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SST based Extreme Fast Charging method for Electric Vehicles

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ABSTRACT

With the number of electric vehicles (EVs) on the rise, there is a need for an adequate charging infrastructure to serve these vehicles. The emerging extreme fast charging (XFC) technology has the potential to provide a refuelling experience similar to that of gasoline vehicles. In this paper, we review the state-of-the-art EV charging infrastructure, and focus on the XFC technology which will be necessary to support current and future EV refuelling needs.The proposed railway micro-grid is discussed, particularly concerning the configuration of the dual-active-bridge converter for regulating the power flow from the railway catenary to the micro-grid during an energy recovery transient, as well as by considering the DC-DC converter that is used in the micro-grid, together with battery storage to provide voltage stability according to the micro-grid operating condition.

KEYWORDS: Electric Vehicle, fast charging, emerging extreme fast charging

1. INTRODUCTION:

In the last decade, the utilization of fossil fuels and pollution problems more in vehicle applications. To overcome these problems the car manufacturer companies introduced electric vehicles. But the cost and weight of battery were not solved, since the batteries must provide power in peak stage and in transient state. These are some severe problems for batteries. Super capacitors and fuel cells have been used to overcome the problems in battery. Either battery or fuel cell or hybrid electric vehicles are environment friendly and more efficient as compared to combustion engine based vehicles. In the present scenario, hybrid electric vehicle and plug-in electric vehicle have been introduced to overcome the insufficient storage of battery operated EV.

In this paper, mainly focused on designing of battery charger for plug-in charge electric vehicle. The PEV charging or discharging conditions for available power and also gives the information provided by the energy management system instead of reducing the charging time by using only maximum power levels. To maintain this EMS, a simple power electronic based topology has been introduced. The design of the charger was based on bi-directional dc-dc converter which improves the efficiency of the system. The proposed DC-DC converter approach fulfills the desired operation of the bi-directional charger in the energy management system as compared with the topologies available in the literature. The power electronic converters have been used to size the passive elements by controlling voltage and current levels within the bounds.

The proposed single stage converter in the literature is simple topology with less components, but to operate the drive motor effectively, the single stage converter faces difficult. To overcome this problems, a boost type single stage converter has been proposed to obtain three-phase voltage even from a low-level DC input source. Single stage inverters has a limited capability to control frequency, power, output voltage and operating point to extract maximum power from the DC source. To extract this condition a boost type dc/dc converter followed by a three phase PWM based inverter is the developed. And also to improve the converter efficiency by reducing switching losses various soft-switching techniques have been proposed.

2. PROPOSED ELECTRIC VEHICLE STRUCTURE:

Generally, an Electric Vehicle is an automobile device and it consists of many components and more number of wires connecting them. The block diagram shown in figure 1, shows the minimum components required for an Electric Vehicle. In general EVs, the combustion engines are replaced by electrical motors and conventional fuel tanks are replaced by battery banks. In EVs both electric motor and batteries plays a key role and occupies 50% of total weight of the vehicle. As from the diagram, battery, power converter, electric motor, charger and energy management systems are the key components.

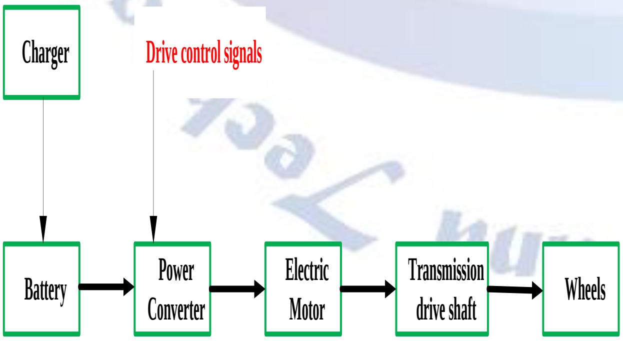

Figure 1: Block Diagram of EV

- In electric cars batteries are fuel sources. In order to reduce the cost and weight of the battery banks a super capacitor or fuel cell and plug-in charge-based devices are the alternative solutions.
- Generally, in EVs there is possibility to use two converters. One converter is to boost the battery or dc voltage by using suitable dc/dc converter and the second converter converters the battery energy to AC, which is required to operate electric motor efficiently. In this paper a single stage three level PWM based converter is proposed.
- In EVs, the batteries acts like fuel tanks and similarly the electric motors acts like an engines. There are different types of electric motors are available in present market like, BLDC motor, Brushed DC motor and Induction Motors. In this paper, the induction motor is chosen as engine in EVs.

DC-DC Converter:

Based on the different configurations of EV, it requires at least one dc/dc converter to interface battery, fuel cell or supercapacitor with common DC link. DC/DC converter might be step-up converter which increases the low-level input voltage or a step-down converter which does the opposite. In EVs, the step-down converter requirement is to operate low level voltage components such as radio, air conditioning, dashboards etc. while the step-up converter is used to obtain required voltage levels to operate motor efficiently.

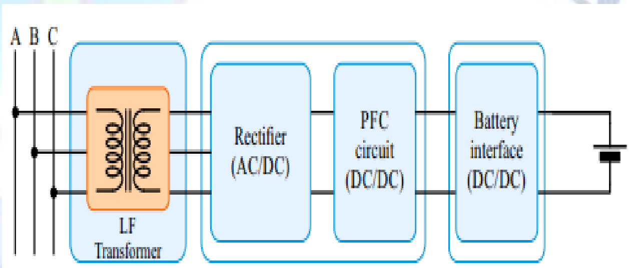

Figure 2: Single-module charger with a non-isolated DC/DC converter

Half-bridge buck-boost DC/DC converter:

The half-bridge buck-boost DC/DC converter is the simplest and most utilized bidirectional DC/DC converter topology, shown in Figure.

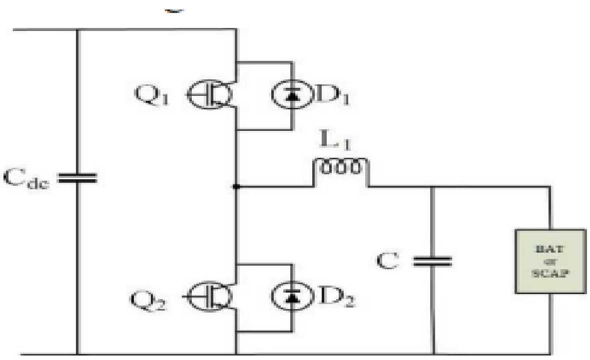

Figure 3:Half-bridge buck-boost DC/DC converter

The capacitor Cdc represents the main drive's DC link and the block BAT/SCAP represents the energy storage element. During braking, energy flows from the DC link towards the energy storage element i.e. the converter functions as a buck converter. The duty cycle of transistor Q1 controls the amount of power conveyed to the battery. During this mode of operation, the inductor L1 functions as a filter. When the energy flows from the battery towards the DC link, the converter functions as a DC/DC boost converter. The duty cycle of transistor Q2 controls the amount power sent to the DC link. During either flow direction, the converter operates in continuous-current mode. This topology advantage is that it only uses two controlled switches in complementary duty cycles which simplifies the excitation circuitry and control.

Interleaved buck-boost DC/DC converter:

The interleaved buck-boost DC/DC converter is a parallel connection of two or more half-bridge DC/DC converters. The control signals are phase shifted by an angle of 360°/n, where n is the number of parallel phases. Fig. shows an example of the converter with 3 parallel phases.

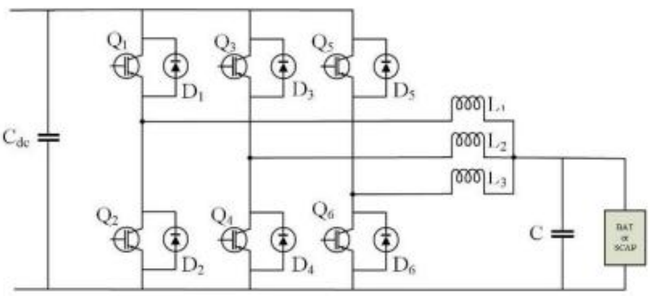

Figure 4: Interleaved buck-boost DC/DC converter

The advantage of this converter is a lower charging current ripple since phase-shifted signals control each phase. For this reason, filters of lower values and dimensions are used. Also, due to current split on multiple phases (I/n), for the same switching frequencies and for the same average output current value, the total losses of the semiconductor switches in this topology are smaller in relation to single phase half-bridge buck-boost DC/DC converter shown in figure 4. For this reason, this converter topology results in higher efficiency and power density [4], [5]. The main disadvantage is the higher cost due to the higher number of semiconductor devices integrated in the converter as well as a more complicated control algorithm [4].

Buck-boost DC/DC converter with coupled inductors

Fig. shows a buck-boost DC/DC converter with magnetically coupled inductors with the same number of turns [5].

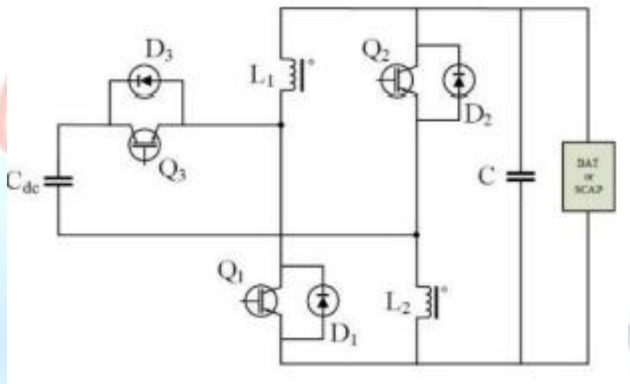

Figure 5: Buck-boost DC/DC converter with coupled inductors

In boost mode, when energy flow is from the BAT/SCAP energy storage element to the DC link Cdc, Q3 switch is not conducting and a control signal are sent to switches Q1 and Q2 simultaneously. When Q1 and Q2 are conducting, inductors L1 and L2 are in parallel and are accumulating energy from the BAT/SCAP energy storage element. When Q1 and Q2 are switched off, the inductors are in series with the load and delivering energy through the diode D3. In buck mode, when the energy flow is reversed, a control signal is sent to Q3 while Q1 and Q2 are off. When Q3 is conducting, the inductors are in series and act as a filter along with the capacitor C. When Q3 is switched off, current flows through forward-biased diodes D1 and D2. Advantages of using this topology instead of the halfbridge buck-boost DC/DC converter are a lower current stress of the switches, a higher efficiency and a higher voltage increase during boost mode [5].

Dual active full-bridge DC/DC converter

This DC/DC converter consists of two bridge converters, one on the high voltage side (primary) and one on the low voltage side (secondary) of a high-frequency transformer Tr, Figure 6. Using transformer, galvanic isolation and a necessary voltage increase or decrease are achieved. Using the leakage inductance Lk and by implementing commutation capacitors Cc1–Cc8, soft-switching is accomplished to reduce switching losses [7].

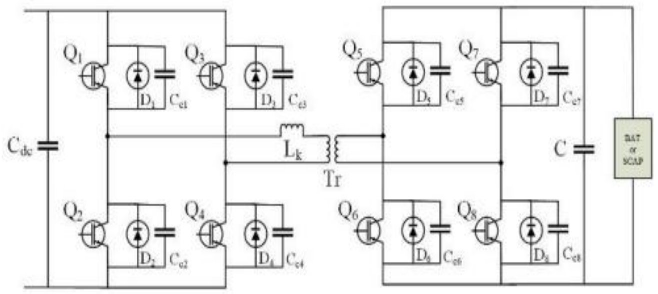

Figure 6: Dual active full-bridge DC/DC converter

Depending on energy flow direction, one converter functions as an inverter and the other as a full-wave rectifier. E.g. if energy flows from the DC link to the battery, the converter connected to the DC link functions as an inverter and the converter connected to the battery functions as a rectifier. The swicthes are switching in diagonal pairs with a duty cycle of 0.5, generating a square-wave voltage waveform on the primary and secondary. Multiple power flow control methods exist for this converter topology. A basic and commonly used one is controlling the phase shift between the transformer's primary and secondary, called the phase shift control strategy. The advantage of this topology is the operation on high frequencies and the consequently usage of a relatively small transformer to achieve galvanic isolation and high-power density assuming that the leakage inductance is sufficiently low [3].

Dual active half-bridge DC/DC converter:

This converter consists of two half-bridge converters, one on the high voltage side (primary) and one on low voltage side (secondary) of a high frequency transformer Tr.

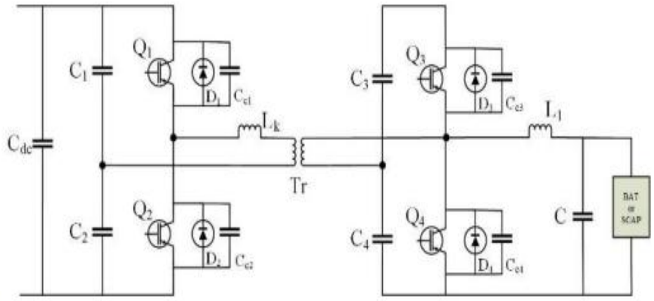

Figure 7: Dual active half-bridge DC/DC converter

Similarly, as in the dual active full-bridge DC/DC converter, the amount of power and direction of energy flow is controlled through the primary and secondary voltage phase shift. During power transfer from the high voltage side to the low voltage side, switches Q3 and Q4 along with the inductor L1 achieve a DC/DC buck converter. During power transfer from the low voltage side to the high voltage side, the aforementioned components accomplish the effect of a DC/DC boost converter. The voltage on the primary and secondary is a square-wave waveform. Primary voltage amplitude is equal to half of the DC link voltage. Secondary voltage amplitude is equal to half the voltage on the series capacitors C3 and C4. In comparison with the dual active full-bridge DC/DC converter, the dual active half-bridge DC/DC converter has half the amount of semiconductor devices for the same amount of rated power. Furthermore, the buck/boost converter on the low voltage side achieves lower current ripple on the side of the energy storage element and lower switch current stresses [10].

Operation Modes of the Proposed Converter:

In addition to mentioned features in [10], such as utilizing multi input and providing multi output, the proposed converter is bidirectional. Therefore, various charging modes such as battery discharge mode, battery charging through the inputs, and battery charge mode in the braking mode are available in the proposed structure which increases the converter's efficiency. The mentioned modes are individually elaborated and mathematically analyzed in follow sub-sections. The proposed converter is subjected to a small voltage stress on the S0 due to the use of the multi-stage m-level multiplier circuit.

Power supply mode with battery discharge:

In this mode, the connected load to the converter is fed from the battery as well as other input sources where the energy from all connected input sources can be used simultaneously. Mathematical analysis is expressed for two inputs (the battery and one main source) and two outputs. In this mode, the switch S3 and Sb (brake switch) is always OFF, switch ST (transfer switch) is always ON, and the rest of the switches, also, are ON. In this mode, the output voltage (VO) is controlled by the switches S0, S1 and S2. This mode of the converter as well as its main waveforms are shown in Figure 8. Four switching orders of converter in this mode are expressed as follow:

1) **Time interval 0<t<D1T:**

In this mode, the load connected to the converter is fed from both the battery and the other sources. Hence, all connected resources can be utilized simultaneously. Mathematical analysis is expressed for two inputs and two outputs. In this mode, the switch S3 and Sb is always OFF, switch ST is always ON, and the rest of the switches are ON. The output voltage (VO) in this mode is controlled by the switches S0, S1, and S2, in which their switching order.

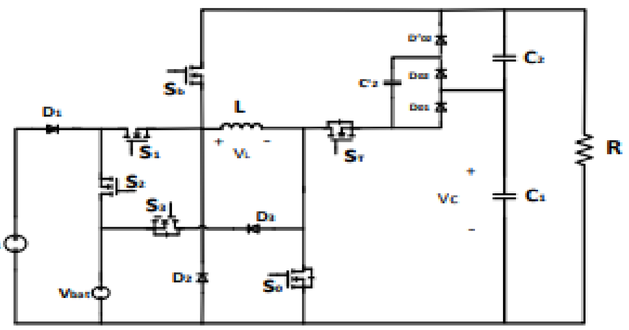

Figure 8: Proposed converter with two-input and two-output

3. SIMULATION DIAGRAMS AND RESULTS

Simulation results are provided to confirm the performance of the proposed converter in three operation modes. Simulations are performed in MATLAB/Simulink environment, and simulation parameters are shown.

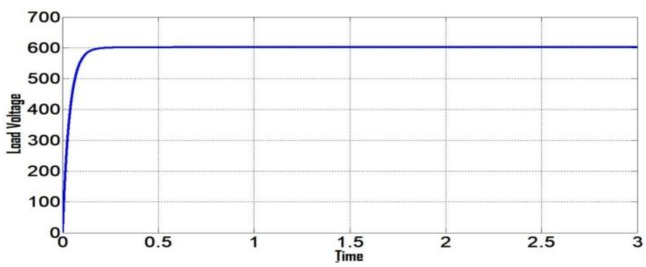

Fig 7: Load voltage of converter (V0) during battery discharge mode using PWM

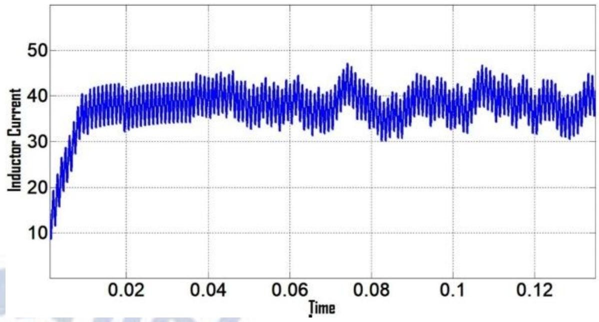

Fig 8: Inductor current (il) during battery discharge mode using PWM

Simulation Results during battery charge in braking mode using PWM:

In this mode, the load voltage considered as input, and there generative energy is stored in battery. In braking state only the switch Sb is activated and the battery charging power supplied through it. The converter operates as a buck converter, and the load voltage is used as the power supply source for the battery charging.

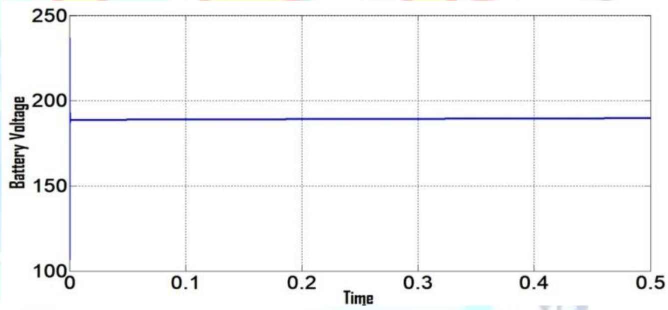

Fig 9: Voltage of battery (Vbat) during battery charge in braking mode using PWM

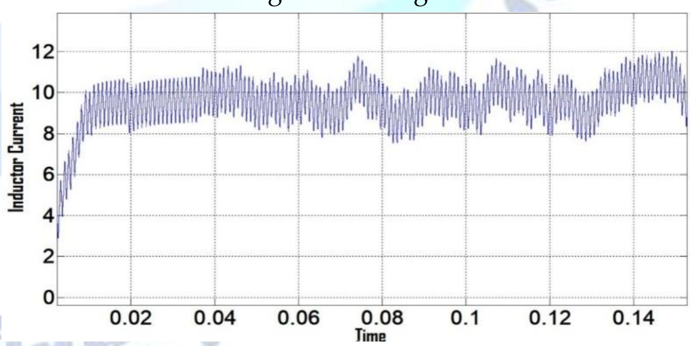

Fig 10: Inductor current (il) during battery charge in braking mode using PWM

Simulation results during battery discharge using SVM:

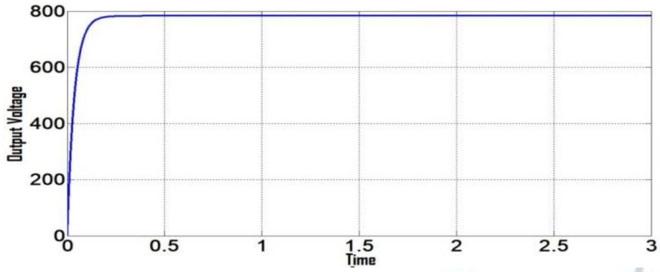

Fig 11: Load voltage of converter (V0) during battery discharge mode using SVM

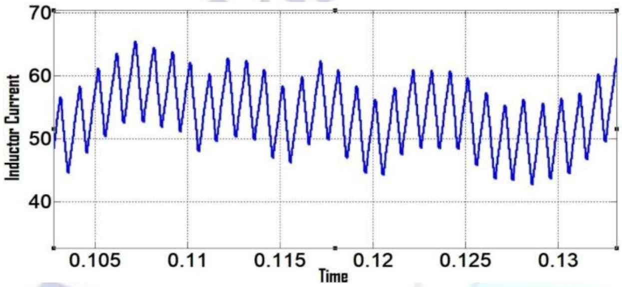

Fig 12: Inductor Current of converter during battery discharge mode using SVM

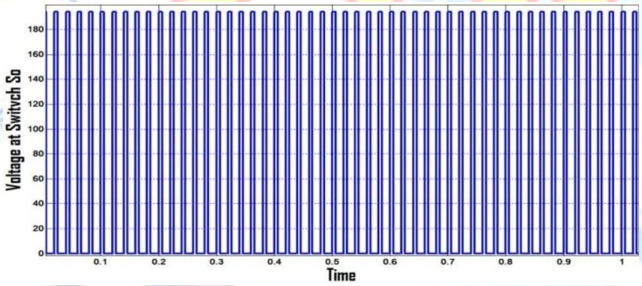

Fig 13: Voltage across switch (So) during battery discharge mode using SVM

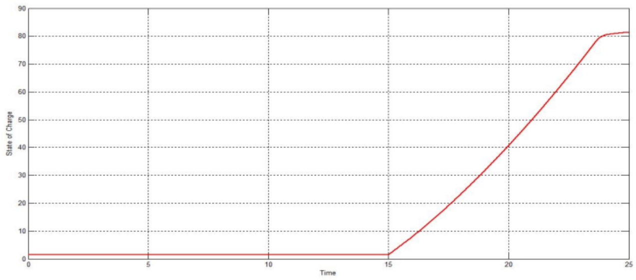

Fig Fig 14: EV Battery Charging Conditions using PWM Controller

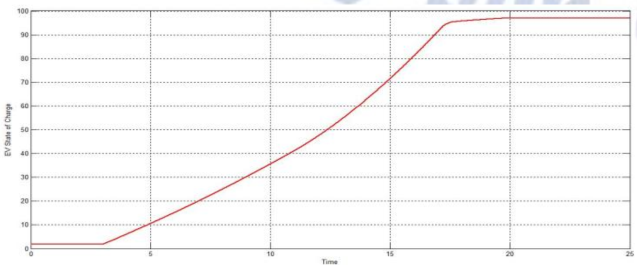

Fig 15:EV Battery Charging Conditions using SVM Controller

Comparitive Table for EV Charging Converter

S.No	DC-DC Converter	Load Voltage	Battery Voltage	SOC
1	Proposed Converter with PWM	600V	150V	82%
2	Proposed Converter with SVM	800V	210V	94%

4. CONCLUSION

This paper proposes a new structure for bidirectional non-isolated DC-DC converter with Space vector modulation technique to improve the performance of dc-dc converter. The main advantages of the proposed converter are capability of using different sources with different voltage and current characteristics, high voltage gain without using high duty cycle, and high-frequency switching and it can be used for transferring energy between different energy resources. Moreover, voltage stress on the main switch is decreased significantly due to the existence of the voltage multiplier inverter in the output. The proposed converter can operate bi-bidirectionally in buck and boost mode. In this paper, the different operation modes of the converter were presented. Simulation results of a two-input two-output converter were validated for the correct operation of the proposed structure. Space vector modulation-based converter involve slow voltage stress on the switching operation of the converter there by providing an ease of flexibility in designing the switching sequence as per the requirements and thus an optimal voltage or current is obtained when compared.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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