High Voltage Boost Converters: A Review on Different Methodologies and Topologies

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Abstract: ***Power converters are a fundamental element in the industries, micro-grids and households appliances providing all the necessary power regulation increasing flexibility of the voltage, current, power and phase. In this review a number of boost converters are studied, responsible for converting a low direct current voltage to a higher magnitude using a number of different methods including coupled inductors, series combination of a capacitor and two parallel inductors and an inductor discharging to two series connected capacitors in transfer of power. The converters encounter two major practical issues sudden rise in di/dt and dv/dt that drastically reduces the efficiency and increases power loss in passive elements and stress in active switches.***

Keywords: Boost Converter, DC power transfer, Zeta Converters, Dual active bridge (DAB), Miller capacitor, V2G operation.

1. Introduction

Boost converter is a fundamental component of a system dealing in changing the direct current power. It is responsible for boosting the input source voltage to a higher level following the law of conservation of power within the system and hence reducing the output current. In this study, a number of boost converter topologies are being considered from different literatures where authors introduced a number of methods including the technique of coupled inductors where two inductors are charged and transfer the power to the capacitor connected parallel across the load [2]. The method of transferring the charge to two parallel capacitors from energized inductor is a method exactly opposite to the previous method. A new topology of bidirectional control of power flow can be implemented in microgrids, renewable energy systems, automotive and other applications using the technique of switched capacitor has been proved to be an efficient method of buck/ boost in a single converter [1]. These converters provide power from source to the battery or battery back to the bus in opposite direction under the operation of buck-boosting the input voltage to a desired output under the necessary bi-directional power transfer conditions [5]. A number of di/dt and dv/dt techniques are implemented on converters to have an independent electronic control on the output terminal to a wide range for reducing the use of passive components. It is made in compact configuration of the power modulators and integrated gate drives [4].

2. Bi-directional Power Flow

In applications of renewable energy systems, railway transportation, automotive transportation and aerospace applications, elevators and escalators, uninterrupted power supplies, batteries, super capacitors and smart grid applications, where the use of bidirectional power flow plays an important role providing power to the bus or controlling the power balance in the system [1,5]. These converters can be efficiently designed for providing the stored power from the battery back to the grid is called as V2G operation [1]. A conventional converters having a drawback of leakage inductance and can be resolved by complex circuitry.

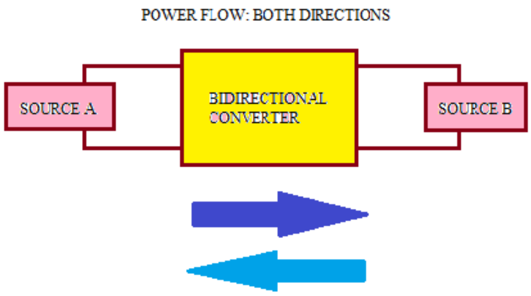

Figure 1: Power Flow in Bidirectional Converter

A general buck-boost converter can be improved into a three- level topology or a multilevel for the wider range of voltage generation and direct current voltage transfer gain. The major disadvantage in these multi-level converters is voltage capacitor balance. Zeta converters can be modified for the use in bidirectional voltage transfer techniques [1].

Dual active bridge (DAB) is a kind of isolated bidirectional dc-dc converter for high power applications. Energy transfer of the converter is controlled by adjusting the phase shift of the two ac voltages produced across the isolated transformer.

3. Power Flow Control by Switching and Semi-conductor Switches

In a distribution system, electrical transformers are existing component required for power flow control in the power system. On the other hand, use of the reactive components i.e. inductors and capacitors make the system more expensive and bulky. It may be considered that the use of series resistance is a way of absorbing power and negatively responsible for significant power loss (fig. 2 and 3). Therefore, the loads may be responsible for absorbing significant electrical power due to its inertia [9].

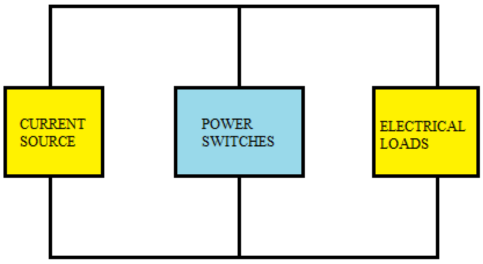

Figure 2: Parallel Configuration of Current Source, Power Switch and Electrical loads

In electrical loads, synchronous machines compensate the reactive power generated in the system. A grid is found to be efficient in adding minimum a synchronous machine to the system for absorbing or supplying reactive power.

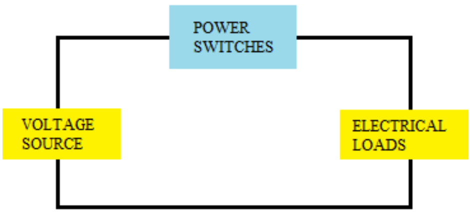

Figure 3: Series Configuration of Voltage Source, Power Switch and Electrical loads

4. Concept of Parallel Capacitor and a Inductor

A method of boosting an input voltage is done, implementing two series capacitors and an inductor. It is successfully designed and capable of increasing the efficiency to a high value of 95.03%. Parallel capacitors are charged during the time when the switch is turned off and energy stored in the capacitor is discharged to an inductor during turn on of the switch [2]. It enhances the voltage build across the inductor and boosts the input voltage.

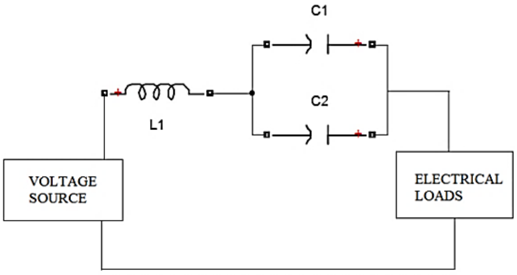

Figure 4: One Inductor Parallel Capacitor Configuration

Octavian Cornea et al. designed a boost converter for converting a voltage of 24V to a higher value of 400V for a power rating of 200W [2]. These circuits produce a very high-current transient which can be resolved by adding an inductor at the output of the parallel capacitor and resistive load circuit. An advantage of this method is reducing transient and efficient regulation of the converter together called as soft charging of switched coupled inductor.

5. Concept of Parallel Inductors and a Capacitor

A number of mutually coupled inductors are winded in a ferrite core of equal mutual inductance and resistance. A low dc voltage is switched in a periodic manner creating a fluctuating voltage across the primary inductor (fig. 5). Therefore, an induced voltage in the other inductors is induced and controlled by switching with semi-conductor switches. Energy stored in the inductors is transferred to a capacitor connected across the load in turn-off time of the switches connected in secondary inductors.

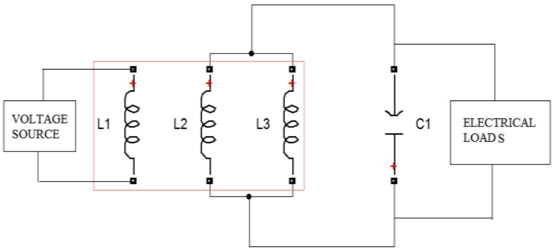

Figure 5: Parallel Inductorsand a Capacitor Configuration

A certain amount of harmonics produced in the converter can be minimized by implementing a harmonics filter. Conditions of di/dt and dv/dt, present in the output and switching characteristics can be reduced with a proper resistance-capacitance and active snubbers in the circuit [3, 5]. In absence of snubber circuit, high voltage spikes are producedacross input source and reflected in output voltage of the converter.

In designing of three single cored mutual inductors having partial resemblance with construction of a three winding transformer produces a finite magnitude of flux leakage in the core. Therefore, two methods are mentioned in testing the leakage and admittance;simulate the circuit considering finite element method (FEM) and laboratory measurements. Terminal Duality Model (TDM) analysis of the mutually coupled inductor in a single core illustrates the one-to-one relationship and terminal leakage measurement [7]. The duality model of mutually coupled inductors defines the magnetic flux distribution and leakage inductance in the inductors. Leakage flux path can geometrically be proved using the dual model of electric and magnetic circuit of the converter. Modeling of the inductor can be stated based on the steady state analysis and electromagnetic transient [8].

6. Single Switch Continuous Conduction Mode

In boost converters, a voltage spike suddenly appears as the switch is being reversed biased. A reverse biased recovery time of the continuous conduction mode creates a problem of dissipation and interference. Several voltage spikes are produced and to overcome these spikes, a number of active and passive circuits are being designed. In the literature, single switched continuous conduction mode converter is designed to reduce the reversed recovery time and switching losses. The proposed converter consists of a coupled inductor rectifier at the input and output node, connecting a rectifier between ground and common node of the coupled inductor rectifier branch. Leakage inductance of the coupled inductors is used to control the di/dt produced in the switches. It helps in both turning off the rectifier and clamping the output voltage. This does not require any extra snubber circuit from parasitic ringing. Boost switches can operate in low voltage turn-on conduction and the inductors provide parasitic capacitance to discharge before the switch is turned on [2].

7. dv/dt and di/dt control

A severe phenomenon of sudden rise of current and voltage within a very short period of time is practically observed in switching elements in converters. The technique of active gate control is used for flexible and independent control in the output current and voltage rise of insulated gate bipolar transistor (IGBT) and metal oxide semi-conductor field effect transistor (MOSFET), replacing the conventional resistance-capacitance (RC) snubber circuits. Miller effect is used to sense the collector terminal voltage and feedback to the gate terminal and reduces the dv/dt phenomenon. A number of advantages of the effect; control circuit begins as soon as drain voltage changes and collector voltage transient starts to rise without additional detection or timing circuit [4].

Controlling of the switch can be done during di/dt by changing the current gain or external impedance in the Miller capacitance. The circuit operates as there is turn on or turn off transient without any additional detection and timing circuits [4].

8. Boost Converter: Thermoelectric Energy Harvesting

Thermoelectric energy harvesting is a revolutionary technology implemented in biomedical engineering. A basic component is a low voltage and low power boost converter responsible forsupplying power to the device placed in the body. Medical and animal tracking sensors and devices are being powered with a maximum boosted voltage and power of 1V and 10uW and an input of 20mV to 250mV from the body. A major challenge is change in body temperature, as one side is placed in cold ambient air and other side in warm condition. Body temperature is affected by a number of parameter including ambient temperature, air flow and thermal insulation due to variety of clothing [6].

Discontinuous conduction mode is considered to be more effective as inductor is prevented from flowing negative and anaverage current is less the half of ripples current. In continuous conduction mode, the capacitor discharges and increases switching loss. The new modified method of synchronous rectifier described in number of literatures states that a reactive gate control uses a comparator to detect the p-type field effect transistor (pFET) becomes reversed biased and triggers a pulse to disable the switch. The two major disadvantages of the circuit; it requires a very fast comparator evaluation and gate driver for pFET. In order to overcome, a static (Complementary Metal Oxide Semi-conductor) CMOS flip-flop is implemented for the operation. The new topology improves overall efficiency of the converter by 15% than a general converter under conventional synchronous rectifier converter [6].

9. Conclusion

DC power transfer is a remarkable operation in every constant voltage system. Harmonics are being produced in the output of converters and can be reduced by filters including resistance-inductor,

inductor-capacitor and resistance-capacitance. The production of harmonics deviate the constant current or voltage output to a sinusoidal waveform results in undesired output of the circuit.

Switches are rapidly turned on or off and used to convert a dc voltage to fluctuating dc in application to mutual inductors results in voltage spike. Sudden spikes of triangular peak increase the voltage and current stress in the switches reducing the life time of elements in circuit.

In dc grid system, power is transferred in both directions using bi-directional DC-DC converter using switched capacitor technique. A number of renewable sources are cascaded including hydro, photovoltaic and wind. Boost converters using technique of energy transfer from series capacitors to an inductor can be used in the distributed system. It is also reliable to use the circuits to reduce the reverse recovery time and enhance performance of the converter and its system. A number of applications of the boost converter are motor drives and robotics in industries; automobile headlight and light emitting diode in lightning; data center and uninterruptable power supply in telecom; plasma research and particle accelerator in physics and pulsed laser and radars in military.

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