USB Dx9 was joined between the trainer's port and USB socket of the computer then the values in table (3) was recorded. It can be seen from the table (3) that, voltage transfer ratio value is higher than the ones in (Saravanan and Babu, (2017) ; Fernão *et al.* (2017) ; Sabzali *et al.* (2014)).

CONCLUSION

This work has reported a double boost converter integrated with voltage multiplier cell for PV and other renewables application. The reported topology adopts a single active power switch for switching control. The new thing about the reported topology is that, the two boosters in the circuit were placed in a position to receive energy from the power switch independently which increases the voltage transfer ratio and reduces the stress across the semiconductor components at the expense of low duty-cycle. The new topology is therefore deemed suitable for PV panels and other renewables application.

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