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Review on Converters used in Electric Vehicle Drive System

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ABSTRACT

Electric vehicles (EVs) are gaining popularity due to their improved performance and environmentally friendly nature. The effectiveness of EVs depends on the successful interface between their energy storage systems and propulsion motor. One of the key components of an EV is the motor converter, which converts the electrical energy stored in the battery into mechanical energy that powers the vehicle's propulsion system. The motor converter used in EV drive system is reviewed. Non- isolated converter for DC/DC conversion and DC/AC converter to drive the motor are stated. Despite their usefulness, EV converters have some drawbacks, large number of components, high current stress, high switching loss, slow dynamic response, and computational complexity. This review examines various EV converter configurations, highlighting their topology, features, components, operation, strengths, and weaknesses.

KEYWORDS: *Electric vehicle, Converters, Inverters, Bi-directional DC/DC converter, Regenerative braking*

1. INTRODUCTION

An electric vehicle (EV) is a type of vehicle that runs on electricity rather than internal combustion. This electricity is usually stored in a battery and supplied to an electric motor, which powers the vehicle's propulsion system. One of the main advantages of EVs is that they produce zero emissions at the point of use, which makes them a cleaner alternative to traditional gasoline-powered vehicles. In addition, the cost of operating an EV is typically lower than that of a gasoline-powered vehicle, as electricity is cheaper than gasoline and EVs require less maintenance.

EVs come in a variety of different forms, including cars, buses, trucks, and motorcycles. Some EVs are fully electric, meaning that they can only be powered by electricity, while others are hybrids, which combine an electric motor with a gasoline or diesel engine.

Overall, electric vehicles are a promising technology for reducing the environmental impact and dependency on fossil fuels of transportation.

2. RESEARCH METHODOLOGY

The research design for this study is a systematic review of literature. The goal of this systematic review is to identify the converter topologies most used in electric vehicle (EV) applications by analyzing a large number of papers on this topic. The sample selection for this study includes identifying and selecting a group of papers that are relevant to the research question "What are the converter topologies most commonly used in electric vehicle (EV) applications?" The sample size is approximately 50 to 60 papers published in recent years.

The sample is selected by searching various academic databases and conference proceedings for papers that specifically discuss converters used in electric vehicles.

Data analysis for this study, is done byCategorizing the papers according to converter topologies and EV applications, using content analysis method, the papers were reviewed and grouped into different categories based on the converter topologies used and the EV applications. This allowed for the identification of patterns and themes in the data, such as which converter topologies were most used in different EV applications.

Cross-checking of results with the literature and making sure that the findings were consistent with the literature review.

Contribution: The main contributions of this study are, the identification of the converter topologies mostly used in EV application, and the classification of these topologies according to the different EV motor power drive systems, which could be useful for researchers and engineers in the field of Electric vehicle. Furthermore, the study aims to provide an up-to-date overview of the state of the art in converter topologies used in EV's.

3. ELECTRIC VEHICLE TECHNOLOGY

A. ELECTRIC VEHICLE CLASSIFICATION

On a day we come across many kinds of electric vehicle in automobile industries, thus EVs can be classified based on the type of engine technology they use to power the vehicle. Here are some common classifications of EVs based on engine technology

Battery electric vehicles (BEVs): These vehicles are powered solely by an electric motor and a battery pack. BEVs do not have a gasoline engine and do not produce any tailpipe emissions.

Plug-in hybrid electric vehicles (PHEVs): These vehicles have both an electric motor and a gasoline engine and can be charged by plugging them into an external power source. PHEVs can run on electricity for a limited distance before switching to gasoline power.

Hybrid electric vehicles (HEVs): These vehicles have both an electric motor and a gasoline engine, but they cannot be plugged in to charge the battery. Instead, the battery is charged using energy recovered from braking and from the gasoline engine.

Fuel cell electric vehicles (FCEVs): These vehicles use a fuel cell to generate electricity, which powers the electric motor. FCEVs are fueled by hydrogen, which is stored in a tank on the vehicle.

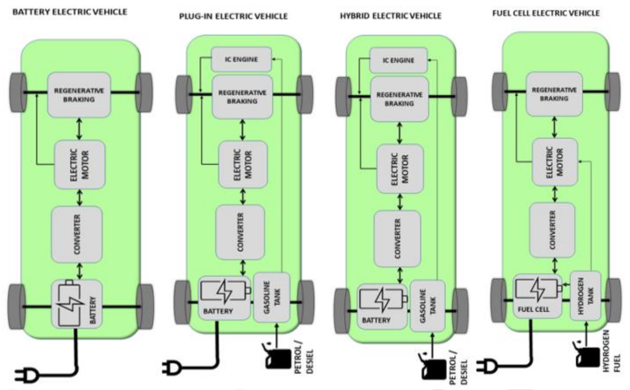

Figure 1: Electric Vehicle Powertrain

B. ELECTRIC VEHICLE ENERGY STORAGE SYSTEM

Energy storage systems are essential for electric vehicles (EVs) as they store and provide the electricity needed to run the vehicle's electric motor. There are several different types of energy storage systems that can be used in EVs, including batteries, supercapacitors, and flywheels. Batteries are the most common type of energy storage system used in EVs and store electricity in chemical form, releasing it as direct current electricity to power the motor.The performance and cost of energy storage systems for EVs are constantly improving and new technologies are being developed to increase the range and efficiency of EVs. For example, the use of advanced battery technologies such as lithium-ion batteries havegreatly improved the range and performance of EVs, making them more appealing to consumers. Energy storage systems for EVs can be classified into four groups based on their application: electrochemical battery systems, chemical storage systems, electromagnetic storage systems, and hybrid systems. (Habib et al., 2021; Hasan et al., 2021)

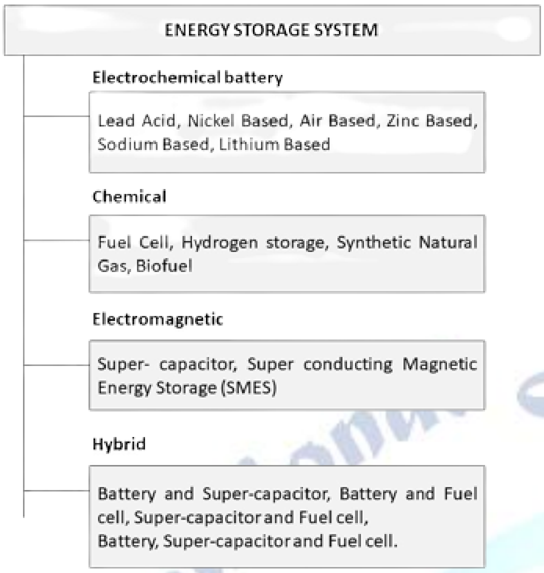

Figure 2: Overview of ESS

C. ELECTRIC VEHICLE CHARGING

Electric vehicle (EV) chargers get their power from the electrical grid. The electrical grid is a network of power plants, transmission lines, and distribution systems that delivers electricity to homes and businesses. The power plants that generate electricity for the grid use a variety of methods to produce electricity, The mix of power sources that are used to generate electricity for the grid can vary depending on the location and the availability of different types of fuel we have thermal generation, hydroelectric generation, biomass generation, and then comes the renewable power sources solar generation, wind generation, geothermal generation. Thermal generation is the largest source of electricity in India, accounting for about 75% of the country's installed generation capacity. Hydroelectric generation accounts for about 17% of installed capacity, while renewable energy sources (including solar, wind, and biomass) account for about 8%. The remaining generation capacity comes from nuclear power.

In some cases, EV chargers may be powered by renewable energy sources such as solar panels or wind turbines. These sources can generate electricity that is used to charge the vehicle's battery directly, without the need for an electrical grid connection. Charging stations powered by Solar charging: Some EV charging stations, or owners have installed solar panels on their homes or businesses to generate electricity for charging their vehicles.

Electric vehicle (EV) charging refers to the process of using electricity to charge the battery of an electric vehicle. There are several types of EV charging technologies conductive charging, inductive charging, battery swapping and on board and off board charging technology. Electric vehicles can be charged by two methods: on-board charging and off-board charging. On-board charging involves using a charger that is installed on the vehicle to convert alternating current (AC) power from a wall outlet or charging station into direct current (DC) power, which is then used to charge the vehicle's battery. Off-board charging involves using a charging station that is separate from the vehicle to convert AC power into DC power, which is then provided to the vehicle's battery directly. The difference between the two methods is the location of the AC-to-DC conversion, which is either on the vehicle (on-board charging) or at a separate charging station (off-board charging). Charging time is the key bottleneck, in ESS.

Level 1 charging: This is the slowest type of charging and is typically done using a 120-volt outlet. It can take anywhere from 8 to 24 hours to fully charge an EV using Level 1 charging.

Level 2 charging: This type of charging is faster than Level 1 and is typically done using a 240-volt outlet. It can take anywhere from 4 to 8 hours to fully charge an EV using Level 2 charging.

Level 3 charging (also known as "DC fast charging"): This is the fastest type of charging and can add hundreds of miles of range to an EV in just a few hours. Level 3 charging stations use specialized high-voltage equipment to charge an EV's battery.

4. ELECTRIC VEHICLE DRIVE SYSTEM

An electric vehicle (EV) consists of several major subsystems, including:

The electric powertrain: This is the main propulsion system of the EV, which consists of the electric motor, the inverter, and the drivetrain. The electric motor converts electrical energy into mechanical energy to power the vehicle, the inverter converts direct current from the battery pack into alternating current for the motor, and the drivetrain transmits power from the motor to the wheels.

The battery pack and charging system: The battery pack stores electrical energy and supplies it to the electric motor, while the charging system is used to recharge the battery pack by supplying electrical energy from an external source. The capacity and performance of the battery pack are key factors that determine the range and performance of an EV.

The on-board computer and vehicle controls: The on-board computer is the central control system of the EV, which manages the overall operation of the vehicle. It receives input from sensors and actuators, processes this data, and sends commands to various subsystems to control the vehicle's functions, such as acceleration, braking, and steering. The vehicle controls include the dashboard, steering wheel, pedals, and other user interfaces that allow the driver to interact with the vehicle.

In this work, different motors employed in electric vehicle and converter used for motor drive are reviewed

D. ELECTRIC VEHICLE MOTORS

Electric vehicles (EVs) use one or more electric motors for propulsion. These motors convert electrical energy into mechanical energy to power the vehicle. There are several types of electric motors that are commonly used in EVs, these motors differ in terms of their construction, operation, efficiency, and cost. Understanding the various types of motors used in EVs is important for selecting the most suitable motor for a given application and optimizing the overall performance of the vehicle.

Electric motors are often required to produce a high level of torque when starting, accelerating, or climbing. This level of torque can be up to 10 times the torque produced at a constant speed. In the field of electric vehicle propulsion, several types of motors are commonly used, including Direct Current (DC) motors, Brushless Direct Current (BLDC) motors, Induction motors, Permanent Magnet Synchronous Machines (PMSM) and Switched Reluctance Motors (SRM). Usage of these motor in commercially available electric vehicle listed in chronological order (Ozdemir, 2020),the motor used, and model of the vehicle are stated.

DC motoris an electric motor that uses direct current (DC) to generate mechanical power, this was employed in early days of EV are batteries are used as a source. They are made up of two main parts: a stator, which is stationary and often contains permanent magnets, and a rotor, which is the rotating part and contains windings. DC motors are advantageous because they can produce a lot of torque at low speeds. However, they have some drawbacks as well. They tend to be large and not very efficient, and the brushes used to transfer electricity to the rotor can cause losses and require maintenance. Additionally, brushed DC motors have limited capacity for regenerative breaking, which is a way of using the motor as a generator to slow down or stop a device. AC motors, which use alternating current, have become more advanced and widely used due to developments in power electronics and control systems, making DC motors less popular in comparison.

AC induction motor, also known as an asynchronous motor, is a type of electric motor that is commonly used in electric vehicles (EVs) and other electric drive systems. Induction motors work on the principle of electromagnetic induction, in which a current flowing in the stator (stationary) windings induces a current in the rotor (rotating) windings. One of the main advantages of induction motors is their simplicity and robustness. Induction motors have fewer parts than other types of motors, such as Interior Permanent Magnet (IPM) motors, which makes them less expensive and easier to maintain. Additionally, they do not require any permanent magnets, which can be expensive and have limited availability, particularly rare-earth magnets. Another advantage of induction motors is their high efficiency. Induction motors have a lower rotor resistance compared to Permanent magnet motors, which results in less energy loss and more efficiency. Induction motors also have a good power factor. The power factor of an induction motor is close to unity, which means that it can effectively use the power that it draws from the power supply. This makes them well-suited for use in EV and other power drive systems, where power consumption needs to be minimized. They are rugged and efficient but require a complex inverter to control the speed.

Tesla is undoubtedly the most popular brand using IM in the automotive market. Some models of Chevrolet, Chrysler, and Renault also use IM in their drive systems

Permanent magnet synchronous motors (PMSMs) are a type of electric motor that is commonly used in electric vehicles (EVs). PMSMs are also known as brushless DC motors or synchronous AC motors. They use a permanent magnet in the rotor (rotating part of the motor) to create a rotating magnetic field, which is synchronized with the stator's (stationary part of the motor) field. PMSMs offer several advantages over other types of motors, including high efficiency, high power density, and good torque characteristics. They are also highly reliable and require minimal maintenance, as they do not have brushes and commutators like brushed DC motors. However, PMSMs can be more expensive to manufacture due to the use of rare earth permanent magnets. They also require a complex inverter to control the speed and torque of the motor. Overall, PMSMs are a popular choice for EVs due to their high efficiency and performance. Examples of EVs manufacturers that use PMSM are Nissan Tino, Honda Insight, and Toyota Prius

Switched reluctance motors (SRMs), are a type of electric motor that is used in some electric vehicles (EVs). SRMs are known for their simple construction, ruggedness, and ability to operate over a wide speed range. They do not have any permanent magnets in the rotor, which makes them less expensive to manufacture than other types of motors, such as permanent magnet synchronous motors (PMSMs). However, SRMs are generally less efficient and have lower power density than PMSMs. They also require a complex control system to optimize their performance. Despite these limitations, SRMs have been used in some EVs due to their low cost and simple design.

Brushless DC motors (BLDCs) are a type of electric motor that is commonly used in electric vehicles (EVs). BLDCs are also known as electronically commutated motors (ECMs) or AC synchronous motors. They use electronic switches to transfer current to the rotor (rotating part of the motor), which eliminates the need for brushes and commutators like brushed DC motors. As a result, BLDCs require less maintenance and generate less heat than brushed DC motors. BLDCs are highly efficient and have a high-power density, which makes them a popular choice for EVs. They also offer good torque characteristics and can operate over a wide speed range. However, BLDCs require a complex inverter to control the speed and torque of the motor, which can add cost and complexity to the system. Overall, BLDCs are a reliable and efficient choice for EVs, and are widely used in many different types of electric vehicles.

5. ELECTRIC VEHICLE CONVERTERS TOPOLGY FOR MOTOR DRIVE

The motor converter, also known as an inverter or drive controller, is a key component in an electric vehicle (EV) that is responsible for converting the electrical energy stored in the battery into mechanical energy that powers the vehicle's propulsion system. The motor converter plays a crucial role in the overall performance and efficiency of an EV, as it controls the flow of electrical energy to the electric motor and regulates the motor's speed and torque.

The configuration of converter in EV can be categorized based on

- Topology classified as: Non – isolated and Isolated converter,
- By direction of power-flow it is classified as: Unidirectional and Bidirectional,
- By energy conversion classified as: inverter (DC/AC converter) and rectifier (DC/DC converter).

Electric vehicle motor drive compress of a battery, front end converter a DC/DC converter to supply a rectified DC voltage to the Inverter that powers the different kinds of motor employed in EV manufacturing.

(Lin et al., 2016), has presented PMSM drive and its operation control. The PMSM drive proposed consist of power circuit consists of a two-leg interleaved bidirectional front-end DC/DC buck-boost converter and three phase inverter which allows for adjustable and boost able DC link voltage to enhance the high-speed driving performance as well as allowing battery bank charging from the motor during regenerative braking. Additionally, robust control schemes are developed that provide good current sharing between modules with fast disturbance rejection response against module faults or recovery.(Lulhe et al., n.d.), discuss various drives used in EV and HEV vehicle, here PMSM is conclude as most used motor, the DC drive and AC drive to operate the motor are compared. Universal DC-DC converter is used (front end converter) as a boost converter when the power flow is from the battery to the DC link, and vice-versa. It can also be used as a buck converter when the power flows from the DC link to the battery a bidirectional power flow during braking, AC drive topology of two three phase inverter, and matrix inverter are explained.

(Liaw et al., n.d.), explains the basic and key technologies of switched-reluctance machine in motor and generator operations and some commonly used front-end converters and their operation controls for SRM drive, for DC source two DC/DC front-end converters are stated one leg buck-boost converter and H-Bridge four quadrant converter. For AC source boost unidirectional and a boost/buck bidirectional switched mood rectifier. The SRM drive consists of asymmetric bridge converter shown has the most flexible PWM switching capability, and it is also the most generally adopted one for SRM drive, two diodes and two switches are required in one phase. For each phase, the lower switch conducts commutation switching, while the upper switch is in charge of PWM switching.(Saranraj U & Hemamalini, 2007), proposes modified single-switch-per-phase converter for SRM drive, which performs better utilization than the asymmetric bridge converter. (Thankachan & Singh, 2020), proposes power circuit formed by the combination of a front-end circuit bidirectional DC/DC converter and a modified-Miller SRM converter.

(Yadav et al., 2016), the proposed BLDC drive power circuit consists of Buck–boost converter and Voltage Source Inverter (VSI) fed BLDC drive system.(Tripathi et al., 2021), proposes a three-phase resonant boost inverter (TPRBI) fed BLDC drive system this AC drive has an advantage in higher maximum torque per ampere, lower value of total blocking voltage compared to conventional VSI-fed PMBLDC motor drive.

(Aguado et al., 2011), proposed an induction motor fed by a Z-source inverter (ZSI), Z-network composed of two capacitors and two inductors connected to the three phase bridge inverter.(Akhtar & Behera, 2021), proposed a converter for long driving range of the electric vehicle , a new distributed inverter fed induction motor (IM) drive is proposed each phase of induction motor is fed by single-phase H-Bridge inverter individually. In this way, it reduces the parallel combination of battery.(Choudhury et al., 2014), proposes induction motor fed by two level and three level inverter.A two-level inverter is a type of inverter that uses two levels of voltage (typically high and low) to control the speed and direction of an induction motor. A three-level inverter, on the other hand, uses three levels of voltage (typically high, medium, and low) to control the speed and direction of an induction motor.

With the above review of the electric vehicle motor drive systems employed, different configurations of DC drives and AC drives are observed. The motors used in EVs are powered by energy storage systems. Without direct connection from ESS to the motor drive, for better performance, a DC/DC converter is employed; that converter must provide a bi-directional power flow because regenerative braking is undertaken in the EV propulsion system.

6. Bi-directional DC/DC topologies

Some of the common Bi-directional DC/DC topologies are stated in this paper(Alatai et al., 2021)

A.BI-DIRECTIONAL BUCK-BOOST CONVERTER

A bi-directional buck-boost converter is a type of DC-DC converter that can operate in both buck and boost modes. It can accept input voltage that is either higher or lower than the desired output voltage and adjust the voltage level accordingly.

HALF BRIDGE TOPOLOGY

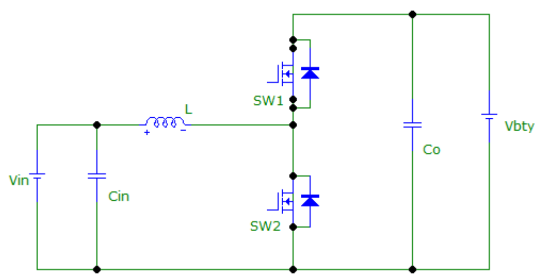

Figure 3: Bi-directional half bridge buck-boost converter

The half-bridge version of the converter is composed of two switches: a high-side switch and a low-side switch. These switches are controlled by a switching circuit, which regulates the input voltage and provides the appropriate output voltage.

During buck mode operation, the converter reduces the input voltage to the desired level. The high-side switch (sw1) is turned on, while the low-side switch is turned off. This allows the input voltage to be applied across an inductor. During this time, the inductor stores energy, which is then released as the high-side switch is turned off, and low-side switch is turned on. This causes the voltage across the inductor to be transferred to the output. During boost mode operation, the converter increases the input voltage to the desired level. The low-side switch is turned on (sw2), while the high-side switch is turned off. This allows the input voltage to be applied across a capacitor. During this time, the capacitor stores energy, which is then released as the low-side switch is turned off, and high-side switch is turned on. This causes the voltage across the capacitor to be transferred to the output.

CASCADED HALF BRIDGE TOPLOGY

Cascaded H-bridge converter is a type of DC-DC converter that combines the features of both a buck-boost converter and an H-bridge converter.

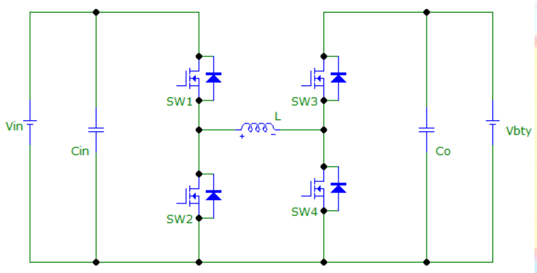

Figure 4: Bi-directional cascaded half bridge buck-boost converter

It can operate in both buck and boost modes and can accept input voltage that is either higher or lower than the desired output voltage, adjusting the voltage level accordingly. The 4-quadrant operation of this topology allows it to function as both a buck and boost converter in both directions, making it highly versatile. However, it also has some drawbacks, such as an increased number of switches resulting in higher switching losses, a more complex control algorithm, and greater turn-on losses due to the reverse recovery of diodes. The H-bridge topology is composed of four switches: two high-side switches and two low-side switches, which can be controlled to allow for bi-directional power flow, making it useful in applications such as battery charging, or grid connected inverters.

B. BI-DIRECTIONAL CUK CONVERTER

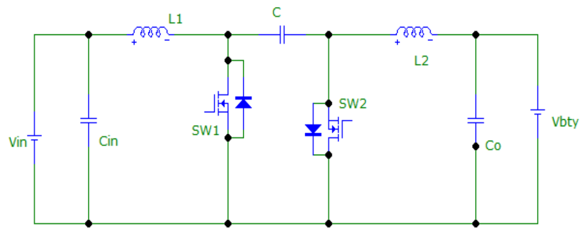

Figure 5: Bi-directional cuk converter

The bidirectional Cuk converter is an improvement over the unidirectional Cuk converter by using MOSFETs instead of diodes, which results in a less ripple in the output. This makes it a better choice for interfacing devices such as supercapacitors and batteries in circuit designs as it produces less ripple compared to other converters like cascaded buck-boost and bidirectional buck-boost converters. The use of L1 and L2 inductors together helps in achieving reduced ripple and the yields current. The control switch in the positive power flow mode is sw1 and it is switched OFF, while the primary diode is the body diode of switch sw2. In the backward power flow, sw2 serves as the active switch while 1 is switched OFF, and the primary diode is the body diode of switch sw1.

C. BI-DIRECTIONAL SEPIC-ZETA CONVERTER

Bidirectional SEPIC/Zeta dc-dc convertercan function as both a conventional SEPIC converter for forward power flow and as a Zeta converter for backward power flow. This is achieved by rearranging the Cuk converter circuit. The SEPIC/Zeta converter can generate either higher or lower output voltage in both directions, but the polarity of the dc buses remains the same.

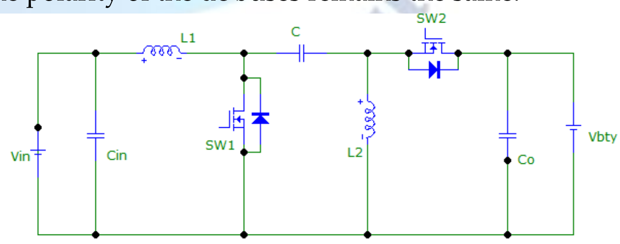

Figure 6: Bi-directional sepic-zeta converter

In forward power flow mode, the SEPIC converter acts as a buck converter and the sw1 switch serves as the power switch while sw2 remains off during the charging period. In backward power flow mode, the converter acts as a boost converter and the sw2 switch serves as the power switch while sw1 remains off during the discharge period. Using inductors L1 and L2 in conjunction can help to reduce output voltage ripple and voltage stress on the switches.

D. INTERLEAVED NON-ISOLATED BI-DIRECTIONAL DC-DC CONVERTER

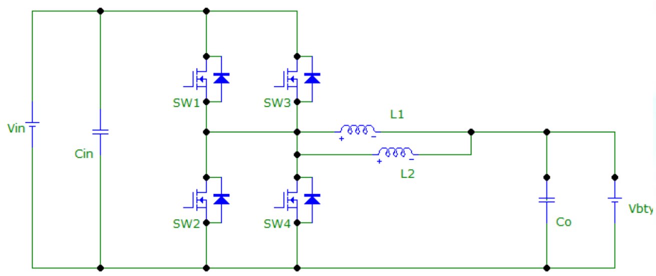

Figure 7: Interleaved non-isolated bidirectional dc–dc converter

An interleaved non-isolated bidirectional DC-DC converter is a type of power converter that can operate in both buck and boost modes, allowing for bi-directional power flow. It is composed of multiple converter modules that are connected in parallel and interleaved, meaning that their switching operations are coordinated such that they are not conducting at the same time.The interleaving of the converter modules allows for a reduction in ripple current, and an increase in the efficiency and power density of the converter. It also reduces the size of the filter inductors required to suppress the ripple current, which can make the converter more compact.

7. INVERTER

In the case of inverter used in motor drive of electric vehicle, is an electrical device that converts direct current (DC) into alternating current (AC). In electric vehicles (EVs), an inverter is used to convert the DC power stored in the battery pack into AC power that can be used to drive the electric motor.

There are different types of inverters used in EVs,(Bellar et al., 1998) each with its own set of advantages and disadvantages. Some common types of inverters used in EVs include:

- Voltage source inverter and Current source inverter
- Quasi resonant inverter using ZVS and ZCS
- Multi-level inverter like Cascaded H-bridge inverter
- Dual inverter which uses two inverters two inverters are used, one for the high-frequency operation and the other for the low-frequency operation, this technique is known as dual inverter.
- PWM inverters.

8. CONCLUSION

This paper consists of a review on converter employed to drive EV motor. Various DC/DC converters used to rectify battery voltage are observed in this paper. The converter used to drive different kinds of electric vehicle motor that is DC/AC inverter are observed. Bi-directional Non-isolated converter topologies which are popularly used in EV for regenerative braking have been reviewed.

Conflict of interest statement

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

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