Performance Assessment of High gain DC-DC converter topologies for PV applications

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Abstract - This paper presents a comparative analysis of DC-DC converters for PV applications. In recent years, due to the lack of conventional energy sources (fossils) like coal, petrol and diesel, the demand for electrical energy is rising gradually. To reduce the demand of electrical energy, alternate methods such as generation of renewable energy sources are essential. Among the various renewable resources, the need for solar energy is gaining a lot of interest due to various advantages such as pollution free, clean and reliable. But, the maximum output voltage of a single solar cell is about 0.7V which is very low. To make any renewable energy system efficient, they need to have a suitable converter. The conventional boost converter has many limitations such as high switching loss, high input current ripple, high output voltage ripple and low efficiency. Hence, to overcome these issues, some high gain converter topologies are employed for PV systems. The topologies analyzed in this paper are single switch cascaded boost converter, cascaded boost converter with reduced losses, single switch inductor capacitor coupled transformerless converter and quadratic boost converter. The performance of these converter circuits are investigated by carrying out the simulation of the circuits using PSIM software. The converter topologies are analyzed based on the parameters such as duty ratio, input current ripple, output voltage ripple and voltage gain. From the results, it is concluded that the high gain DC-DC converter for PV applications provides an enhanced gain and high efficiency compared to the other converter topologies.

Key words : High gain converters, Renewable energy, Input current ripple, Output voltage ripple

INTRODUCTION

The generation of electricity using renewable energy resources is increasing day by day due to the depletion of fossil fuels and rise in CO_2 emissions. Among the various renewable resources, the need of solar energy is gaining a lot of interest due to its advantages such as pollution free, clean and reliable form of energy. The output of solar panel is variable since it depends on irradiation and operating point. In order to regulate the output voltage from PV panel, DC-DC converters are being used. Conventional DC-DC boost converters are employed for PV, but to achieve high voltage gain it has to be operated with extremely high duty cycle. This results in serious reverse recovery problems, higher losses and increases the rating of semiconductor devices [1]. To overcome this problem, different types of high gain converter topologies have been discussed in the literature.

High gain DC-DC converters are fast growing switching power converters for photovoltaic applications. Different topologies are being developed, in order to achieve higher voltage gain, low switching stress, low ripple and cost effective converters [2]. One of the major criteria for the selection of converter topologies is based on the number of switching devices. The high gain topologies investigated in this paper are configured with less number of switching devices and thus it results in low switching stress. The next parameter to be considered is the voltage gain of the converter circuit. The high conversion ratio can be obtained by using quadratic type of boost converters.

The quadratic converters can provide high voltage gain conversion but the switching stress in this type of converter is more or less equal to the output voltage. As a replacement for this, coupled inductor topologies can be used to achieve high voltage gain but their efficiency is degraded due to losses associated with the leakage inductors [3].

The efficiency and reliability can be increased with the use of capacitor-diode voltage multiplier technique. But the drawback in this topology is that it cannot provide ultra high voltage gain conversion at moderate duty cycles. To overcome these problems, the following topologies are preferred, single switch cascaded boost converter, cascaded boost converter with reduced losses, single switch inductor capacitor coupled transformerless converter and quadratic boost converter. Among these topologies, a high gain topology using voltage lift converters provides higher voltage gain with smaller ripples than the conventional DC-DC boost converters. The merits of this topology also includes high power density, high efficiency and relatively non-expensive in simple structure. The proposed converter is an integration of boost converter with quadratic boost converter whose voltage gain can be given as the sum of the voltage gains of the individual converters [4].The topologies selected for investigation in this work are studied and simulated in PSIM and their functional parameters are evaluated and compared.

I. Topologies of High gain DC-DC converters

The dc-dc converters are building blocks of distributed power supply systems in which a common dc bus voltage is converted to various other voltages according to requirements of particular loads. These systems are common in space stations, ships, airplanes, as well as in computer and telecommunication equipment. Another major area of dc-dc converter applications is related to the utility ac grid. In case of failures in utility grid, there must be a backup source of energy, for example, a battery pack which incorporates a DC-DC converter [5]. The different topologies of high gain DC-DC converters are explained as follows :

Topology 1:

Cascaded Boost Converter with Single Switch

Circuit Diagram:

The circuit diagram of cascaded boost converter with single switch is shown in Fig.1 ,

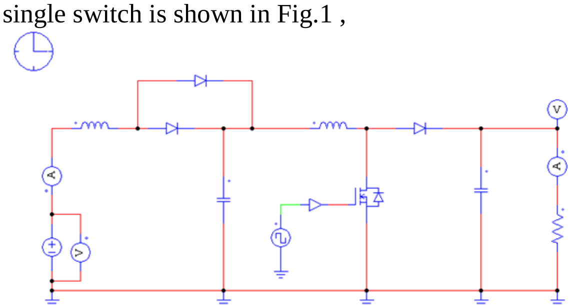

Fig.1, Cascaded boost converter with single switch

Operation

This topology has an active switch S_1 and the diodes are passive in nature. During mode 1 when the Switches gets turned ON, the input voltage charges the inductors L_1 and L_2. The charge in inductor L_2 is increased by the capacitor C_1 and the output voltage V_0 is given by the capacitor C_2 [6].

In mode 2, when switches are turned OFF the charges in the inductors L_1, L_2 and L_3 are discharged to the load along with input voltage.

The steady state operating conditions of the converter is given by,

$$V_{c1}=\frac{Vin}{(1-D)} \quad \text{---------- (1)} \qquad V_{c2}=\frac{Vin}{(1-D)2} \quad \text{------------ (2)}$$

$$i_{L1}=\frac{Vin}{(1-D)4\,R} \quad \text{---------- (3)} \qquad i_{L2}=\frac{Vin}{(1-D)3\,R} \quad \text{------------ (4)}$$

The simulation is carried out for an input voltage of 37.8V and it has been boosted to 151.1 V. The results are shown in Fig.2,

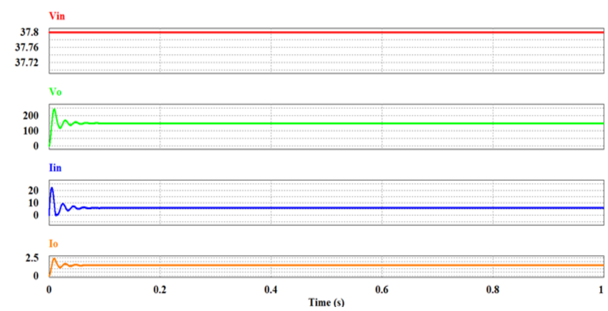

Fig.2, Simulation results of Cascaded boost converter with single switch

Topology 2:

New cascade boost converter with reduced losses Circuit Diagram :

The circuit diagram of cascade boost converter with reduced losses is shown in Fig.3,

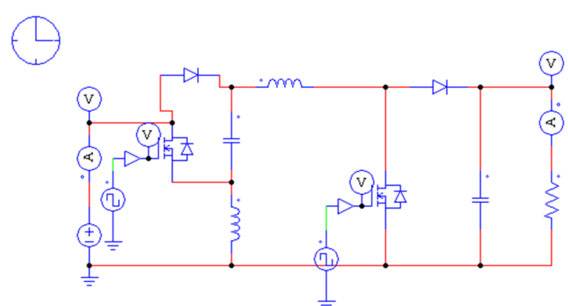

Fig.3, Cascade boost converter with reduced losses

Operation

This converter operates in continuous conduction mode with three major intervals in each switching cycle.

During first interval, both the switches are in ON state and the charging of inductors takes place. During second interval, switch S_2 gets turned off and the inductor L_2 is discharged into the output capacitor C_2. At the third interval of switching cycle, S_1 is kept in OFF state and S_2 becomes turned ON. Now the stored energy in L1 is transferred to C_1 through D_1 [7].

The voltage gain of this topology is given by,

Voltage gain $=\frac{1}{(1-D1)(1-D2)}$ ---------- (5)

Where D_1 and D_2 are the duty ratios.

The simulation is carried out for an input voltage of 37.8V and it has been boosted to 151.4 V. The results are shown in Fig.4,

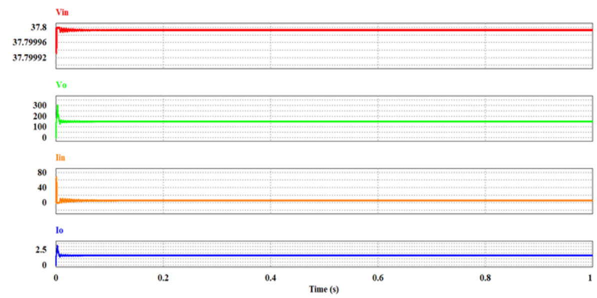

Fig.4, Simulation results of Cascade boost converter with reduced losses

Topology 3:

Single Switched Inductor Capacitor coupled Transformerless High Gain Converter for PV Application

Circuit Diagram

The circuit diagram of Single Switched Inductor Capacitor coupled Transformerless High Gain Converter for PV Application is shown in Fig.5,

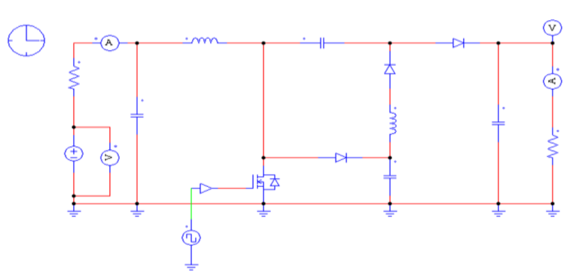

Fig.5, Single Switched Inductor Capacitor coupled Transformer less High Gain Converter

Operation:

This topology consists of a single switch MOSFET S_1 and a clamping diode D_1 for the current path, resonant diode Dr for the flow of unidirectional current during resonant operation and an output diode Do. The capacitors and inductors are kept for energy transfer and storage purpose.

In mode 1, the switch S_1 is gets turned ON, the inductor is charged by input voltage and the resonant capacitor Cr is charged by the coupling capacitor (Cc). During the off-time of MOSFET, the energy captured by Cc is transferred to Cr, which in turn is transferred to the load. The resonant current together with the inductor current forms the current in the switch [1].

In mode 2, the switch S_1 is turned OFF, the clamping diode D_1 is turned ON by the leakage energy stored in the inductor during ON time of the switch and the coupling capacitor Cc is charged which causes the voltage on the switch to be clamped.

In mode 3, as the capacitor Cc got charged so that the output diode Do is forward biased. The energy stored in the inductor and capacitor Cc is being transferred to the load and the clamp diode D_1 continues to conduct while Cc remains charged.

In mode 4, diode D_1 is reversed biased and as a result, the energy stored in inductor and in capacitor Cr is simultaneously transferred to the load. The capacitor Cr is charged to satisfy the balance of the charge in steady state operation [1].

In mode 5, the MOSFET S_1 is turned ON again and the output diode Do will be reversed biased at the end of this mode then the next switching cycle starts.

The simulation is carried out for an input voltage of 37.8V and it has been boosted to 114.6 V. The results are shown in Fig.6,

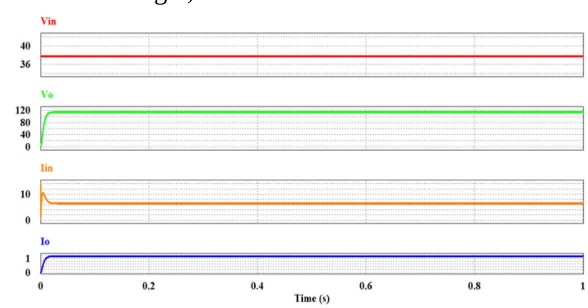

Fig.6, Simulation results of Single Switched Inductor Capacitor coupled Transformer less High Gain Converter

Topology 4:

PV Based High Voltage Gain Quadratic DC-DC Converter Integrated with Coupled Inductor

Circuit Diagram

The circuit diagram of PV Based High Voltage Gain Quadratic DC-DC Converter Integrated with Coupled Inductor is shown in Fig.7,

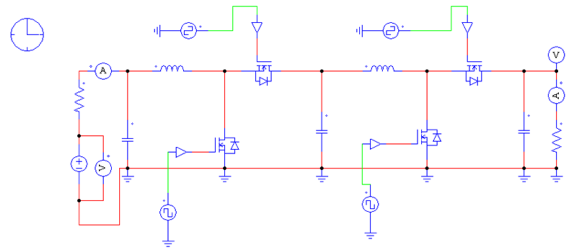

Fig.7, High Voltage Gain Quadratic DC-DC Converter Integrated with Coupled Inductor

Operation

This topology presents a bidirectional quadratic converter for wide conversion ratio. The bidirectional quadratic converter is made by cascading two boost converters. The bidirectional mode of operation is carried out by replacing the diodes with the switches along with body diodes.

The Quadratic boost mode of operation is achieved when the switches S_1 and S_3 operate at the same duty cycle and same instant of time. When switches S_1 and S_3 turn-off body diodes of the switches S_2 and S_4 are operated. In this mode of operation switches, S_2 and S_4 is always turned off [3].

The Quadratic buck mode of operation is achieved when the switches S_2 and S_4 operate at the same instant of time with same duty cycle. Body diodes of the switches S_1 and S_3 are turned on when switches S_2 and S_4 turn-off. In this mode of operation switches, S_1 and S_3 is always turned off [3].

The simulation is carried out for an input voltage of 37.8V and it has been boosted to 138.6 V. The results are shown in Fig.8,

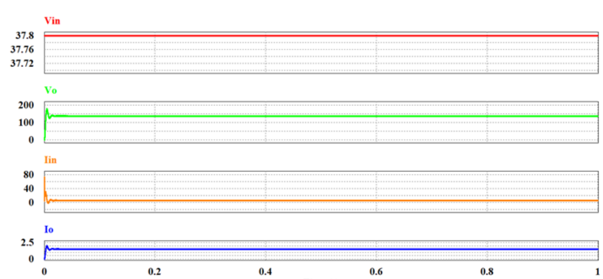

Fig.8, Simulation results of High Voltage Gain Quadratic DC-DC Converter Integrated with Coupled Inductor

Topology 5:

High Gain DC-DC Converter

Circuit Diagram :

The circuit diagram of High Gain DC-DC Converter for PV Applications is shown in Fig.9,

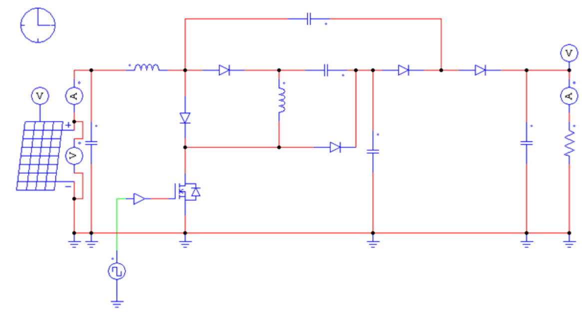

Fig.9, High Gain DC-DC Converter

Operation

The proposed topology is highly efficient compared to the above mentioned topologies of DC-DC converters. It is interfaced with solar at the input side.

During mode 1 the switch gets turned ON and the diodes D_1 and D_4 are also turned ON simultaneously. The current through the capacitors are equal to that of the opposite inductors.

During mode 2, the switch gets turned off, and the diodes D_2, D_3 and D_5 gets turned ON. Now the voltage across capacitors becomes equal and the current through the inductors starts decreasing linearly [4].

The voltage gain of this topology is given by ,

Voltage gain = $\frac{2-D}{(1-D)2}$ ---------- (6)

Where D is the duty ratio.

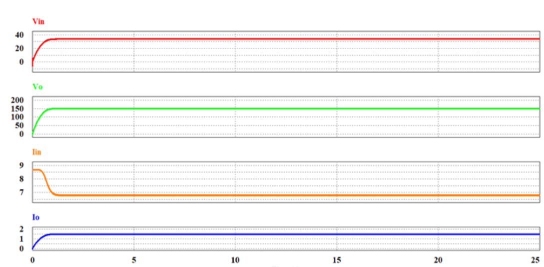

Fig.10, Simulation results of High Gain DC-DC Converter for PV Applications

From Fig.10, it is shown that the input voltage of 37.8 V is boosted upto 150V and the input and output power ratings are also approximately equal.

II. Comparison of parameters

The comparison of the topologies are done based on the parameters such as duty ratio, input current ripple, output voltage ripple and the results are given in this section . The simulation is carried out for an input voltage of 37.8V for all the topologies and the respective output voltage and currents are measured. The power rating for the converter topologies is 250 W.

Table 1: Comparison of High gain DC-DC converter topologies

Topologies	Duty cycle	Output Voltage ripple (V)	Input Current ripple (A)
1	0.75	0.2	0.01
2	0.5	0.7	0.45
3	0.7	0.25	0.015
4	0.5	0.05	0.005
5	**0.4**	**0.0005**	**0.001**

From table 1, it is found that the proposed converter has low input current ripple and output voltage ripple than the other converter topologies.

A graph drawn between the duty cycle and the input current ripple as well as with the output voltage ripple is shown in Fig.11 and Fig.12 respectively.

Fig.11, Waveform for input current ripple with respect to the duty cycle

Fig.11, shows the variation in input current ripple with respect to the duty ratio for the topologies discussed in this paper. It is clear that the proposed high gain DC-DC converter has very low current ripple compared to the other topologies. It is in the range of 0.001 A .

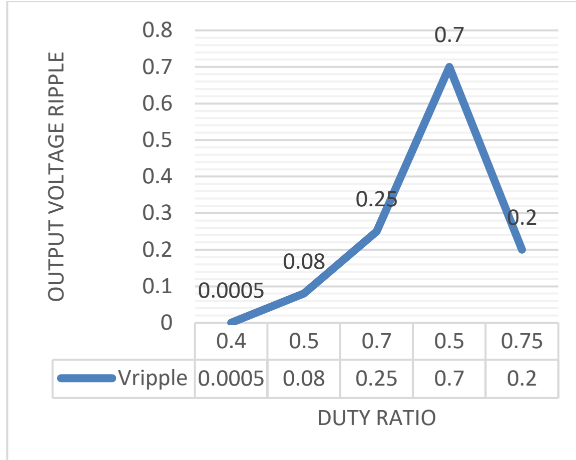

Fig.12, Waveform for output voltage ripple with respect to the duty cycle

Fig.12, shows the variation in output voltage ripple with respect to the duty ratio for the topologies discussed in this paper. It is clear that the proposed high gain DC-DC converter has very low voltage ripple compared to the other topologies. It is in the range of 0.0005 V .

The voltage gain of the proposed topology is calculated for different duty ratios and it is given in Table 2. The respective waveform is shown in Fig.13,

Table 2 : Voltage gain of proposed converter for different duty ratios

Duty Ratio	Voltage Gain
0.1	2.34
0.2	2.81
0.3	3.46
0.4	4.45
0.5	5.9
0.6	8.6
0.7	13.96
0.8	25.46

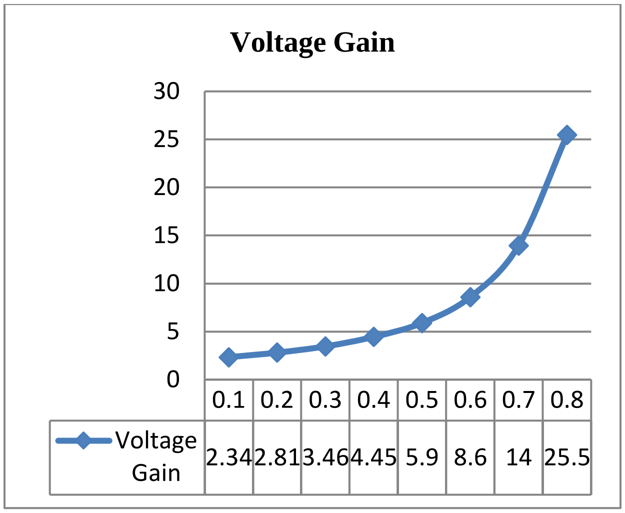

Fig.13, Waveform for voltage gain at different duty ratios

The variation of voltage gain with respect to the duty ratio is shown in Fig.13, and it is found that high conversion gain can be achieved even at low duty ratio. For the required power rating, high voltage conversion has been achieved at a duty ratio of 0.4

III. Conclusion

This paper has investigated the various high gain DC-DC converter topologies for PV applications. The high gain DC-DC converter topology is interfaced with PV panel and the output voltage, output current and power ratings are measured. This topology results in high output voltage gain at a minimum duty cycle with reduced ripple at the input and output side. Hence, the proposed high gain converter topology is suitable for PV applications.

IV. References

[1] Lopamudra Mitra and Ullash Kumar Rout, “Single Switched Inductor Capacitor coupled Transformerless High Gain Converter for PV Application”, IEEE transactions, pp-1213-1219, 2016.

[2] Divya Navamani.J, Vijayakumar.K , Jegatheesan.R, “Study on High Step-up DC-DC Converter with High Gain Cell for PV Applications”, International Conference on Advances in Computing & Communications, ICACC-2017, 22- 24 August 2017, Cochin, India, Procedia Computer Science 115 (2017) pp-731–739

[3] Anish Ahmad, R. K. Singh and R. Mahanty, “Bidirectional Quadratic Converter for Wide Voltage Conversion Ratio”, IEEE transactions, 2016.

[4] Hoiam Elobaid Mohamed and Abbas A. Fardoun, “High Gain DC-DC Converter for PV Applications”, IEEE transactions 59th International Midwest Symposium on Circuits and Systems (MWSCAS), pp-591-596, october 2016.

[5] Dakshina M. Bellur and Marian K. Kazimierczuk, “DC-DC Converters for Electric Vehicle Applications,” IEEE Transaction.,pp- 286-293, 2007.

[6] Jorge Alberto Morales-Saldaña, Roberto Galarza-Quirino, Jesús Leyva-Ramos, Enrique Eduardo Carbajal-Gutierrez and Ma. Guadalupe Ortiz-Lopez, “Modeling and Control of a Cascaded Boost Converter with a Single Switch”, IEEE transactions, 2006.

[7] Mohammad Lotfi Nejad, Behzad poorali, Ehsan Adib and Ali Akbar Motie Brijandi, “ New Cascade boost converter with reduced losses”, IET Power Electronics, Vol. 9, Iss. 6, pp. 1213–1219, 2016.