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SIMULATION AND EVALUATION OF SWITCHED INDUCTOR BOOST DC-DC CONVERTER FOR PV APPLICATION

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ABSTRACT

This paper presents the simulation and evaluation of Switched Inductor Boost Converter for PV Application under MATLAB/Simulink software. This paper introduces a boost converter with high dc gain to increase the low output voltage of photovoltaic (PV) module. The inductor of the conventional boost converter is replaced with the switched inductor branch. As a result, the conversion gain ratio of the boost converter can be increased. Simulation results and analyses are provided to evaluate the operation of the converter.

Keywords: switched inductor, boost converter, photovoltaic, matlab,simulink.

1. INTRODUCTION

Photovoltaic (PV) is considered as a very important source of renewable energy. Photovoltaic have several advantages such as clean, pollution-free, safe, quiet, low maintenance costs, low operating costs, and has long life time [1]-[4]. Their sources of energy, which is derived from solar energy, are also widely available and it is free.

A common appropriate PV power plant system is shown in Figure 1. PV power plant system consists of Solar PV Panel, Boost DC-DC Converter, energy storage element, and dc-ac inverter. In this system, the high power dc-dc converter is required to boost the output voltage of PV module to the high voltage DC Bus requirement.

The low output voltage of the PV module is one of the challenges in case of grid connection or high voltage dc applications. In these applications, some of PV modules should be connected in series to meet the required level of voltage. However, when more PV modules connected in series, partial shading condition will be affected a serious problem. It causes a big reduction in PV output power if one or more PV modules are under partial shaded [4]-[6]. The solution for partial shading problems are used the ac modules. But the ac module need high voltage gain conversion ratio because of the low voltage of the PV modules [5]-[6].

The boost DC-DC converters are widely used in industrial application. Theoretically, a boost dc–dc converter can achieve a high step-up voltage gain with an extremely high duty ratio near to 100% [6]-11]. However, in practice, the step-up voltage gain is limited due to the effect of power switches, rectifier diodes, the equivalent series resistance (ESR) of inductors and capacitors, and the saturation effects of the inductors and capacitors [6]-[11].

The conversion efficiency and high voltage gain are not easy to achieve with conventional boost converter due to parasitic component [6]. In order to obtain high output voltage, the conventional boost converter should

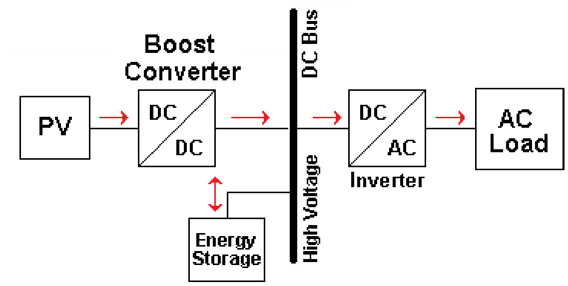

Figure-1. PV power plant system.

operate at extreme duty cycle. This condition limits the switching frequency and converter size, and also increases the electromagnetic interference (EMI) levels [7]. Many research papers are being proposed several compensation topologies for overcoming these challenges and improving quality.

Many topologies have been presented to provide a high step-up voltage gain [6]–[12]. The coupled inductor techniques provide solutions to achieve a high voltage gain, a low voltage stress on the active switch, and a high efficiency without the penalty of high duty ratio.

In this paper, a simulation and evaluation of Switched Inductor Boost DC-DC Converter is executed under MATLAB Simulink software. The performance of Switched Inductor Boost DC-DC Converter was tested by considering the effect of duty cycle variation.

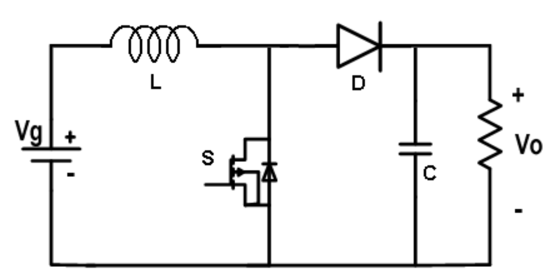

Figure-2. Conventional boost DC-DC converter (CBC).

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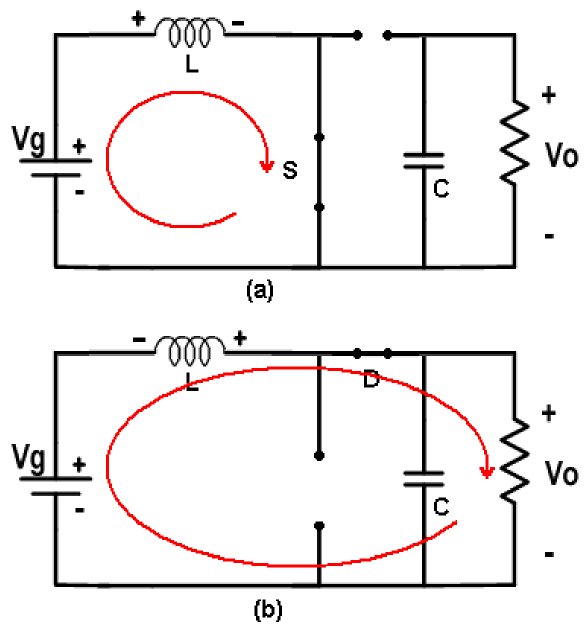

Figure-3. Operation mode of CBC. (a). Mode 1 (b). Mode 2.

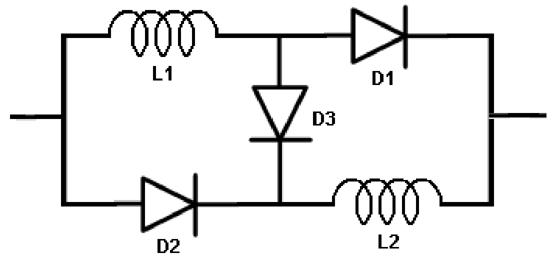

Figure-4. Switched inductor branch.

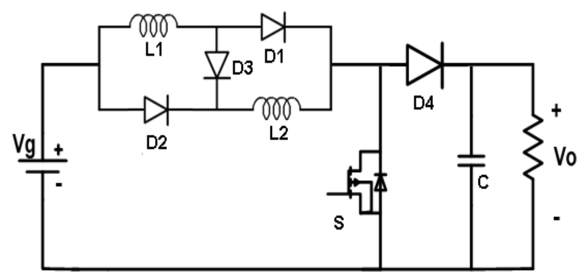

Figure-5. Switched inductor boost DC-DC converter (SIBC).

2. BOOST DC-DC CONVERTER

A. Conventional boost DC-DC converter

The Boost DC-DC Converter is a DC to DC power converter with an output voltage greater than its input voltage. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. The circuit diagram of the conventional boost dc-dc converter (CBC) is depicted in Figure-2.

In a conventional boost converter, the output voltage is always higher than the input voltage. The switch operations of the converter can be explained as follows:

(a) When the switch is closed, current flow from voltage source through the inductor in clockwise direction as shown in Figure-3(a). The inductor stores energy by generating a magnetic field. Polarity of the left side of the inductor is positive.

(b) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed, and left side of inductor will be negative as shown in figure 3.b. As a result, voltage source will be in series with the inductor causing a higher voltage to charge the capacitor through the diode.

Based on the steady state analysis, the dc output voltage of the conventional boost dc-dc converter can be expressed as (1), where the duty cycle, D, is defined as the time relationship of the switch is conduct relative to the total switching period.

$$V_O = \frac{1}{1-D} \cdot V_{in} \tag{1}$$

From (1) at steady state it can be verified that the gain ratio between output and input voltage becomes:

$$Gain = \frac{V_O}{V_{in}} = \frac{1}{1-D} \tag{2}$$

B. SWITCHED INDUCTOR BOOST DCD CONVERTER

Figure-4 shows the switched inductor branch which has been introduced in [12]. It consists of two parts of inductors and three diodes. By replacing the inductor of the conventional dc-dc converter with the switched inductor branch, the result circuit is called switched inductor dc-dc boost converter (SIBC). Figure-5 shows the circuit diagram of the switched inductor boost dc-dc converter.

In a switched inductor boost converter, the switch operations of the converter can be explained as follows:

(a) When the switch is closed, current flows from voltage source through both of the inductors in parallel connection as shown in Figure-6.a. Both of inductors store some energy by generating a magnetic field. Polarity of the left side of the inductor is positive [7],[12].

(b) When the switch is opened, current will be reduced as the impedance is higher. The current flows from voltage source through both of the inductors in series connection as shown in Figure-6(b).

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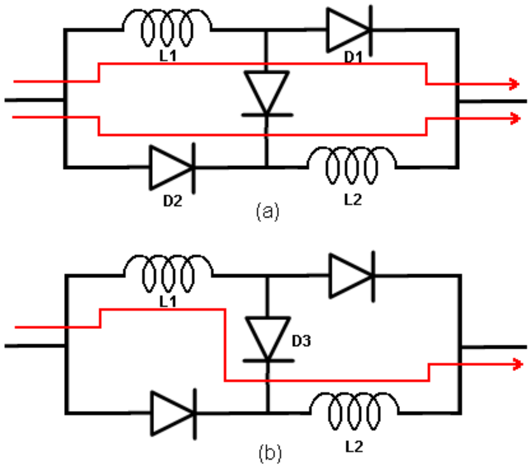

Figure-6. Current flow in switched inductor branch. (a). Mode 1 (b). Mode 2.

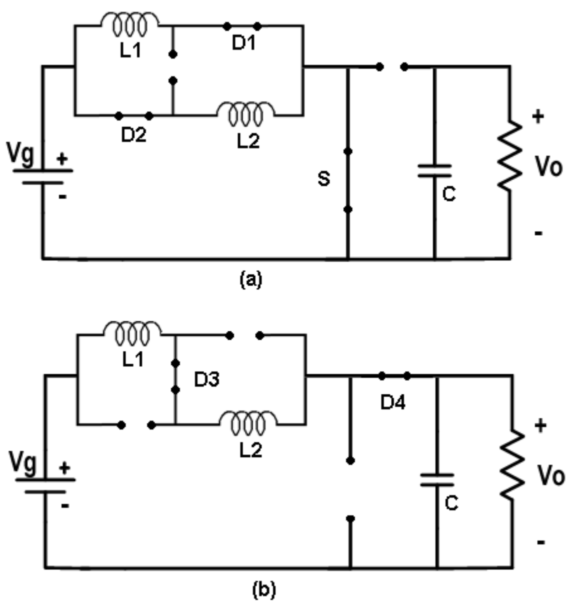

Figure-7. Operation mode of SIBC. (a). Mode 1 (b). Mode 2.

The magnetic field previously created will be destroyed to maintain the current towards the load. Thus the polarity will be reversed, and left side of inductor will be negative. As a result, voltage source will be in series with both of inductors causing a higher voltage to charge the capacitor through the diode [7], [12].

Figure-7 shows the operation modes of the converter. The switched inductor boost converter has two modes of operations. Mode 1 occurs when switch S is ON, this causes diodes D1 and D2 to be ON and diodes D3 and D4 to be OFF. Both of inductors are charging in parallel. Figure-7 (a) shows the converter circuit of mode 1. Mode 2 occur when switch S is OFF, this causes diodes D1 and D2 to be OFF and diodes D3 and D4 are ON. Both of inductors discharge in series. Figure-7 (b) shows the converter circuit of mode 2.

Based on the steady state analysis, the dc output voltage of the switched inductor boost dc-dc converter can be calculated as follows:

During switch on period,inductor voltages are:

$$V_{L1} = V_{in} \tag{3}$$

$$V_2 = V_{in} \tag{4}$$

$$V_{L1} + V_{L2} = 2.V_{in} \tag{5}$$

During switchoff period,

$$V_{L1} + V_{L2} = V_O - V_{in} \tag{6}$$

The average DC voltage in the inductor L1 and L2 during one switching period is equal to zero and can be expressed as (7).

$$V_{L1} + V_{L2} = D.(2.V_{in}) + (1-D).(V_O - V_{in}) = 0 \tag{7}$$

From (7), it can be verified that the output voltage of converter at steady state can be written as:

$$V_O = \left(\frac{1+D}{1-D}\right) V_{in} \tag{8}$$

Hence, at steady state condition, the gain ratio between output and input voltage becomes:

$$Gain = \frac{V_O}{V_{in}} = \frac{1+D}{1-D} \tag{9}$$

By comparing (2) and (9), the gain of the switched inductor boost dc-dc converter is higher than conventional boost dc-dc converter by a factor of (1+D). Theoretically, the gain of the switched inductor boost converter and conventional boost dc-dc converter can be plot as a function of duty cycle as shown in Figure-8.

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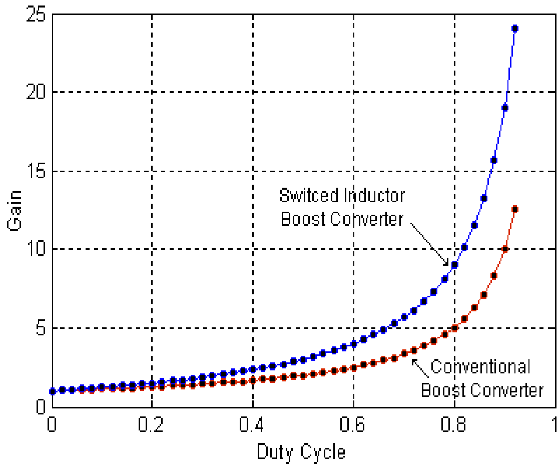

Figure-8. Gain of converter vs duty cycle.

3. MODELING AND SIMULATION

In order to evaluate the performance of the converter, the model of the switched inductor and conventional boost converter circuit were implemented using MATLAB Simulink model.

Figure-9 shows the model of the switched inductor boost converter circuit. The contents of inductor branch subsystem in Figure-9 are shown in Figure-10. Circuit parameters of the converters are listed in Table-1.

Testing was conducted by changing the duty cycle value of the Conventional Boost Converter and the Switched Inductor Boost Converter to investigate the effect of changing the duty cycle to the output voltage of converter. The output voltage of both converters will be compared at the same duty cycle value. The input voltage Vin is made constant.

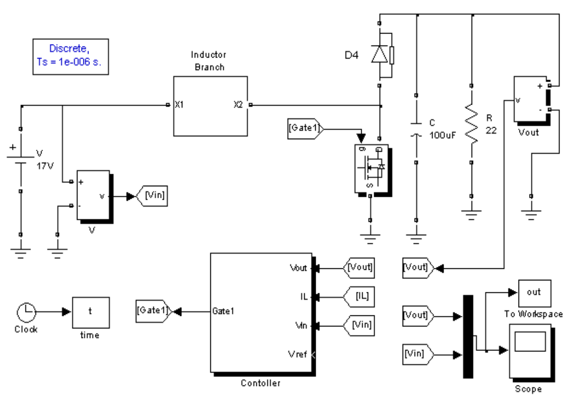

Figure-9. Model of switched inductor boost dc-dc converter.

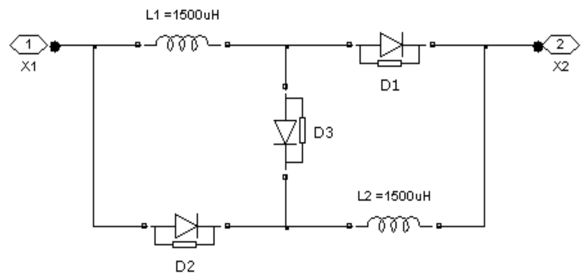

Figure-10. Inductor branch subsystem.

Table-1. Circuit parameters of the converters.

Parameter	Value
Vin	17V
L1	1500uH
L2	1500uH
C	100 µF
F	20 kHz
Load	22 ohm

4. RESULT AND ANALYSIS

The performance of Conventional Boost Converter and the Switched Inductor Boost Converter were simulated in MATLAB Simulink software. In this test, input voltage Vin=17V is taken to represent the PV output voltage at the maximum power condition. The purpose of this test is to compare the output voltage of both converters at the specific duty cycle value.

A. Output voltage of converter under duty cycle variation

Data collection was performed for five different duty cycle values. Testing was conducted by varying the duty cycle value of 0.5, 0.6, 0.7, 0.8 and 0.85. It is aimed to see the effect of changing the duty cycle to the output voltage of both converter.

The output voltage of conventional boost dc-dc converter for each duty cycle values are shown in Figure-11. While output voltage of switched inductor boost dc-dc converter for each duty cycle values are shown in Figure-12.

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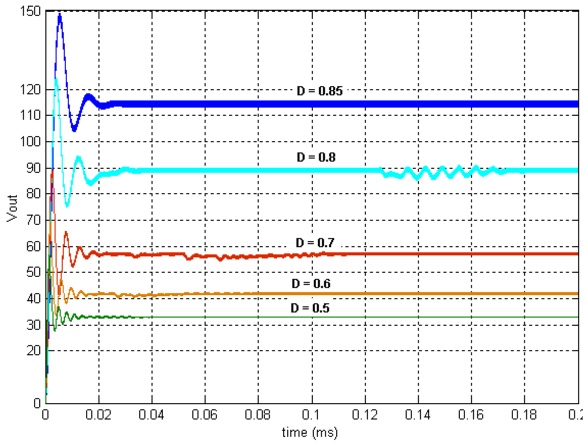

Figure-11. Output voltage of conventional boost converter under duty cycle variation.

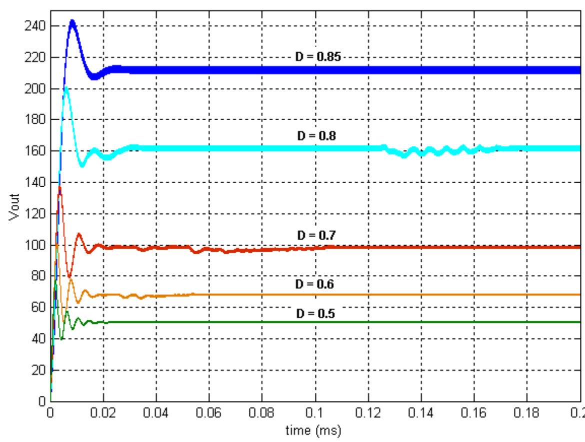

Figure-12. Output voltage of switched inductor boost converter under duty cycle variation.

B. Steady state output voltage comparison

Here, the steady state output voltage of switched inductor boost dc-dc converter was compared with conventional boost dc-dc converter. Testing was conducted on five different duty cycle values i.e. 0.5, 0.6, 0.7, 0.8 and 0.85. It is aimed to see the gain comparison between both converter in the specific value of duty cycle.

The steady state output voltage of switched inductor boost dc-dc converter and conventional boost dc-dc converter for each duty cycle values are shown in figure 13 to 17.

Figure-13 shows output voltage of switched inductor boost dc-dc converter and conventional boost dc-dc converter at D = 0.5. With input voltage of 17V, the switched inductor boost dc-dc converter can produce output voltage of 51V, while conventional boost dc-dc converter only produces output voltage of 33V.

Figure-14 shows output voltage of both converter at D = 0.6. The switched inductor boost dc-dc converter produce output voltage of 68V, while conventional boost dc-dc converter only produces output voltage of 42V.

Output voltage of switched inductor boost dc-dc converter and conventional boost dc-dc converter at D = 0.7 are shown in Figure-15. The switched inductor boost dc-dc converter can produce output voltage of 99V, while conventional boost dc-dc converter only produces output voltage of 57V.

At D = 0.8, output voltage of switched inductor boost dc-dc converter and conventional boost dc-dc converter are shown in Figure-16. With input voltage of 17V, the switched inductor boost dc-dc converter can produce output voltage of 161V, while conventional boost dc-dc converter only produces output voltage of 88V.

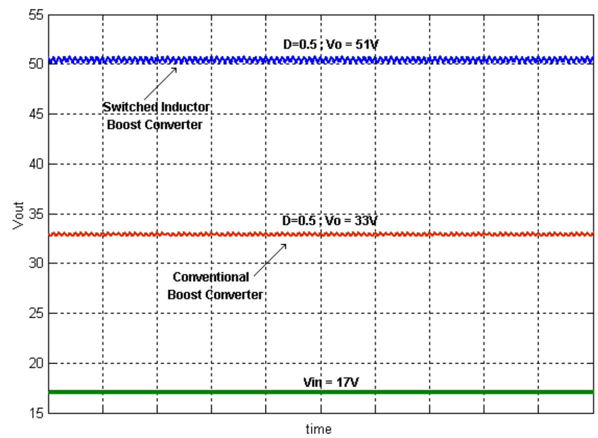

Figure-13. Output voltage of converters at D=0.5 (Vin = 17V).

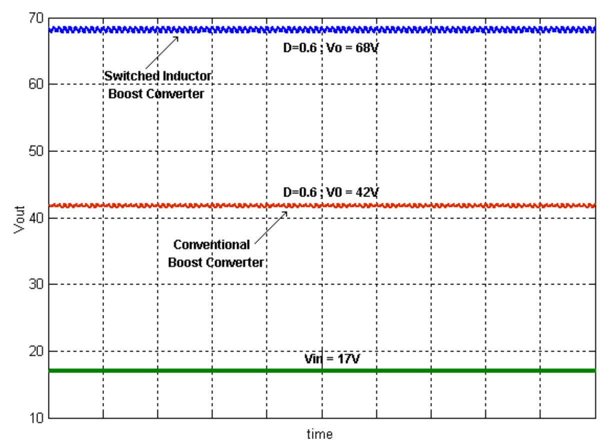

Figure-14. Output voltage of converters at D=0.6 (Vin = 17V).

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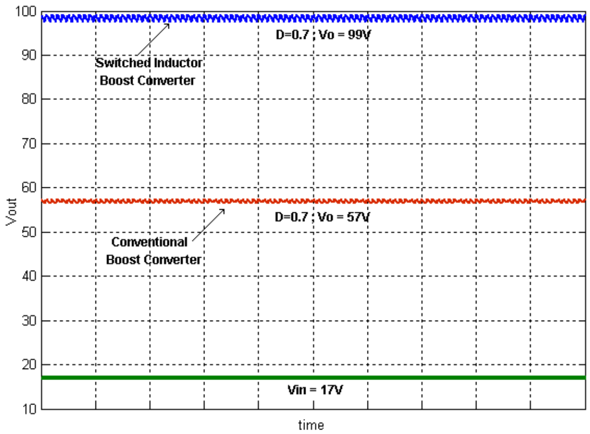

Figure-15. Output voltage of converters at D=0.7 (Vin = 17V).

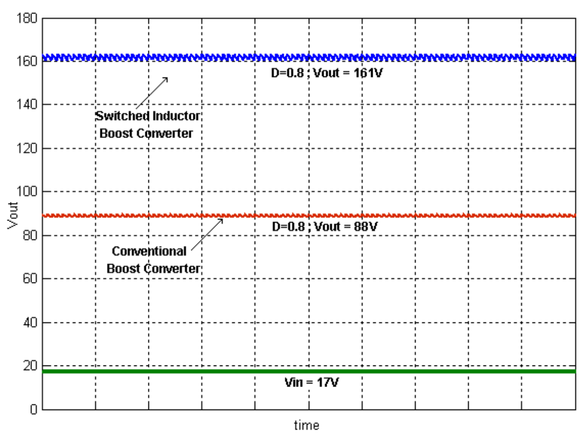

Figure-16. Output voltage of converters at D=0.8 (Vin = 17V).

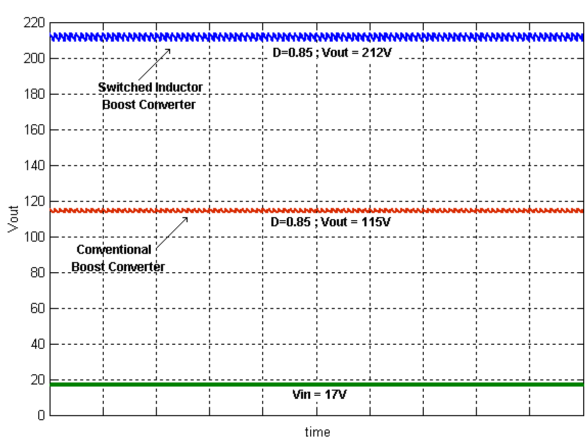

Figure-17. Output voltage of converters at D=0.85 (Vin = 17V).

Figure-17 shows output voltage of switched inductor boost dc-dc converter and conventional boost dc-dc converter at D = 0.85. With input voltage of 17V, the switched inductor boost dc-dc converter can produce output voltage of 212V, while conventional boost dc-dc converter only produces output voltage of 115V.

5. CONCLUSIONS

A simulation and evaluation of switched inductor boost dc-dc converter is presented. The performance of switched inductor boost dc-dc converter has been compared with conventional boost dc-dc converter. The simulation results show that the gain of switched inductor boost dc-dc converteris higher than conventional boost dc-dc converter by a factor of (1+D).

REFERENCES

[1] M. G.Villalva, J.R.Gazoli, and E.R.Filho. 2009. Comprehensive approach to modeling and simulation of photovoltaic arrays. IEEE Trans. Power Electronics. 24(5).

[2] M. Abdulkadir, A. S. Samosir and A. H. M. Yatim. 2012. Modeling and Simulation based Approach of Photovoltaic system in Simulink model. ARPN Journal of Engineering and Applied Sciences. 7(5).

[3] M. Abdulkadir, A. S. Samosir and A. H. M. Yatim. 2013. Modeling and Simulation of a Solar Photovoltaic System, Its Dynamics and Transient Characteristics in LABVIEW. International Journal of Power Electronics and Drive Systems. 3(2).

[4] M. Abdulkadir, A. S. Samosir and A. H. M. Yatim. 2012. Modelling and simulation of maximum power point tracking of photovoltaic system in Simulink model. PECon 2012, IEEE International Conference on Power and Energy.

[5] A. S. Samosir and A. H. M. Yatim. 2008. Implementation of new control method based on dynamic evolution control with linear evolution path for boost DC-DC converter", PECon 2008, IEEE International Power and Energy Conference.

[6] G.kranthi Kumar, Ch.Sampath Kumar, D. Kumara Swamy. 2013. A DC–DC Boost Converter for Photovoltaic Application. International Journal of Engineering Research and Development. 8(8).

[7] O. Abdel-Rahim, M. Orabi, E. Abdelkarim, M. Ahmed and M. Z. Youssef. 2012. Switched Inductor Boost Converter for PV Applications. Applied Power Electronics Conference and Exposition (APEC), Twenty-Seventh Annual IEEE.

[8] Amitava Das, Vinay Kumar Rajput, Amrita Chakraborty, MainakDhar, Sukanya Ray, RakhiDutta. 2010. A new transformerless dc-dc converter with high voltage gain. International Conference on Industrial Electronics, Control and Robotics, 2010.

[9] A. S. Samosir, T. Sutikno and A. H. M. Yatim. 2011. Dynamic evolution control for fuel cell DC-DC converter. TELKOMNIKA (Telecommunication Computing Electronics and Control). 9(1).

[10] A.S. Samosir, M. Anwari, A.H.M. Yatim. 2010. Dynamic evolution control of interleaved boost DC-DC converter for fuel cell application. 9th International Power and Energy Conference, IPEC.

[11] A. S. Samosir and A. H. M. Yatim. 2009. Implementation of new control method based on dynamic evolution control for dc-dc power converter. International Review of Electrical Engineering. 4(1).

[12] B. Axelrod, Y. Berkovich and A. Ioinovici. 2008. Switched capacitor/switched-inductor structures for getting transformer less hybrid dc–dc PWMconverters. IEEE Transactions on Circuits and Systems. 55(2).