Design And Simulation Of A High Gain Boost Converter With Continuous Input Output Current

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Abstract

This paper proposes a high gain modified Cuk converter for voltage boosting application. This proposed topology is highly capable to overcome the maximum duty restriction of a boost converter to reach the high output input voltage ratio. Higher gain of the converter eliminates the use of transformer which reduces the cost and size of the converter. This proposed converter offers continuous input current as well as continuous output current. For better voltage boosting capability and continuous current, this converter will be widely accepted for renewable energy applications, battery storage-based inverter applications and various industrial applications. Use of single switch reduces the complexity and cost of the system.

Keywords: *Continuous input-output current, Voltage boost, Voltage lifting , Ripple reduction, Cuk converter*

1. Introduction

With the increase in the CO2 emission and the increase in fossil fuel cost, use of Photo Voltic (PV) electrical power generation is gaining popularity day by day [9]. Due to the reduction of the fossil fuel storage the power sectors are moving towards the PV based microgrid. The major issue for the micro grid is that the DC bus voltage and the PV panel voltage are not same. Most of the cases the PV voltage is less then 48V [5]. Where the total energy is generated by a number of small power generating units, generating lower voltage. To boost up the voltage in those cases boost converter is needed [7]. Sometimes in PV applications energy storage system are introduced. For medium power application the battery nominal voltage is 48V in most of the cases. To generate a 230 V AC a minimum bus voltage of 330V DC is needed. Where the 330 V bus voltage is not available external DC-DC converter is introduced to maintain the bus voltage or else the inverter output voltage is boosted up by the transformer. Between DC-DC converter and inverter the DC-DC converter should operate at higher frequency than the inverter. So, the DC-DC converter magnetics should be smaller than the inverter transformer. In normal boost converter though the 99% duty is possible theoretically, but in practical cases the duty is restricted after 80%[1]. For 80% duty the maximum output to input voltage ratio will be 5 times, which is not sufficient to supply an inverter DC bus. To increase the output voltage of the converter transformer-based DC-DC converter has been introduced, where the voltage ratio can be adjusted by the help of turns ratio. There are different topologies in transformer-based DC-DC converter- full-bridge, half-bridge, single switch (Flyback, Forward) isolated Power supply. In low power application generally flyback or forward converter are used. Where Isolation is provided magnetics size of the converter should be increased. To avoid this kind of problem different voltage lifting topology has been introduced.

This paper proposes a high gain modified Cuk converter for voltage boosting operation. This proposed topology is capable to increase the gain of the converter upto two times of a boost converter. There are several topologies to improve the gain of a DC_DC converter. Voltage gain can be improved in non-isolated topology by adding some external circuitry of some passive elements. To control the current of the passive elements sometimes external switches are needed. This proposed topology offers high gain by using single switch operation which makes the control simple and avoids the synchronization between different gate pulse. Most of the single switch isolated converter suffers from the discontinuous input current which is not recommended. Boost converter generally provides continuous input current and discontinuous output current. For a Cuk converter both the input and output current are continuous. By using continuous current the peak current can be reduced. Use of Discontinuous conduction reduces the life of batteries and has effect on the load and other connected devices on the DC Bus.

2. PROPOSED CONVERTER

This proposed topology states a high gain non isolated boost converter. This proposed topology can be used to increase the gain of a conventional boost converter upto two times. This topology follows some operation of boost converter, Cuk converter and voltage lifting topology. Here the input and output current both are continuous. For ideal condition load voltage, C3 voltage and C2 voltage are same. During the discharge of capacitor C2,the capacitor C3, Co and inductor L3 are charged. After that C3 discharges which will reduces the ripple of the output voltage and current. This load side L-C circuit works as a π-filter which makes the output current near to constant. This proposed topology reduces output ripple as well as the output filter. Where the self-lift Cuk converter gives output like a boost converter by reducing the output current ripple, this proposed topology increases the gain two times of a boost converter and reduces the output current ripple. To increase the gain no external switch is needed. The single switch operation of the converter reduces the size and complexity of the control. To improve the gain two times from a self-lift converter only two diode and a LC circuit is needed. Continuous conduction operation of the inductor current ensures about the less current ripple in the input side. As input side of the converter follows the boost converter topology it draws continuous current from the input bus which reduces the peak current stress at the bus as well as reduces the capacitor size at the DC bus. For the voltage boosting operation an artificial bus is made by the help of capacitor C1. It is considered that the capacitor voltage is near to constant. To reduce the voltage ripple capacitance of the capacitor should be increased. During charging of the capacitor C1 is connected across the supply (By ignoring the voltage drop across the semiconductor devices). During Discharge the capacitor is connected in series with the supply voltage. During charging time, the inductor L1-L2 and capacitor C1 are connected in parallel with the source and during discharge their series combination will increase the voltage gain of the converter.

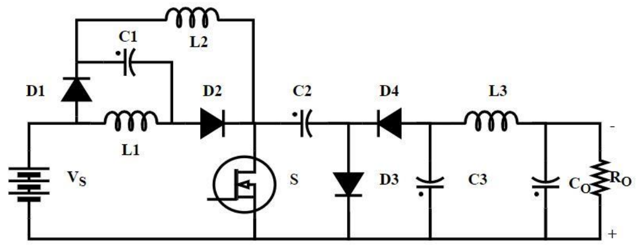

Figure 1. Schematic diagram of the proposed Converter

When the Switch is on, the diode D1 and D2 are in forward biased condition. L1 is charged by the path Vs-L1-D2-S. A voltage magnitude of the value of supply voltage minus semiconductor drop is applied across L1 during the charging time. Inductor L2 will also charge by the same process. When the switch S is turned on, diode D4 is forward biased and the capacitor C2 discharges through the switch S and D4. The capacitor C2 current is divided in two parts- one is charging the capacitor C3 and another is charging the L3 and transferring power to the load. During this mode D3 is reversed biased where the C2 capacitor voltage is applied across the diode. By ignoring the semiconductor voltage drop C3 is in parallel with the C2 during DT interval. C2 voltage and the C3 voltage will be same. As the inductor L3 is connected in series with the load, it reduces the current ripple and peak current stress through the load.

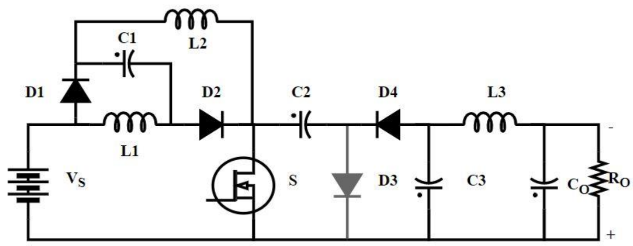

Figure 2. Current conduction when the switch is on

When the switch is on

$$V_S = V_{L_1} = V_{L_2} = V_{C_1}$$

$$V_o = V_{C_3} = V_{C_2} = V_{C_1}$$

When the Switch is in off condition C2 will stop discharging. Diode D1, D2 and D4 are reverse biased and D3 is forward biased. As the inductor L1-L2 are in discharging mode the voltage polarity of the inductor changes. In that instant series combination of L1-L2, source voltage and the capacitor C1 charged by the source voltage, charge the capacitor C2 through the path Vs-L1-C1-L2- C2-D3. In this mode charge stored in the inductor L1-L2 is transferred to the capacitor C2. Capacitor value will be sufficient to withstand the voltage ripple for that it is considered that the capacitor C1 voltage is equal to the source voltage.

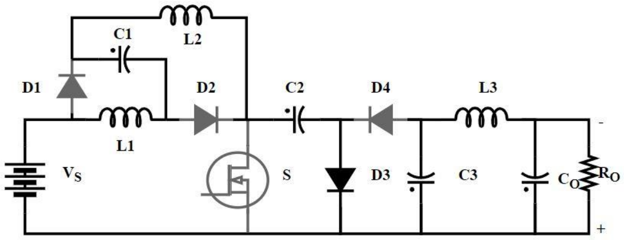

Figure 3. Current conduction when the switch is off

In that instant from the capacitor C2 no energy is transferred to the load side. At the starting time of this interval the inductor L3 will be in charging mode when the energy is supplied by the capacitor C3. After that the inductor and the capacitor C3 will supply energy to the load Inductor L3 basically reduce the current ripple in the output side.

When the switch is off

$$V_{C_1} = V_S$$

$$V_{L_1} = V_{L_2} = \frac{V_S D}{1\text{-}D}$$

$$V_{C_2} = V_{C_1} + V_S + V_{L_1} + V_{L_1}$$

$$= \frac{2V_S}{1\text{-}D}$$

3. DESIGN CONSIDERATION AND ANALYSIS

For design of the converter, it is considered that the voltage of the capacitor C3 and Co are same. Between the two capacitor a series inductor is present there is no switching device present, which ensure that voltage of the two capacitors will be nearly equal. The inductor is used to reduce the output current ripple. So, the current ripple of this converter will be lower than the boost converter and the Cuk converter. When the switch is ON the capacitor C2 and C3 are parallel. So, the average voltage across the capacitor C2 and C3 will be same. It will be better to select all of the capacitors at a value to reduce the voltage ripple. The inductor L1 and L2 are discharged at same current and same interval as well as they are charged by the same voltage also which ensure that both of the inductor will be same value. Both of the Ton time and Toff time inductor current is flowing. Inductor are connected with the source in series which ensure about the continuous conduction of the source current.

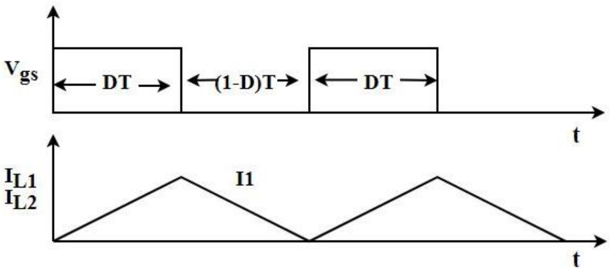

Figure 4. Inductor current

Inductor value should be more than the critical value for continuous conduction. Continuous conduction of the inductor ensures about the continuous input current from the source. For design simplicity the critical mode is considered and the inductor is selected more than the critical value. The Capacitor C1 should be sufficient enough to reduce the voltage ripple.

Peak current of the inductor L1 & L2

$$I_1 = \frac{2I_O}{1-D}$$

Where I_o= Average output current of the converter

D is the duty cycle of the converter.

Output voltage of the converter

$$V_O = \frac{2V_S}{1-D}$$

Where V_S is the source voltage

The critical Inductance value will be

$$L_{1,2} = \frac{V_S DT(1-D)}{2I_O}$$

Where T is the time period.

Maximum voltage stress across the diode D1 and D2

$$\frac{V_S}{1-D}$$

Maximum voltage applied across the switch, diode D3 and D4 are

$$= \frac{2V_S}{1-D}$$

4. SIMULATION AND RESULT ANALYSIS

This proposed high gain boost converter has been designed for continuous conduction operation according to the above-mentioned equation. The system has been designed to boost voltage level form 48V to 330V with the operating frequency of 100KHz.

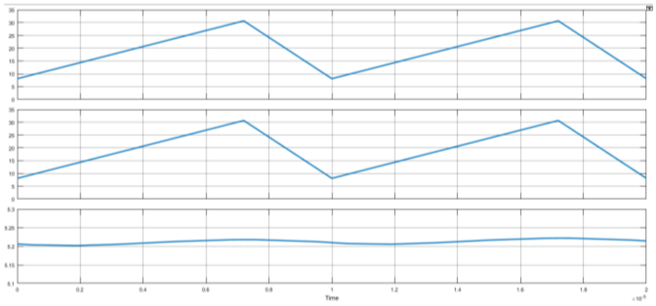

Figure 5. Inductor current (IL1, IL2, IL3)

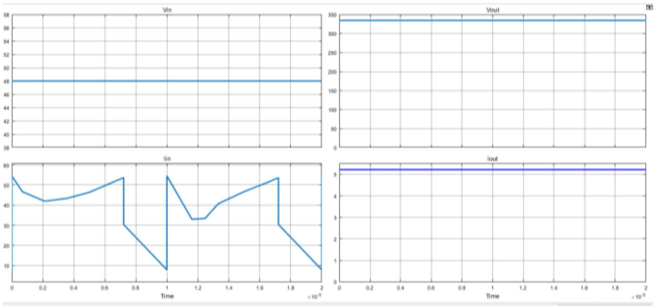

Figure 6. Input output voltage current

This proposed system has been designed for a 5A output. The L3 value is taken 1/3 times of the L1. All the inductor are designed for the continuous conduction operation. From the figure of the inductor current it is observed that all the inductors are operating in continuous conduction mode having a positive offset. In the output inductor L3, current ripple is 0.05A which is much less. This type of less ripple content output is highly recommended. From the input output voltage current curve, it has been observed that output voltage and current both are ripple free. In input current waveform it has been observed that the minimum input current is 8A, which ensures about the continuous conduction operation. The input current is taken from the bus without using capacitor. By using a capacitor in the input side, the input current ripple can be reduced. This converter has been simulated for duty of 0.72 with the input voltage of 48V. According to the above-mentioned equation expected output voltage is 342.8V but in the simulation result the output voltage is 334.2V. The voltage difference occurs because the voltage drop due to the semiconductor devices during the charge and discharge of the inductor is not considered in the equation.

5. Conclusion

This proposed converter has been designed and simulated in MATLAB Simulink. All the inductor are operating in continuous conduction mode. The simulated output voltage is close to the calculated output voltage as per the equation. There is a voltage drop due to the switch and the diode which is not considered in the equation for which a voltage difference between equation and actual system is observed. The voltage drop is ignored because of the complexity of the equation. This system can be used in microgrid system. This system will be highly accepted for renewable energy application and battery storage-based inverter application. Minimum 330V is required for a inverter DC bus to generate 230V AC. This system is capable to supply power from 48V battery or the 48V PV panel to the inverter DC bus. Both of the input and output current of the converter is continuous which reduces the peak current. The output current contains very less ripple which is suitable for load.

References

[1] *M. Zhu, T. Wang and F. L. Luo, "Analysis of voltage-lift-type boost converters," 2012 7th IEEE Conference on Industrial Electronics and Applications (ICIEA), Singapore, 2012, pp. 214-219.*

[2] *W. Yanxin, Z. Qiaojie and M. Tao, "High gain boost converter with reduced current ripple," 2017 Chinese Automation Congress (CAC), Jinan, China, 2017, pp. 5448-5452.*

[3] *A. Laha, "A High Voltage Gain Quadratic Boost Converter using a Voltage Doubler and Voltage-Lift Technique," 2020 IEEE International Conference on Power Electronics, Smart Grid and Renewable Energy (PESGRE2020), Cochin, India, 2020, pp. 1-6.*

[4] *Anirban Giri, Debadyuti Banerjee, "Design and Simulation of a Voltage Lifting Cuk Converter Based Maximum Power Point Tracking System For Different Environment and Load Conditions," International Conference on Communication, Computing and Nano-Microwave Technology(CCNMT2022), Kolkata,India,2022,pp.71-74.*

[5] *N. Gupta, D. Almakhles, M. S. Bhaskar, P. Sanjeevikumar, J. B. Holm-Nielsen and M. Mitolo, "Novel Hybrid High Gain Converter: Combination of Cuk and Buck-Boost Structures with Switched Inductor for DC Microgrid," 2020 2nd Global Power, Energy and Communication Conference (GPECOM), Izmir, Turkey, 2020, pp. 47-52.*

[6] *K. -B. Park, G. -W. Moon and M. -J. Youn, "Nonisolated High Step-up Boost Converter Integrated With Sepic Converter," in IEEE Transactions on Power Electronics, vol. 25, no. 9, pp. 2266-2275, Sept. 2010.*

[7] *J. C. Rosas-Caro, F. Mancilla-David, J. C. Mayo-Maldonado, J. M. Gonzalez-Lopez, H. L. Torres-Espinosa and J. E. Valdez-Resendiz, "A Transformer-less High-Gain Boost Converter With Input Current Ripple Cancelation at a Selectable Duty Cycle," in IEEE Transactions on Industrial Electronics, vol. 60, no. 10, pp. 4492-4499, Oct. 2013.*

[8] *N. Gupta, D. Almakhles, M. S. Bhaskar, P. Sanjeevikumar, J. B. Holm-Nielsen and M. Mitolo, "Novel Hybrid High Gain Converter: Combination of Cuk and Buck-Boost Structures with Switched Inductor for DC Microgrid," 2020 2nd Global Power, Energy and Communication Conference (GPECOM), Izmir, Turkey, 2020, pp. 47-52.*

[9] *H. E. Mohamed and A. A. Fardoun, "High gain DC-DC converter for PV applications," 2016 IEEE 59th International Midwest Symposium on Circuits and Systems (MWSCAS), Abu Dhabi, United Arab Emirates, 2016, pp. 1-4.*