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Full Length Research Article

A Modified Boost-Boost High Gain DC-DC Converter for Photovoltaic (PV) Based Off-Grid Applications

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ABSTRACT

This study presents a single switch non-isolated DC-DC converter good for photovoltaic (PV) applications. The proposed topology was constructed using two classical DC-DC boost converters by arranging them in cascade for providing high voltage gain, low duty-cycle, less stress across the semiconductor devices, less size, and low cost. The operating principle and steady-state analysis of an individual component of the proposed topology in continuous conduction mode (CCM) are discussed and the results obtained improved the ones in literatures. The prototype of 120 V DC output voltage with 9 V DC input voltage is implemented and the result obtained validate the simulated result of the proposed converter.

Keywords: DC-DC converter, Photovoltaic (PV), Single switch, High gain, Duty-cycle.

INTRODUCTION

Due to some environmental issues such as CO_2 emissions and greenhouse effects, researchers have now turn their attentions to renewable energy as a source of electricity generation (Saravanan and Babu, 2017). Renewable energy is natural, infinite source of electric power (Saravanan and Babu, 2017;Kumar *et al*., 2017). There are many forms of renewable energy, but altogether, solar and wind power are the most commonly used due to their availability (Dileep and Singh, 2017; Nakpin and Khwan-On, 2016). Low temperature, luminosity and area for installation are some of the factors that affects the performance of solar power system (Revathi and Prabhakar, 2016; Pires *et al*., 2016). Photovoltaic (PV) system is the common solar power generation adopted today, simply due to its longer lifespan, easy installation, less pollution, zero noise and requires less maintenance (Gopi and Sreejith, 2018).

PV technology for electricity generation can either be for grid or off-grid application (Boukenoui *et al*., 2017). Depending on the purpose it is meant for, they always end up generating less than the demand power, and the quest for higher power generation is the reason why PV panels are connected in series-parallel arrangement (Guangqun and Xuezhi, 2012). And this arrangement is the reason why it requires a very large number of PV panels and wide area for installation (Saravanan and Babu, 2017). Normally, PV panels generates voltage ranging from 12 V–75 V which cannot be utilize for grid or off-grid applications (Fathabadi, 2016). A power converter can be used to step-up the efficiency of the power generated from the PV panels, and it can also be used to charge batteries.

There are two types of power converter, isolated and Non-isolated power converters (Engin and Çak, 2016). The isolated power converters require the use of transformers but the disadvantages are voltage gain is highly dependent on the turn ratio, large duty-cycle and leakage inductance of the transformer which are problems not only on practical purposes but also in industrial implementations (Fernão *et al*., 2017). Therefore, scientist are now exploring many non-isolated converters which are believed to be more user friendly, cheaper, simple and their voltage gain can simply be achieved at the expense of duty-cycle only since they are transformer less.

From the literature, many non-isolated topologies have been proposed. Nakpin and Khwan-On

(2016) proposed a DC-DC converter for PV applications. But the reported topology was found to have many components which make the cost of the topology too high. A quadratic converter with voltage multiplier reported by Navamani *et al*. (2016) exhibits a high voltage gain and low duty-cycle at the expense of too much components. A switched inductor and switched capacitor integrated with boost capacitor topology was proposed in Tewari and Sreedevi (2018), though, the reported topology shows some promising in voltage gain. However, high duty-cycle and too much components (cost) are what makes the proposed topology not suitable. Boost with self-lift cuk converter reported in Fernão *et al.* (2017) has many components, high duty-cycle and low voltage gain. The comparison shows that, it is hard to design a cheap topology with low duty-cycle and higher gain. A converter has to suffer from at least one of such issues (Navamani *et al*., 2016).

This work presents a single switch transformer-less DC-DC converter with low duty-cycle, less number of components and higher voltage gain capability. The proposed converter is a product of two classical boost converters arranged together in cascade. The topology used only one active switch which is placed to receive the output of the first stage and fed it to the second stage of the converter as shown in Figure 2. This position of the switch shows how two converters work with a single switch different from any circuits in the literature. Besides, the 555-timer used to generate switching signal from the source voltage to the gate of the switch enhanced the output voltage than using other signal generator in cascade arrangement. And this in turns, can improve the voltage gain of converter in same arrangement (cascade). Simulation/experimental analysis of the proposed converter are presented and discussed in details. To verify the performance of the proposed converter, a laboratory set-up was prepared and tested.

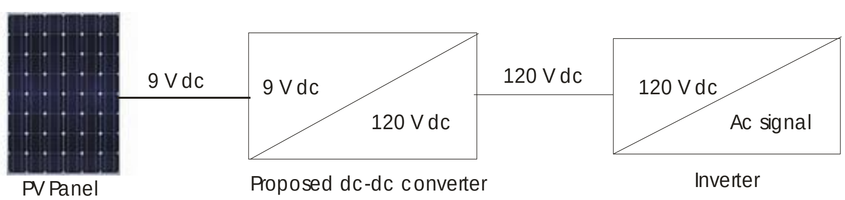

Figure 1: Graphical representation of the system.

MATERIALS AND METHODS

Materials

The proposed topology comprises of one input inductor L_1, diode D_1, and capacitor C_1 in the first stage, while the second stage was configured by one active power switch, input inductor L_2, output diode D_2, output capacitor C_2, and 555-timer. All the components were purchased from MICA electronics Ltd, Kano. Nigeria.

Methodology

Experimental Design

Two broad approaches were adopted for this study: simulations and experiment. The simulation was done using multism version 11.0.1. Experimental validation was carried out using TPS version (3371) at the electronics Laboratory of the Bayero University, Kano, Nigeria. The design circuit of Sabzali *et* al. (2014) was adopted with modification. The modification involved reduction of SEPIC converter and arranging the two boost converters in cascade. The topology of the proposed circuit is shown in Figure 2. It was built by combining two classical boost converters together following the method

Nakpin and Khwan-On (2016) by replacing the dc-link capacitor with second boost converter, thereby rendering all the remaining components less useful. In order to achieve high voltage gain with minimum number of components and low duty-cycle, the output of first stage of the presented converter was fed to the second stage converter (i.e. cascade arrangement). And the power switch was placed there to switch the output of the first boost converter and then fed it to the second boost converter.

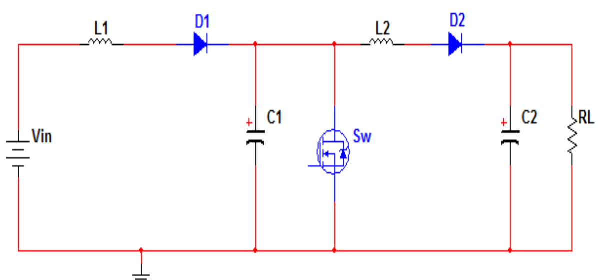

Figure 2: The proposed high step-up dc-dc converter topology.

The operation of the converter during (CCM) can be divided into 3 stages viz:

Stage 1: When switch S_w and diode D_o are turned ON. Diode D_1 is OFF. The V_{in} energy stored in L_1 was delivered to C_1 and L_2. Then, L_2 delivered energy to C_o through D_o. The output voltage dropped a bit and the current in the L_1&L_2 increased linearly.

Stage 2: When S_w and D_1 are turned ON. And D_O is turned OFF. The V_{in} energy stored in L_1 was delivered to C_1 and L_2 through D_1. Then, L_2 delivered energy to C_o. The output voltage dropped a bit and the current in the L_1 increased linearly.

Stage 3: When S_w is turned OFF. The energy V_{in} stored in L_1 was delivered to C_1 and L_2 through D_1. Inductor L_2 delivered energy to C_O through D_O.

CIRCUIT ANALYSIS

From the Figure 2, the theoretical analysis can be deduced from the circuit as:

$$V_{in} = V_{L1} = V_{C1} \qquad (1)$$

Where: V_{in} represent the input voltage, V_{L1} inductor voltage and V_{C1} voltage of the capacitor C_1.

That is to say, there is no switching effect on the first stage of the proposed converter.

But, for the second stage;

$$V_{C1} = V_{SW} \qquad (2)$$

But, from (1),

$$V_{C1} = V_{in} \qquad (3)$$

When the switching signal of Figure 3 is applied to the power switch, the input/output voltage relationship of Figure 2 can be represented as:

$$V_{in}\partial T = (V_{C2} - V_{in})(1-\partial)T \qquad (4)$$

Where, ∂T is the duty-cycle and time when the switching signal is high. And, $(1-\partial)T$ is when the switching signal is low.

$$V_{in}\partial T = (V_{C2} - V_{in})(T - \partial T) \qquad (5)$$

$$V_{in}\partial T = V_{C2}T - V_{C2}\partial T - V_{in}T + V_{in}\partial T \qquad (6)$$

Equation (6) reduces to;

$$V_{C2}T(1-\partial) = V_{in}T \qquad (7)$$

But, $V_{C2} = V_O$

Therefore, equation (7) becomes;

$$V_O = V_{in}\frac{1}{(1-\partial)} \qquad (8)$$

Or

$$\frac{V_O}{V_{in}} = \frac{1}{(1-\partial)} \qquad (9)$$

For the two boost converters, equation (9) becomes;

$$M = \frac{V_O}{V_{in}} = \frac{1}{(1-\partial)^2} \qquad (10)$$

Equation (9) can further be expressed as:

$$V_O - V_O\partial = V_{in} \qquad (11)$$

Solving equation (10) for ∂ yield:

$$\partial = \frac{V_O - V_{in}}{V_O} \qquad (12)$$

RESULTS

The simulation analyses of the new converter are depicted in Figures 4 to 10. The experiment was done to validate the simulations at such, the corresponding experimental parameters can be evaluated from the theoretical equations derived from Figure 2. The lists of the parameters used which include their respected values of the proposed converter are analyzed and shortlisted in details in Tables 3.0 and 4.0.

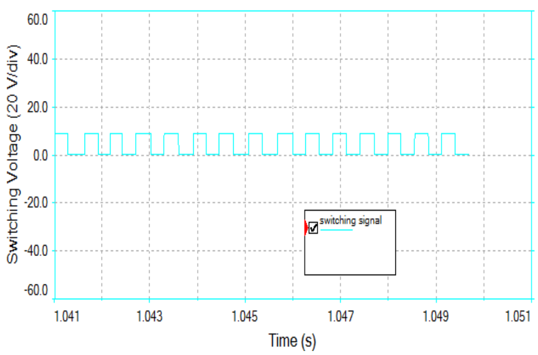

Figure 3: Switching Signal.

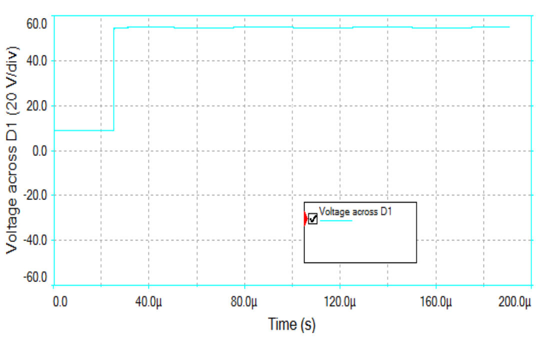

Figure 4: Voltage across D_1

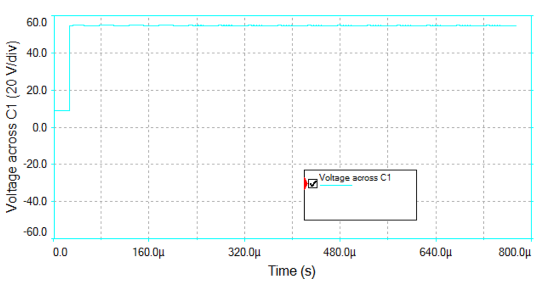

Figure 5: Voltage across C_1

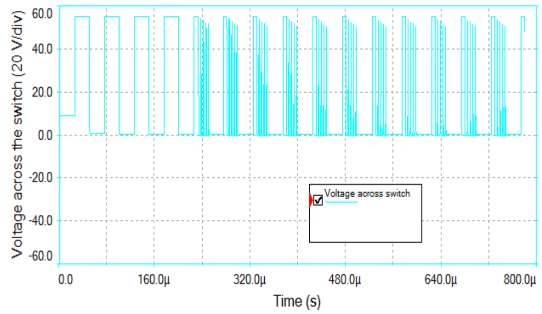

Figure 6: Voltage across the active switch.

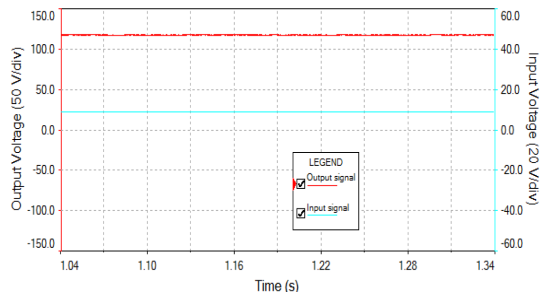

Figure 7: Input and Output signal.

Figure 8: Prototype of the proposed high step-up dc-dc converter designed on TPS 3371.

Table 1: List of parameters and their values selected from Datasheet.

PARAMETER	VALUES
$C_1 = C_2$	0.2 µF
$L_1 = L_2$	250 µH
$D_1 = D_2$	MUR410
Power switch	IRFZ48N

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

PARAMETER	VALUES
Input DC voltage	9 V
Output DC voltage	120 V
Switching frequency	3 KHz
Duty-cycle	0.5
Voltage gain	13.33

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

PARAMETER	VALUES
Input DC voltage	**9 V**
Output DC voltage	110 V
Switching-frequency	3 KHz
Duty-cycle	0.84
Voltage gain	12.23

DISCUSSION

Simulation:

Figure 2 was realized from simulation using multism version 11.0.1. Duty-cycle was set to$(\delta = 0.5)$ from the 555-timer used for gate-source voltage V_{GS} value. And it is clear that the value used is less compared to the values of other converters found in (Sabzali *et al*., 2014; Tewari and Sreedevi, 2018) and (Pires *et al*., 2016). The output signal of 120 V DC voltage from 9 V DC input voltage was confirmed and depicted in Figure 7. From the same (Figure 7), it means that, voltage gain of the proposed converter is equals to $(M = 13.33)$ which is bigger than the ones in Pires *et al*. (2016); Tewari and Sreedevi (2018) and Sabzali *et al*. (2014). Half of the output voltage is expected to pass across each components and it can be observed from Figures 4, 5 and 6 that $\left(V_{comp.} = 58\ V\right)$ was obtained, that means the stress is reduced to minimum. In terms of cost and size, it can be seen from Figure 2 that, less number of components $(8 - components)$were used to realized the reported topology which is smaller and cheaper than the reported topologies in Sabzali *et al*. (2014); Tewari and Sreedevi (2018) and Pires *et al*. (2016).

Experiment/theoretical:

The components in Figure 2 were placed on (PC BOARD) of trainer (TPS 3371 model) as shown in Figure 5. Then USB-D9 was connected in between the trainer's port and computer's socket and signal depicted in fig. 7 was obtained.110 V DC output voltage was obtained from 9 V DC input. 555-timer was used to tap out V_{GS} from the source to the switch which is depicted in figure 3 above. The best value of the duty-cycle $(\delta = 0.5)$was used. But, according to the design equation in (12); the calculated duty-cycle is $(\partial = 0.84)$. The voltage gain was calculated using equation (10) and (M=12.23) was realized, which is better than the value presented in Saravanan and Babu, (2017); Ching-ming et al., (2017); (Sabzali et al., 2014).

CONCLUSION

This work presented a higher step-up DC-DC converter with high voltage gain, less number of components, low size at the expense of low duty-cycle which can be useful if implemented and attached with individual PV panel for electricity generation. The result obtained shows that 555-timer can be a better substitute to other operational amplifiers in providing the switching signal. 120 V dc output voltage with 9 V input was tested for performance validation. Simulation and experimental results were tabulated, but a slide difference was observed from experimental analysis and it was due to the fixed value of duty-cycle used.

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