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A High Voltage Gain Switched-Inductor Buck Boost Convertor With Coat Circuit

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Abstract— *Voltage gain of the conventional buck boost convertor is limited due to the impact of parasitic parameters in the circuit. A coat circuit was introduced to overcome this problem. Many convertors like Buck Boost, CUK, SEPIC with coat circuit have been analyzed and high voltage gain was obtained. This paper presents a study on a high voltage gain switched inductor buck boost convertor with a coat circuit. Switched inductor circuit consist of two inductor and three diodes instead of the inductor in the conventional buck boost convertor. This circuit does not need any additional active switches which makes circuit more complex. The switched inductor combination gives higher voltage gain than conventional and conventional with coat circuit. High gain convertors are mainly used for solar purposes to step up the voltage. The simulation is carried out using MATLAB/SIMULINK.*
Keywords—*switched inductor, coat circuit, buck boost convertor, inductor volt-second balance, high voltage gain, low voltage stress*

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I. INTRODUCTION

Due to inadequate requirement of fossil fuels and also the high amount of pollution produced from burning it, Renewable energy got more importance in the society. Solar energy and wind energy are the most eco-friendly renewable energy for power generation. PV cells converts solar energy to electrical energy. But the produced output is very low which cannot be used for normal purposes. So we use a step up convertors of high gain to get a required level voltage from PV arrays [1]-[3]. Conventional buck-boost convertor can be used as step-up convertor, but the voltage gain is limited.

High gain can be obtained by cascading 2 or more step up convertors which can avoid extreme duty cycle. But these circuits contain 2 or more switches which makes the control circuit more complicated and also total efficiency is also reduced [4]-[7]. The generated low voltage from PV arrays should be fed to grid for transmission only after conversion to high voltage. Many types of voltage multipliers, coupled inductors, coupled capacitors and transformer circuits has been introduced to improve the voltage gain. The use of transformers increases the overall size of the circuit and therefore the cost for implementing it [8]-[9]. The leakage energy of the inductors in the coupled inductor circuits increases the voltage stress across the components. Switched inductors has a very high voltage gain but its voltage stress across the diodes and other components reduces its efficiency [10]. Switched capacitor circuits faces many problems. It requires large switches and therefore it needs a complex control circuits [11].

Then introduced a circuit named “coat circuits” which consists of capacitors, diodes and inductors. This circuit can be cascaded with conventional buck- boost convertor, SEPIC convertor, CUK convertor, boost convertors and it gives a very high voltage gain. This circuit is named as coat circuits because its acts as a coat to the conventional circuits mentioned above. It acts like a protection from high voltage stress across the elements like coat protecting us from cold weather. It does not require any additional active switches. So the control circuit is same as that of conventional buck boost convertor [12].

In this paper, we propose a step-up convertor for high voltage gain. Conventional buck boost convertor was cascaded with coat circuits to get a high voltage gain [13]. Here we replace inductor in the main topology with a ladder inductor-diode combination. So this circuit is a combination of switched inductor circuit with conventional buck-boost convertor and coat circuit. Main drawback of switched inductor was high voltage stress. So we combined coat circuit with switched inductor circuit to minimize the voltage stress across the components. Here it does not need any additional active switches. So control circuit is same as that of conventional buck boost convertors. Simulation and circuit analysis is done for the circuit with basic cell. For higher voltage gain we can add additional cells to the circuit.

II. PROPOSED CONVERTOR TOPOLOGY

A. POWER CIRCUIT

Circuit diagram of conventional buck boost convertor is shown in fig 1. This circuit is the combination of step-up and step-down convertor.

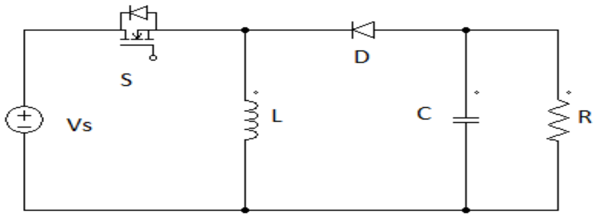


Fig 1. Conventional buck boost convertor

Conventional buck-boost convertor has limited voltage gain because of the limitation in increasing duty cycle. It can be overcome by switched inductor buck-boost convertor. Voltage gain is increased by the switched inductor buck boost convertor. But the voltage stress across components is high which reduce the overall efficiency and also stability of the circuit. So a circuit named coat circuit was introduced to reduce the voltage stress. Here we are analyzing circuit with one coat circuit. It can be extended up to N level each level consist of 1 diode, 1 inductor and 2 capacitors. Fig 2 shows a conventional buck boost convertor with a coat circuit.

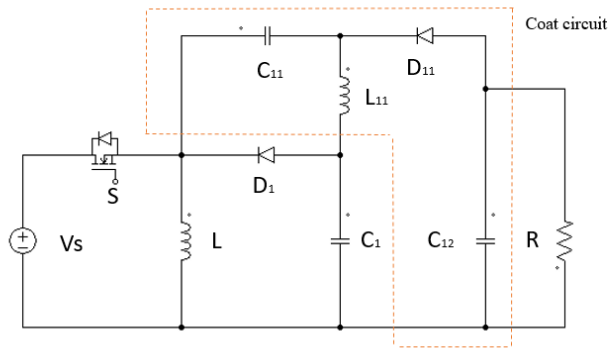


Fig 2. Buck boost convertor with a coat circuit

Proposed convertor topology is the combination this buck boost convertor and the switched inductor circuit. Fig 3 shows the proposed convertor circuit.

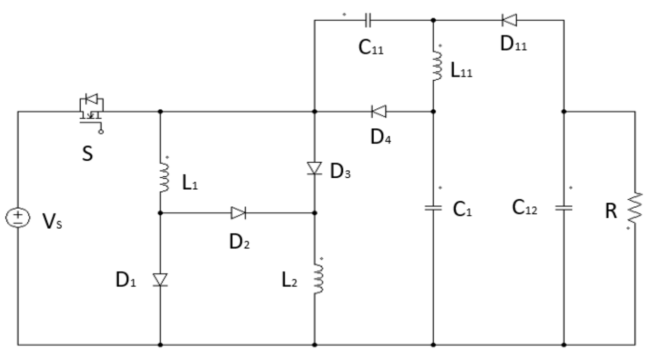


Fig 3. Proposed convertor

In the proposed convertor, inductor in the conventional topology is replaced by inductor-diode ladder shaped circuit. This circuit provides the maximum gain to the topology.

B. MODES OF OPERATION

Proposed topology consist of one basic coat cell. Inductor circuit acts differently in each modes. Inductor charges in parallel and discharges in series. So each inductor voltage makes very much impact in circuit.

1. Mode ON

Fig 4 shows mode of operation when switch is on (mode on). In this operation, switch S, diodes D1 and D3 is on. D2 and D4 is in off mode. Inductors L1 charges through D1 and L2 charges through D3. Both the inductors charges to a value equals to input voltage Vs. C12 supplies voltage to load R.

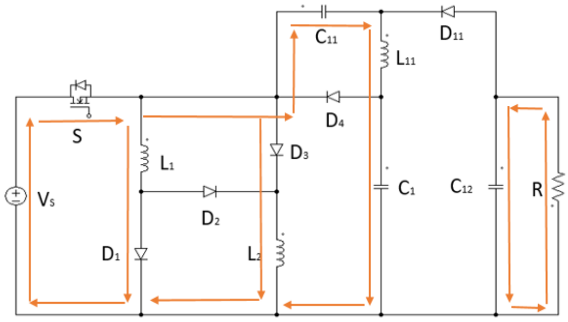


Fig 4. Mode of operation when switch is on

2. Mode OFF

Fig 5 shows mode of operation of circuit when switch is off. In this mode, switch S, diode D1 and D3 is off. Diode D2, D4 and D11 is on. Inductors L1 and L2 are de-energizing to capacitor C1. Both the Inductors are in series with this capacitor C1. This mode charges the Capacitor C12 with supplies to load.

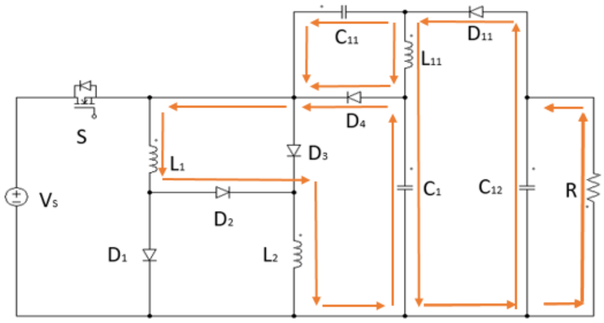


Fig 5. Mode of operation when switch is off.

Energy stored in the Inductors L1 and L2 are initially supplied to load R and C12. Charged capacitor C_1 also discharges through L_1 and L_2. Capacitor C_{11} also discharges through L_1 and L_2 to the load.

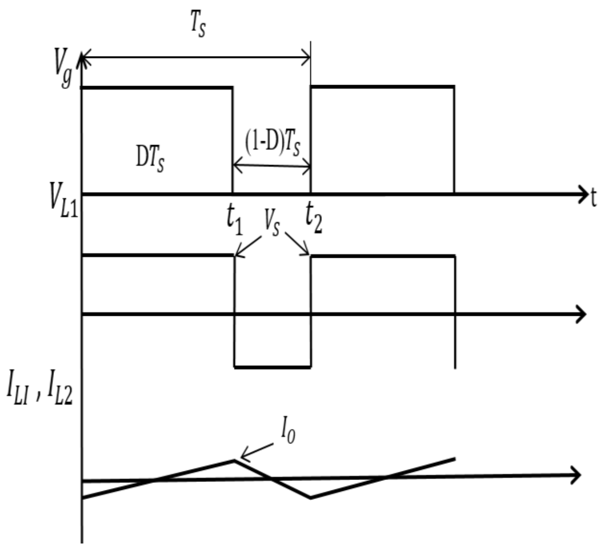


Fig 6. Key waveform of the proposed convertor

C. ANALYSIS ON TOPOLOGY

Initially supplied Vs energizes the inductor L_1, L_2 in parallel. Capacitor C_{11}, inductor L_{11} and capacitor C_1 also energizes by the supply voltage Vs.

From Fig 4 equation for the inductive voltages are,

$$V_{L1} = V_{L2} = V_S = V_L \qquad 1$$

Where,

V_{L1} is the voltage across inductor L_1

V_{L2} is the voltage across inductor L_2

Vs is the input voltage

$$V_{L11} = V_S + V_{C1} - V_{C11} \qquad 2$$

Where,

V_{L11} is voltage across inductor L_{11}

V_{C1} is the voltage across capacitor C_1

V_{C11} is the voltage across capacitor C_{11}

Stored energy in these inductors and capacitors are discharged through the L1 and L2. Considering L_1 and L_2 are same. Then voltage across L_1 and L_2 will be same.

From Fig 5, equations for inductive voltages are,

$$V_{L1} + V_{L2} + V_{C1} = 0$$

$$V_L = -V_{c1}/2 \qquad 3$$

$$V_{L11} = V_{C1} - V_0 = -V_{C11} \qquad 4$$

By inductor volt second balance principle,

From equation 1 and 3

$$D\,(V_S) = (1\text{-}D)\frac{V_{C1}}{2}$$

$$\frac{V_{C1}}{V_S} = \frac{2D}{1-D} \qquad 5$$

From equation 2 and 4

$$D\,(V_S+V_{C1}-V_{C11}) = (1\text{-}D)\,(V_{C1}-V_0) = (1\text{-}D)\,(V_{C11})$$

From equation 5

$$D\,(V_S+\frac{2D}{1-D}V_S - V_{C11}) = (1\text{-}D)\,V_{C11}$$

$$V_{C11}=\frac{D(1+D)}{1-D} \qquad 6$$

From equation 4, 5, and 6

$$V_0 = V_{C1} + V_{C11}$$

$$V_0=\frac{2D}{1-D}V_S+\frac{D(1+D)}{1-D}V_S$$

$$V_0=\frac{D(3+D)}{1-D}V_S \qquad 7$$

Voltage gain of the proposed convertor is

$$\frac{V_0}{V_S}=\frac{D(3+D)}{1-D}$$

No.	Type	Voltage gain
1	Conventional Buck Boost Convertor	$\frac{D}{1-D}$
2	Buck Boost Convertor With Coat Circuit	$\frac{2D}{1-D}$
3	Proposed Convertor Topology	$\frac{D(3+D)}{1-D}$

Table 1. different convertors with their Voltage Gain Ratio.

Table 1 shows three types of convertors and their voltage gain ratios. The proposed topology and buck boost convertor shows high voltage gain than conventional buck boost convertor.

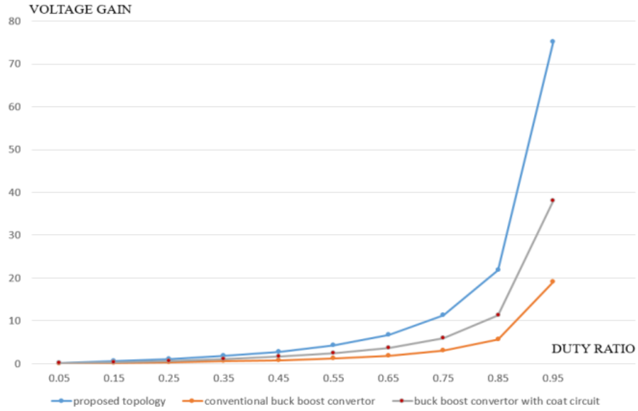


Fig 7. Graphical representation of Voltage gain vs duty ratio for different DC-DC convertor.

Fig 7 shows the variation in voltage gain of three DC-DC convertors when varying duty cycle from 0–1. From the Fig 7, we can see the variation of voltage gain of proposed topology and other two convertors. Conventional buck boost convertor only shows voltage gain of a value below 20 even in high duty cycle. Buck boost convertor with coat circuit has improved their voltage gain to a maximum of 35–40. Proposed convertor shows a very high voltage gain ratio. Voltage gain ratio varies from 70–80 at very high duty cycle which is almost double than buck boost convertor with coat circuit.

II. SIMULATION RESULTS

The proposed topology is designed for 1 level coat circuit for 920 W with an input voltage of 48 V. Switching Frequency is set to 100 KHz. The values of capacitors and inductors are taken according to the design. Table 2 shows the specifications of inductors, capacitors and other components taken for the simulation. Simulation is carried out by MATLAB/SIMULINK.

Parameter	Values
Input voltage V_S	48 V
Output voltage V_O	700 V
Output power	920
Switching frequency	100KHz
Switch	MOSFET
Capacitor	C_1, C_{11}, C_{12} = 4μF
Inductor	L_1, L_2 = 300μH, L_{11} = 950μH
Load	533 Ω

Table 2. specification of parameters for simulation.

Fig 8 shows the simulation circuit for the proposed topology by using the parameters mentioned in the table 2. Running time is set to .1 sec.

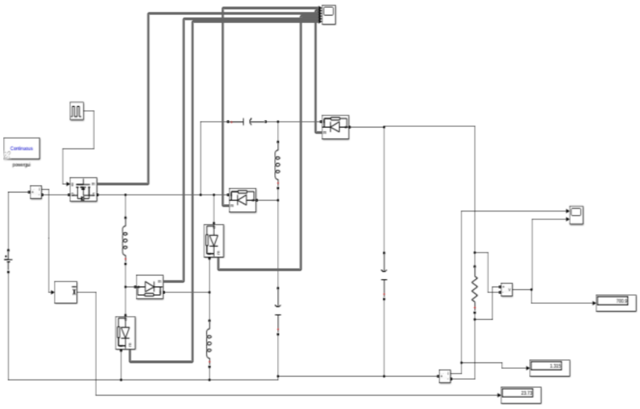
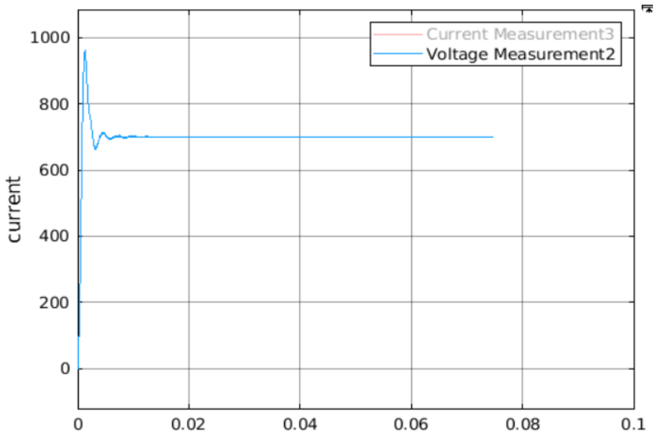
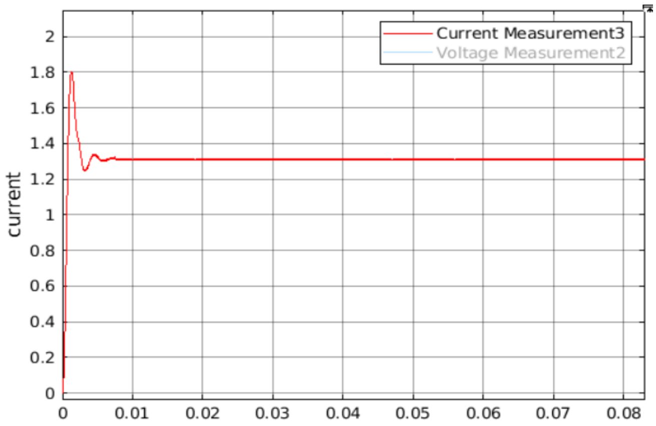


Fig 8. Simulink circuit of the proposed convertor

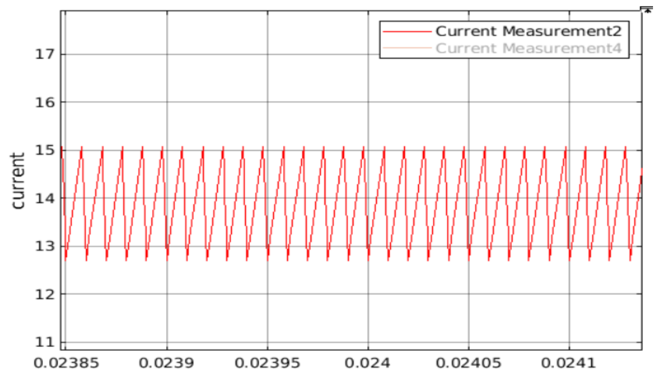
Fig 9 shows the output waveforms corresponding to the Simulink diagram shown in Fig 8. By referring to Fig 9(a), voltage is increased to 1000 and then damned to the voltage of 700 V. Fig 9(b) shows the Current waveform which is also similar to Voltage waveform. Output current is measured as 1.315 A. From the simulation, we got the output power as 920 W. Current ripple across the inductor L_1 and L_2 is shown in Fig 9(c). from the Fig 9(c), current ripple of the inductor L_1 and L_2 is 2.2 A, where input current is 23.13 A. Fig 9(d) shows the voltage stress across the switch S. voltage stress across the switch s is determines as 400. Voltage across diodes increases as the output voltage is 700. Voltage stress across switches and all diodes were 250 V. but the Output voltage was 400V. But for the proposed topology, Output voltage is 700 V, so the stress also increased to 400V. also voltage stress across capacitor is also increased than the buck boost convertor with coat circuit. Fig 10 shows the voltage stress across every diode present in the circuit. Voltage stress across main diodes D_4, and D_{11} are seen to be 400 V, and the diodes in the switched inductor circuit D_1, D_2, and D_3 shows a voltage stress of voltage below 200 V.



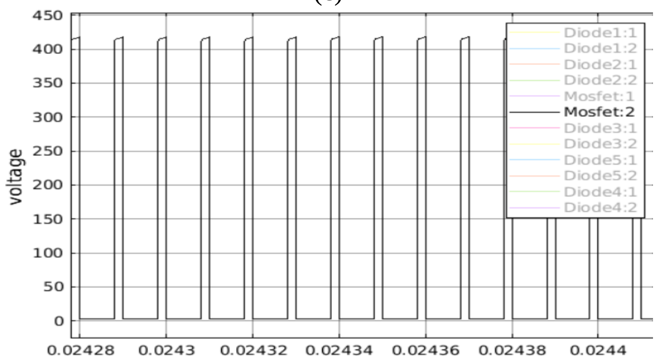
(a)



(b)

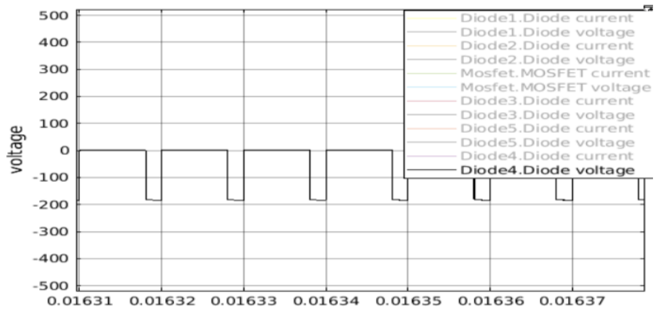


(c)

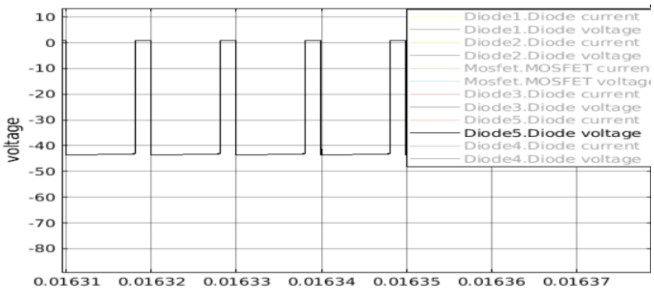


(d)

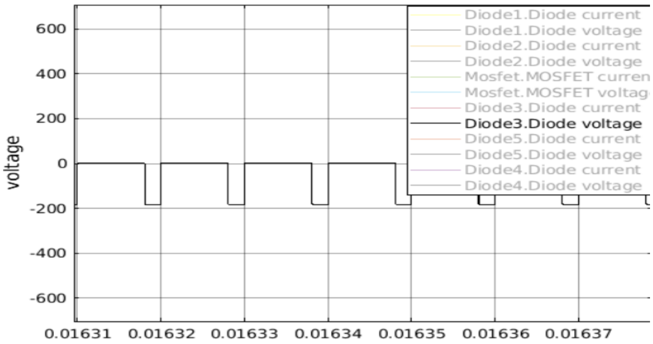
Fig 9. waveform of the proposed topology simulated in Matlab/SIMULINK. (a) Output voltage waveform (b)Output current waveform (c) waveform of current ripple of inductors L_1 and L_2. (d) voltage stress across the switch S.



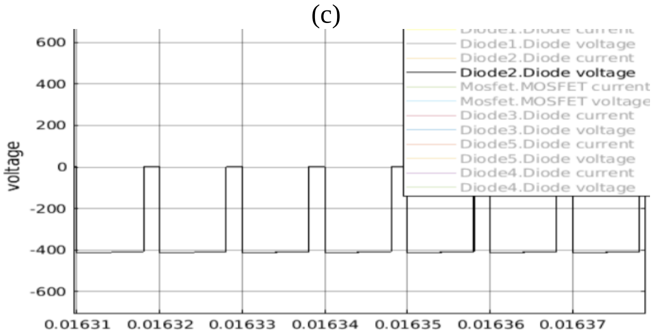
(a)



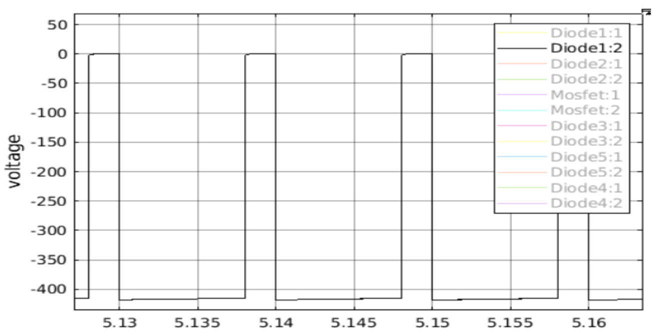
(b)



(c)



(d)



(e)

Fig 10. Voltage stress across diodes. (a) Diode D_1, (b) Diode D_2, (c) Diode D_3, (d) Diode D_{11}, (e) Diode D_4

III. CONCLUSION

In this paper, we have discussed about conventional buck boost convertor, buck boost convertor with coat circuit and also switched inductor buck boost convertor circuit. Our paper proposed a combination of a switched inductor, conventional buck- boost convertor and a coat circuit with 1 basic cell. Voltage gain ratio is higher compared to other circuit mentioned above. We can also increase the number of basic cells for higher voltage gain. From the results of the simulations for the proposed convertor, circuits shows the characteristics desired for solar connection to grid.

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