© APR 2021 | IRE Journals | Volume 4 Issue 10 | ISSN: 2456-8880

A Two Stage Coupled Inductor Based Cascaded Dc-Dc Converter with A High Voltage Gain

SOUNDARYAGURULAKSHMI R V

B.E student, EEE Department, Sri Ramakrishna engineering college, Coimbatore, India

Abstract- In this paper, a new high step-up cascaded DC-DC converter is presented. The first stage of the proposed converter is a buck-boost converter with modified converter topology. The second stage is a boost converter with coupled inductor and voltage multiplier cells. The literature has reported on various voltage-boosting techniques, in which fundamental energy storing elements (inductors and capacitors) and/or transformers in conjunction with switch and diode(s) are utilized in the circuit. These techniques include switched capacitor (charge pump), voltage multiplier, switched inductor/voltage lift, magnetic coupling, and multistage/-level, and each has its own merits and demerits depending on application, in terms of cost, complexity, power density, reliability, and efficiency. The energy stored in the leakage inductor of the coupled inductor is recycled by a passive voltage clamp to a capacitor thereby improving the efficiency. Besides, the blocking voltage across the MOSFET switch is reduced in the proposed topology due to voltage clamp circuit. Finally, broad applications of dc–dc converters are presented and summarized with comparative study of different voltage-boosting techniques. The steady-state analysis of the proposed converter is presented in the paper.

Indexed Terms- Buck-boost converter, cascaded converter, coupled inductor, high step-up DC-DC converter, voltage clamp circuit.

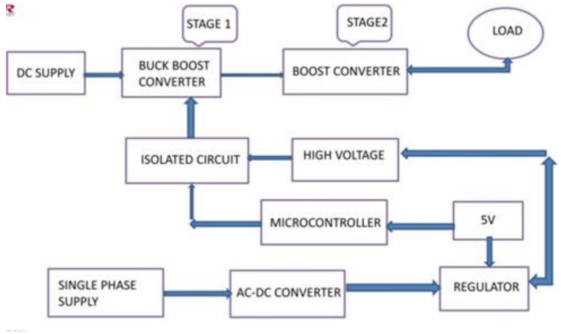
I. INTRODUCTION

Switch mode step-up dc–dc converters originated with the development of pulse width modulated (PWM) boost converters. Step-up dc–dc topologies convert lower dc voltage levels to higher levels by temporarily storing the input energy and then releasing it into the output at a higher voltage level.

Usually, the conventional boost converter is applied for step-up applications, since it has a simple structure and high efficiency. However, in spite of low efficiency near the unity duty cycle, it has also step-up ratio limitations. In order to obtain a high voltage gain, different techniques are proposed for DC-DC converter. One of the most widely used techniques is to utilize switched capacitor or switched inductor cells. These converters have two major modes: the cells are charged in parallel in one mode and then discharge in series in the other mode to obtain high voltage gain. Voltage multiplier and voltage lift are the other techniques that are used for achieving high voltage gains. The proposed converter has an inductor, a coupled inductor, a MOSFET switch, five capacitors, and six diodes. The first stage of the converter is a buck-boost converter with modified converter structure. The second stage is a high step-up converter with coupled inductor and voltage multiplier cells. The output of the first stage and the input source together are the input of the second stage. The energy stored in the leakage inductor of the coupled inductor is recycled by a passive voltage clamp to a capacitor. Therefore, the efficiency is improved.

II. OPERATING PRINCIPAL

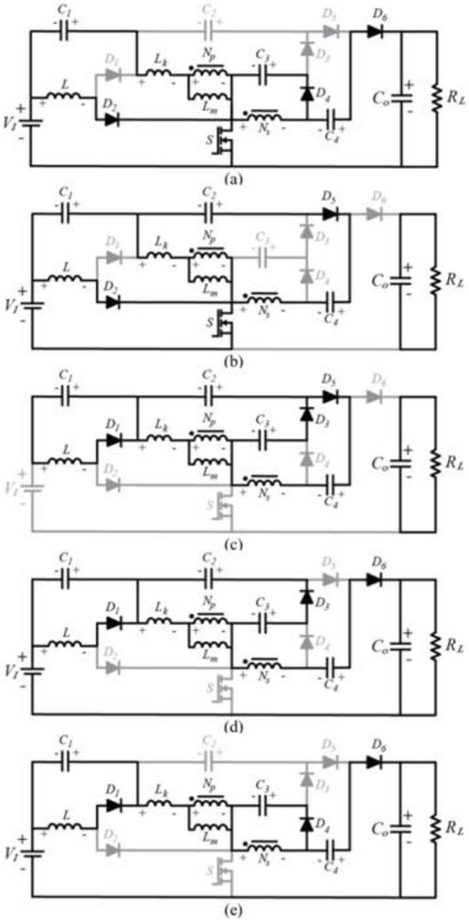
The converter consists of a DC voltage source in the input (VI), an inductor, a coupled-inductor, a power switch (S), six diodes, and five capacitors. Also, a resistive load is used at the output.



- During one switching period, the voltages across all the capacitors in the converter are considered to be constant because the capacitors are sufficiently large.
- All components are ideal except the coupled inductor, for which a leakage inductance is considered.

Continuous conduction mode (CCM) operation of the proposed converter includes five intervals in a single switching period. The operating stages are explained as follows:

- Mode I [t0≤t≤t1, see Fig. 3(a)]: In this interval, the main switch and diodes D2, D4, and D6 are turned on. The inductors L, Lk, and Lm are charged by the input source. The output capacitor is discharged to the load. This mode ends when the inductor currents Lk and Lm become equal.
- Mode II [t1≤t≤t2, see Fig. 3(b)]: In this interval switch S, diodes D2 and D5 are turned on. The inductors L, Lk, and Lm are charged by the input sources. Capacitor C4 is charged by the secondary side current of the coupled inductor and the energy is stored in the capacitors C1 and C2. The output capacitor provides energy to the load. This mode ends by turning the switch S off.
- Mode III [t2≤t≤t3, see Fig. 3(c)]: In this mode, switch S is turned off. Diodes D1, D3, and D5 are turned on. The leakage inductor current is decreased linearly. Capacitor C1 is charged by inductor L. Capacitors C2 and C3 is discharged to capacitor C4. This mode ends when the magnetizing and leakage inductor currents become equal.
- Mode IV [t3≤t≤t4, see Fig. 3(d)]: In this time interval diodes D1, D3, and D6 are turned on. The leakage inductor is demagnetized to capacitor C2 through diode D3. The secondary side current of the coupled inductor flows through diode D6 and charges the output capacitor. Capacitors C3 and C4 are discharged to capacitor C2 and the output capacitor, respectively. This mode ends when diode D3 is turned off.
- Mode V [t4≤t≤t5, see Fig. 3(e)]: In this mode diodes D1, D4, and D6 are turned on. Capacitors C1 and C3 are charged by inductor L and the secondary side of the coupled inductor, respectively. The magnetizing and leakage inductor currents are decreased linearly. Capacitor C4 is discharged to the load. This mode ends by turning the switch S on again.



(a)

(b)

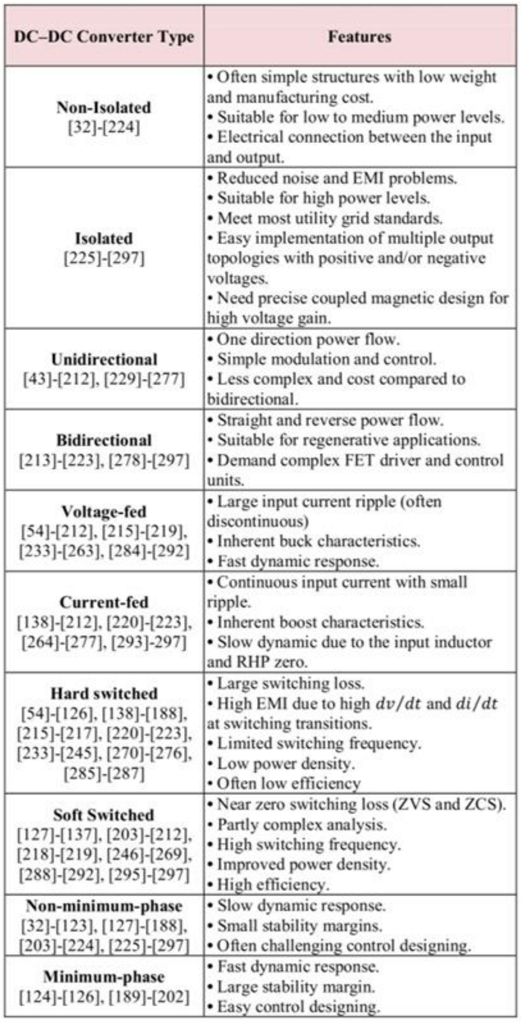
(c)

(d)

(e)

III. DIFFERENT VOLTAGE-BOOSTING TECHNIQUES

Step-up converters are used to implement various voltage boost techniques in dc–dc converters. Five major subsections are included, namely switches, voltage multiplier, switched inductor and VL, magnetic coupling, and converters with multistage level structures. In the following section, the general structures of these techniques are first illustrated and then major circuits are illustrated their underlying concepts. This technique has the two advantages of providing efficient regulation and eliminating current transients, which together are known as the soft-charging of SC converters. In this methodology for implementing this technique on several reviewed SC circuits was presented, which led to the development of a family of high-performance resonant SC converters. This converter employs the distributed stray inductances of each SC module to provide zero current turn ON and OFF to the devices, as a consequence, voltage and current spikes are reduced, power losses are minimized, and efficiency is increased.



DC–DC Converter Type	Features
Non-Isolated [32]-[224]	• Often simple structures with low weight and manufacturing cost. • Suitable for low to medium power levels. • Electrical connection between the input and output.
Isolated [225]-[297]	• Reduced noise and EMI problems. • Suitable for high power levels. • Meet most utility grid standards. • Easy implementation of multiple output topologies with positive and/or negative voltages. • Need precise coupled magnetic design for high voltage gain.
Unidirectional [43]-[212], [229]-[277]	• One direction power flow. • Simple modulation and control. • Less complex and cost compared to bidirectional.
Bidirectional [213]-[223], [278]-[297]	• Straight and reverse power flow. • Suitable for regenerative applications. • Demand complex FET driver and control units.
Voltage-fed [54]-[212], [215]-[219], [233]-[263], [284]-[292]	• Large input current ripple (often discontinuous) • Inherent buck characteristics. • Fast dynamic response.
Current-fed [138]-[212], [220]-[223], [264]-[277], [293]-297]	• Continuous input current with small ripple. • Inherent boost characteristics. • Slow dynamic due to the input inductor and RHP zero.
Hard switched [54]-[126], [138]-[188], [215]-[217], [220]-[223], [233]-[245], [270]-[276], [285]-[287]	• Large switching loss. • High EMI due to high dv/dt and di/dt at switching transitions. • Limited switching frequency. • Low power density. • Often low efficiency
Soft Switched [127]-[137], [203]-[212], [218]-[219], [246]-[269], [288]-[292], [295]-[297]	• Near zero switching loss (ZVS and ZCS). • Partly complex analysis. • High switching frequency. • Improved power density. • High efficiency.
Non-minimum-phase [32]-[123], [127]-[188], [203]-[224], [225]-[297]	• Slow dynamic response. • Small stability margins. • Often challenging control designing.
Minimum-phase [124]-[126], [189]-[202]	• Fast dynamic response. • Large stability margin. • Easy control designing.

IV. APPLICATIONS AND COMPARISON OF DC–DC CONVERTERS

Step-up dc–dc converters have been used for wide range of power conversion applications from the milli-watt scale upward e.g., from energy harvesting to MW-level high-voltage dc transmission systems. The recent emphasis on energy efficiency and renewable energy development has intensified research on step-up converters in both academia and industry. Some applications driving this demand include energy harvesting, medical implantable devices, portable devices, gadgets, and appliances, lighting technology, space and avionics, transportation (automotive and railway) technology, telecommunications, data center, industrial, renewable energy, and DG in dc micro grids, high-voltage technology (physics research, medical, and military), high-voltage/power dc–dc converters, and high-voltage dc (HVDC) systems in utility grid applications.

In the automotive transportation sector, various dc–dc converter types have been used in the electrification systems of EVs, FC-EVs, and plug-in HEVs. Based on their power flow direction, these converters can be classified as unidirectional or bidirectional. Unidirectional dc–dc converters are also used in onboard applications such as sensors, controls, utility, entertainment, and safety equipment. Bidirectional dc–dc converters are required for battery charging in regenerative braking and for back-up power. In the abovementioned applications, the voltage level of the battery storage system (∼180–360 V) is usually lower than in the loads (∼400–750 V), which led to the implementation of step-up dc– dc converters. Uninterruptable power supply (UPS) is another type of dc–dc converter application for use in integrated battery storage systems in which bi-directionally operating dc–dc conversion is desirable.

In high-power railway transportation systems, extracting the regenerative energy of a traction motor in the braking mode is a critical operation that requires the use of a bidirectional dc–dc converter. Furthermore, trains with battery storage systems should employ bidirectional dc–dc converters in order to maintain their dc voltage within a specific range (500–600 V) in interconnected operating mode and supply the dc feeder voltage (1–2 kV) in isolated operating mode. Similarly, the exploitation of regenerative energy from the electric motor of an elevator or escalator system in downward motion relies on the proper utilization of bidirectional dc–dc converters.

V. RESULT

The proposed converter boosts the input voltage 30V to 1363V in the output. Therefore, the voltage gain of the simulated converter is about 45. The inductor currents in which the inductor currents Lm and Lk are continuous. Therefore, the proposed converter operates in the CCM. The capacitor voltages are in which the output voltage is smooth enough and its voltage is about 1363V.The voltage across the main switch and its current. As shown in this figure, the voltage across the switch is clamped to 230V. Therefore, the voltage stress of the power switch in comparison with the output voltage low. As shown in the figure, by turning off the diode D3, the diode D4 is turned on; and by turning off the diode D5, the diode D6 is turned on. It justifies the validity of the converter analysis. The proposed converter topology is utilized without the voltage and power controller loops, because the aim and focus of this paper is to propose the new converter topology. However, advanced control techniques can be applied in order to regulate the output voltage of the converter in the case of changes in the load as well as the reference voltage.

CONCLUSION

In this paper, a new coupled-inductor-based cascaded DCDC converter with high voltage gain is proposed. The ongoing technological progress in high-voltage step-up dc–dc converter has five primary drivers—energy efficiency, power density, cost, complexity, and reliability—all of which also influence each other to some extent. The first stage of the converter is a buck-boost converter with a modified structure. The second stage is a high step-up converter with coupled-inductor and voltage multiplier cells. The output of the first stage and the input source together are the input of the second stage. The energy stored in the leakage inductor of the coupled inductor is recycled by a passive voltage clamp to a capacitor. Therefore, the converter efficiency is improved. Besides, the blocking voltage across the main MOSFET switch is reduced in this structure with voltage clamp circuit. Thus, a low on-resistance switch could be used which decreases conduction loss. The steady state analysis of the proposed converter is presented in the paper.

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