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SMART CONTROL ALGORITHMS FOR ENERGY OPTIMIZATION IN ELECTRIC VEHICLE POWER ELECTRONIC SYSTEMS

Nidhish Chaubey

Research Scholar Kalinga University Raipur Chhattisgarh

Dr. Manoj Kumar Nigam

Kalinga University Raipur Chhattisgarh

Abstract

The fast rise in the use of electric vehicles (EVs) necessitates the use of smart power management solutions that improve efficiency, dependability, and driving range. The purpose of this work is to examine the creation of intelligent control algorithms that are capable of optimizing the energy use of power electronic systems in electric vehicles (EVs). These systems include DC-DC converters, traction inverters, and onboard chargers. The suggested solution utilizes artificial intelligence, machine learning, and adaptive control approaches to optimize power flow in real time, minimize switching losses, and decrease overall harmonic distortion. Hardware-in-the-loop tests and simulations show that energy usage is improved, thermal stress is reduced, and battery life is extended. The results indicate that smart control algorithms have the potential to substantially improve the overall efficiency of a system, giving a scalable route towards electric mobility that is more economical and environmentally friendly.

Keywords: Smart Control Algorithms, Energy Optimization; Electric Vehicles (EVs), Power Electronics, DC-DC Converter, Traction Inverter, Adaptive Control.

INTRODUCTION

The global trend towards electric vehicles (EVs) is evolving into something more than just a passing fascination. In view of the urgent need to reduce emissions of greenhouse gases and achieve sustainable development goals on a worldwide scale, electric vehicles (EVs) as a possible substitute for internal combustion engines (ICEs) are under consideration. Driving an electric car is one of the most effective methods to accomplish the goals of enhancing air quality, lowering emissions of greenhouse gases, and fostering a cleaner and more environmentally friendly atmosphere. It is important to electrify the transportation sector, which is responsible for around 24 percent of all emissions, in order to accomplish the goal of achieving net-zero emissions. The adoption of electric cars is being encouraged by governments all over the world via the implementation of stringent emission rules and the provision of incentives such as tax credits, subsidies, and reduced registration fees. This is being done in an effort to speed up the transition. India, Norway, China, and the United States of America are among the main economies that are seeing a parabolic surge in the production and sales of electric cars. Taking into account the legislation that are already in place, the International Energy Agency (IEA) forecasts that the number of electric cars on the road will expand from 26 million in 2022 to 245 million in 2030.

On the other hand, the adoption and utilisation of electric cars are greatly reliant on the efficiency of their electrical systems. The engine, control electronics, and battery system of electric cars are the components that determine the capabilities of these vehicles. Among the many components that contribute to the efficient management and conversion of electrical energy between the battery, the electric motor, and other onboard systems, the power electronics are an essential component. It is necessary to have power electronic components like as inverters, converters, and onboard chargers in order to convert the direct current (DC) that is supplied by the batteries into the alternating current (AC) that is used by the electric motors and then back again during the process of regenerative braking. For example, inverters do this by changing the frequency and amplitude of the electrical current. This allows them to control the speed and torque of the motor. By delivering power to low-voltage subsystems like as sensors, infotainment, and lighting, DC-DC converters work in a manner that is similar to the previous example. This allows for consistent performance across the whole vehicle.

The advancements in power electronic technology have an impact on the range of electric cars, the amount of time it takes to charge them, their reliability, and their overall cost. Gallium nitride (GaN) and silicon carbide (SiC) are examples of wide-bandgap (WBG) semiconductor materials that have been included into power electronic systems. These materials have made it feasible to achieve increased power density while simultaneously reducing weight. These developments, which result in components that are smaller and lighter, allow manufacturers to improve vehicle design and energy management. This is made possible by the fact that these advancements. The development of innovative thermal management systems for power electronics has also contributed to improvements in the safety and durability of electric vehicles. These systems help prevent components from overheating and provide a longer lifespan. It is possible for consumers to have longer driving ranges and lower running expenditures if they make use of power electronics that have a high efficiency. These systems are able to conserve up to ten percent more energy than conventional ones, which is the reason behind this.

Types Of Charging System for EVs

Charging stations are the locations where electric cars may be refuelled since they are centralised locations. The majority of the charging station is comprised of components like as connectors, cables, and a method of connecting to the conventional electrical grid. It is essential that there be a well-functioning network of charging stations in place if electric cars are to receive widespread adoption. When the batteries in electric cars run out of power, they need additional charging time. Although the grid supplies alternating current (AC), the batteries that are used in electric vehicles are responsible for storing direct current (DC). As a result, it is very necessary for the charger to have the capability to switch the voltage from alternating current to direct current. According to the Electric Power Research Institute, there are three unique charging levels: AC level 1, AC level 2, and DC quick charging. Each of these charging levels is described in more detail below. Although the traditional charger is slower and has a power output of 1.4 kW for AC level 1 charging, it is not used as often as other types of chargers because of these characteristics. In most cases, it takes between eight and seventeen hours for the battery to be fully charged using this mechanism. Chargers that operate at AC level 2, which are the most popular, have the capacity to provide 3.8 kW of power. As a result, the normal amount of time required to fully charge an electric vehicle's battery is four hours when utilising the conventional charging methods.

Before the charging process begins, the rectified AC is transformed to DC. This particular technology has a working voltage range that extends from 200 V to 450 V, which is a higher value. The output power of the charger may vary anywhere from 20 kW to 90 kW, depending on the current rating of the charger (either 80A or 200A). Based on this information, the amount of time required to fully charge the battery might range anywhere from twenty to eighty minutes. An electric direct current (DC) fast charger that has 45 kW of power and 200A of current can charge a battery in thirty minutes, as stated by the study that was released.

Impact of Ev Integration on Distribution System

There is now adequate generating potential on a national scale to charge electric automobiles. This is the case at the present time. The fact that this varies from place to region is an essential point to keep in mind. The distribution system is the most critical component to consider when determining whether or not the power supply is capable of meeting the demand for CS.

It is very necessary to make use of smart charging in order to successfully manage the widespread adoption of environmentally friendly electric automobiles. It will be feasible to control the increasing penetration of electric cars by using the algorithms that have been developed via the use of vehicle-to-grid technology. These algorithms will also make it possible to maintain a smooth load. It is anticipated that as smart grids become more popular, there will be a rise in the prevalence of smart grids that make use of distributed energy resources. It will make it feasible for electric cars to connect in a plug-and-forget manner, with the vehicles allowing for the identification and supply of the essential information for an energy transaction. This will make it possible for electric cars to connect.

The energy stored in an EV can be used in a variety of ways, including:

- Peak shaving
- Load smoothing
- Backup source
- Ancillary services

There is a possibility that the use of dispersed energy resources might be advantageous to the management of electric vehicle energy. This comes in very handy when it comes to making decisions about energy management on a local level without engaging the system operator regarding such decisions. A rise in the distribution loss will occur if there is a load that continues to grow. As a result of this, the utilisation of resources that are spread is favourable in terms of lowering the amount of system loss. There is a possibility that the use of electric cars might potentially ease congestion on gearbox lines. In the end, the combination of these factors leads in the emergence of opportunities for utilities to make investments in transmission and generation.

Service Incentives

One of the primary functions of an electric vehicle (EV) is to provide its driver a form of transportation that is both sustainable and kind to the environment. Today, however, electric vehicles (EVs) have the ability to operate as energy storage units that are able to adapt to changing circumstances by using vehicle-to-grid (V2G) technology. This is made possible by smart networks and the integration of renewable energy sources. In this particular scenario, it is vital to give appropriate service incentives in order to ensure the efficacy of the system and attract the participation of users. The economic paybacks that electric cars get are among the most attractive incentives since they balance the relatively high purchase price of electric vehicles, which makes them more cost-effective in the long term. Some examples of these programs include lowering the price of electricity during off-peak hours, providing users with direct monetary compensation for energy that is sent back into the grid, and providing consumers who participate with tax credits or other incentives. There are non-monetary benefits, such as priority parking, high-occupancy vehicle lanes, and premium charging spots, that have the potential to encourage users just as much as monetary incentives.

The usage of electric vehicles in cycles of frequent charging and discharging is a significant reason for concern since it leads to the degradation of batteries and a reduction in the expected lifetime of the vehicle. There is a possibility that intelligent energy management systems that improve battery use and reduce depth-of-discharge cycles might assist in extending the life of batteries and mitigating the hazards associated with them. Moreover, real-time monitoring and predictive diagnostics may be used to provide users and grid operators with notifications on the current state of the battery. This makes it possible to use the system more efficiently and reduces the expenses of maintenance over the long term. If tests reveal that well-managed systems that make use of advanced management algorithms can limit annual battery wear below 2%, then customers are more likely to sign up for services that facilitate vehicle-to-grid connectivity.

Due to the fact that there are thousands of electric vehicles that are not being utilised, there is a significant opportunity for grid stabilisation and ancillary services like as frequency control, voltage management, and load balancing in regions where the adoption of electric vehicles is high. These services are necessary for successfully regulating renewable power sources because of the unpredictability of the sources themselves. To ensure that these grid services are delivered in a consistent manner, one method that may be used is to provide incentives to owners of electric cars to encourage them to keep their vehicles plugged in when they are not being used. Owners of electric vehicles (EVs) who make their vehicles accessible during periods of high demand or low generation may be able to take advantage of time-of-use pricing models or subscription-based incentives that are made available by utility providers and developers of charging infrastructure.

Fleet operators and enterprises who use electric cars may find that such incentive schemes are highly beneficial to their operations. It is possible to accomplish transportation and energy storage via the conversion of fleets that are held by firms that are involved in logistics, ridesharing platforms, and delivery services. It is necessary for governments and regulatory bodies to take proactive measures in order to guarantee that owners of electric vehicles are compensated fairly, to build systems for the sharing of data, and to establish clear rules for the connection of utilities to vehicles. The United States of America, Japan, and the Netherlands are only few of the countries that have conducted pilot programs that have shown the technical and economic viability of incentive-driven schemes. These studies have given out a road map for the wider implementation of these schemes.

In order for vehicle-to-grid systems to function well, there are three essential components that must be present: user engagement, prepared infrastructure, and allowing regulatory frameworks. Incentives for services that are not just transparent but also well-structured encourage users to get active, which speeds up the transition to an energy system that is low in carbon emissions, robust, and decentralised. At the end of the day, electric vehicles are more than simply a mode of transportation; they are also essential components for an intelligent and sustainable energy future. These incentives will assist in getting customers on board with energy efficiency standards.

General Overview for Planning of Charging Infrastructure

It is impossible for a modern transport network to operate without the well-planned and established infrastructure for charging electric vehicles (EVs). This infrastructure is important for the widespread adoption of EVs and for their operation without any problems. However, one of the most significant challenges associated with this topic is determining the optimal positioning and dimensions of charging stations inside a certain power distribution network. In the course of this endeavour, it is necessary to take into account a variety of factors, including as the comfort of the users, the stability of the grid, the cost, the limitations of the power system, and the patterns of traffic. A placement strategy that is successful results in users experiencing decreased range anxiety, the grid experiencing balanced energy demand, and infrastructure expenditures being reduced to the greatest extent possible.

A strategy that is meticulous is required in order to successfully address this complicated matter. The first thing that has to be done is to choose a metropolitan zone or test network in which to establish the charging infrastructure. It is possible for these networks to be different depending on whether they are situated in an urban, suburban, or rural region. Existing roads, electrical grids, and traffic data are all components of these networks. After determining the location of the test zone, a comprehensive set of input parameters is acquired. A few of these elements include the number of cars that are already on the road, the frequency with which people travel, the anticipated demand for charging, the cost of electricity, the availability of land, the capacity of the grid, and environmental constraints. It is feasible that socioeconomic data and trends in urban movement might be of great assistance in determining probable user hotspots.

The construction of objective functions serves as a guiding principle for the process of efficiency optimisation. Among the most typical goals are the reduction of waiting times, the enhancement of overall system reliability, the maximisation of charging station coverage, and the reduction of installation costs. In accordance with these objectives, the technical and operational constraints that must be maintained are outlined. Accessibility, space restrictions, voltage stability, transformer capabilities, and power load limits are some examples of the kind of issues that fall under this category. In some planning contexts, additional considerations include things like the need for battery switching stations and the inclusion of renewable energy sources.

OBJECTIVES

1. To create and put into practice intelligent control algorithms for EV power electronic converter and inverter real-time optimization
2. Reducing switching and conduction losses by combining adaptive control techniques with machine learning.

RESEARCH METHOD

The bidirectional converter, which is utilised in commercial applications and transforms one level of electrical voltage into another level at the load side, has seen significant developments in recent years. These advancements have been made possible by increased technology. In Figure.1, which is a block schematic of the system, the bi-directional DC-DC converter system that is used for an electronic vehicle is shown. The bidirectional DC-DC converter is comprised of a number of different components, including a full-bridge DC-DC converter, a storage element, converter switching, a control system, and an interconnection system. In order to make it possible for the power converter to handle the transfer of power from a low voltage energy source to a high voltage energy source and vice versa, it is necessary for the power converter to have a certain number of power switches and storage components. An additional requirement is that it must have a high-power conversion efficiency as well as galvanic isolation.

It is possible to create an isolated BDC in situations where the rectifier diode of a unidirectional converter may be made to be replaced by power switches that are adjustable. This is a debate that is more generic. These converters are not suited for use with industrial loads because the current system is experiencing problems such as high voltage spikes, a leaky inductance component, and increased switching losses as a consequence of hard switching operation. These problems are associated with the fact that the current system is experiencing these problems. The DAB-BDC method is the most often used methodology among the isolated BDC methods that are now accessible, and it has been successfully drawing the attention of researchers over the course of the last ten years.

The direct alternating current (DAB) battery direct current (BDC) system offers a number of advantages, the most important of which are soft-switching operation, minimum voltage stress on power switches, low conduction losses, and efficient utilisation of high-frequency transformers and their parasitic leakage inductance. In the context of this chapter, a unique SRBDC converter that combines control technique has been proposed as a potential solution. The following advantages are associated with the SR-BDC that was suggested, as shown by the outcomes of a recent research study by the following: 1) The duty cycle of the switches on the main and secondary sides can be easily calculated, which allows for the identification of the voltage transfer ratio with relative ease. 2) In order to bring the voltage under control, a fundamental technique known as pulse width modulation (PWM) is used. This technology offers a broad voltage range. 3) ZVS was obtained for each and every one of the power switches that fell inside a comprehensive range of voltage and load. Additionally, the switching frequency is selected to be reasonably close to the resonant frequency of the series resonant tank. This helps to make the component design of magnetic devices more transparent.

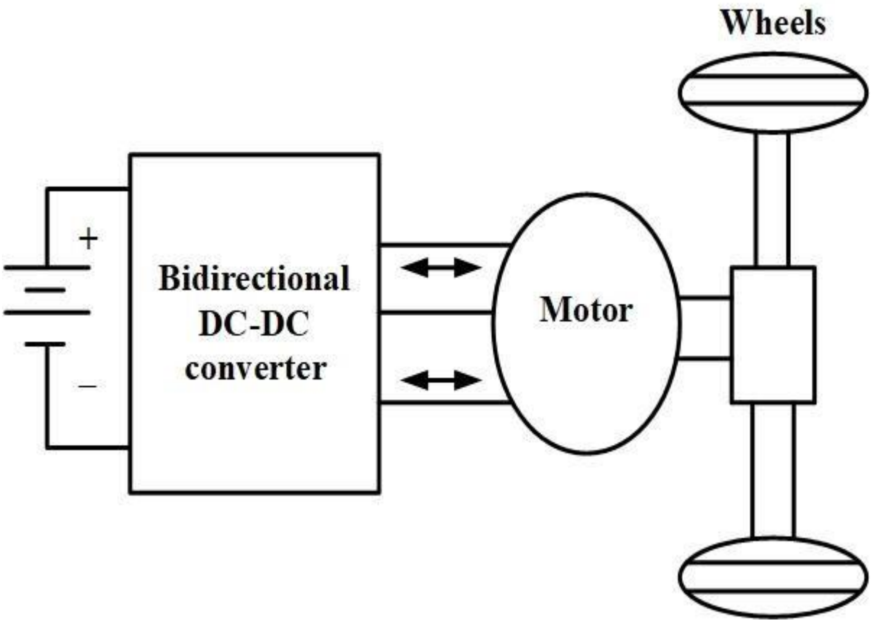

Figure 1: Schematic of bidirectional DC-DC converter for electrical vehicle application

Bidirectional DC-DC Converter

A bidirectional DC-DC converter is also known as a two-stage DC-AC and AC-DC converter. This kind of converter facilitates the conversion of electricity in both directions. An input of low voltage is transformed into an input of high voltage, and an input of high voltage is changed into an input of low voltage with a high switching frequency. Both of these conversions take place simultaneously.

The circumstances of the environment are unpredictable at the periods when we are producing energy via the use of solar photovoltaic and wind power production. It is not possible for us to depend only on the generation of individual power because of the oscillations that occur in the power that is generated. As a consequence of this, the energy system ensures that batteries and supercapacitors are always in alignment with one another. In the event that the system is shut down or when the output of the energy system varies owing to atmospheric circumstances, these energy storage devices are intended to store more energy during times of low load demand and to offer backup power in the event that the system is shut down. Accordingly, it is essential to possess BDC converters in order to make it possible for electricity to flow in both directions. Through the use of controlled power switches, it is feasible to turn a normal direct current-direct current converter into a bidirectional converter. The use of a diode in conjunction with a MOSFET or IGBT, which enables current to flow in both directions via the utilisation of controlled switching, is the means by which this is done.

Non-Isolated Bidirectional DC-DC Converter (NIBDC)

Electrical isolation between the power supply and the load may be achieved by the use of an NIBDC converter, which eliminates the need for a high-frequency transformer. Because they do not include a transformer for galvanic isolation, NIBDC DC-DC converters are not only lightweight but also incredibly efficient. This makes them an excellent choice for applications that need little power, but they are expressly forbidden from being used in high-power applications due to safety concerns at all times.

Bidirectional Buck-Boost DC-DC Converter

The following is an expression of the basic topology of a bidirectional converter. In Figure 2, you can see a schematic depiction of a buck-boost converter. This representation is accessible for viewing. In this way, M1 is engaged in line with the duty cycle while the boost operation is being carried out; however, M2 is not triggered in this manner. While the converter is operating in the buck mode, M2 will be engaged in line with the duty cycle. On the other hand, M1 cannot be activated by the converter while it is functioning in this mode of conduction. The fact that there is no crossing of power switches makes it possible to provide a small dead band between the two operations that are being carried out in this operation despite the fact that there is no crossing of power switches. Within the context of bidirectional power flow, the approach that is being given is referred to as the NIHB-BDC topology, and it is believed to make it easier for a boost converter as well as a buck converter to perform well. Not only are these topologies more effective, but they are also simpler to comprehend.

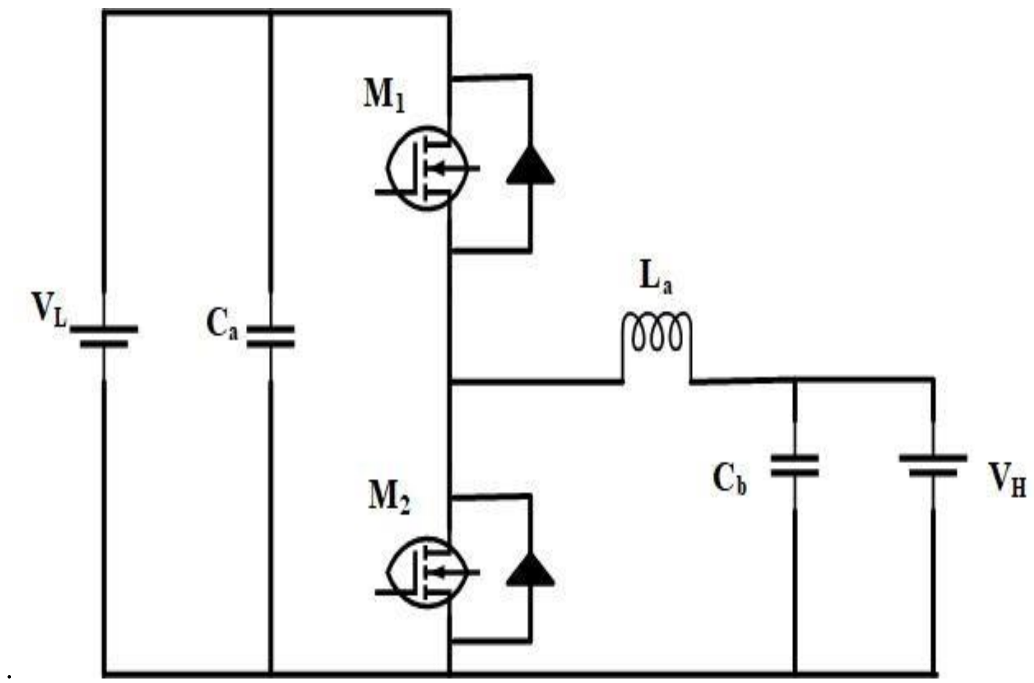

Figure 2: Bidirectional Buck-boost DC-DC Converter

Cascaded Bidirectional Buck-Boost DC-DC Converter

As can be seen in Figure 3, the design of the converter is achieved by cascading a buck and boost converter. This architecture is responsible for performing the design of the converter. Using this approach, it is possible to carry out activities in each of the four quadrants inside the system. Consequently, this topology is used in order to step-up the voltage and step-down the voltage in both the forward and reverse directions. This was done in order to get the desired effect. This converter is more popular and reliable than other converters since it functions in four quadrants, which is a feature that distinguishes between them. However, it does have certain limitations, such as the fact that extra power switches have additional conduction losses, in addition to complex control and switching losses. These are only some of the constraints.

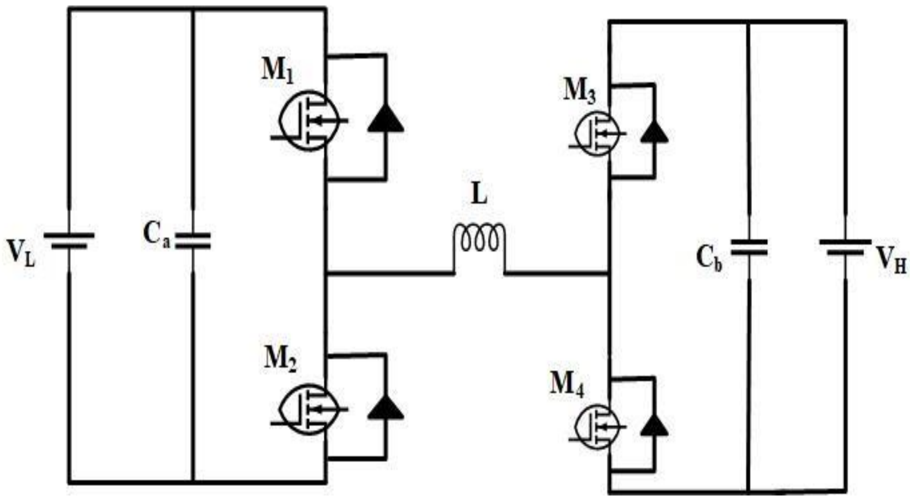

Figure 3: Cascaded bidirectional Buck-boost DC-DC Converter

Bidirectional CUK DC-DC Converter

Because of the way it was designed, the unidirectional cuk converter that can be seen in Figure 4 has been transformed into a bidirectional cuk converter. As a result of its decreased current and voltage ripple compared to unidirectional topologies, bidirectional cuk converters are advantageous for the purpose of charging batteries and supercapacitors. This is due to the fact that the ripple in both the current and the voltage is less. The unmodulated output current that is being generated will be reduced as a consequence of the connection of the inductor. When the inductors La and Lb are connected to one another, it is predicted that the undulation output current would decrease as a consequence of this connection. Should the M1 switch be activated while the M2 switch remains in its off position, it is possible for the charging current to go via the body diode of the M2 switch. This method of conduction is often referred to as the charging mode or the forward mode of conduction. In the same manner as when the M2 switch is activated and the M1 switch is maintained in close proximity when the discharging mode is active. It is possible for the discharging current to work since it is permitted to flow through the body diode of M1.

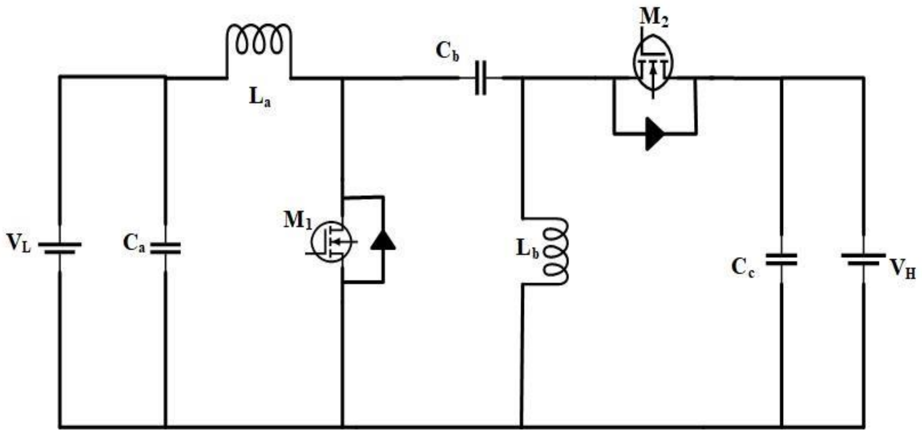

Figure 4: Bidirectional CUK DC-DC Converter

Bidirectional SEPIC-ZETA DC-DC Converter

Figure 5 depicts the SEPIC-ZETA DC-DC converter, which is a better version of the cuk converter. This enhanced version may be seen in the figure. The forward mode of the conduction converter of the bidirectional converter performs the tasks of a SEPIC power converter, whilst the reverse mode of the conduction converter performs the functions of a ZET converter. The SEPIC-ZETA converter may function in either step-up or step-down mode, depending on the circumstances that pertain to its operation. In order to facilitate the flow of forward power, the power MOSFET M1 is enabled, while the MOSFET M2 is left closed. This configuration serves as a buck converter. When operating in the reverse power flow mode, on the other hand, it performs the role of a boost converter, and M2 is removed from the equation. Through the coupling of inductances La and Lb, it is possible to obtain a decrease in the ripple in the voltage output as well as the rated voltage stress on the switch.

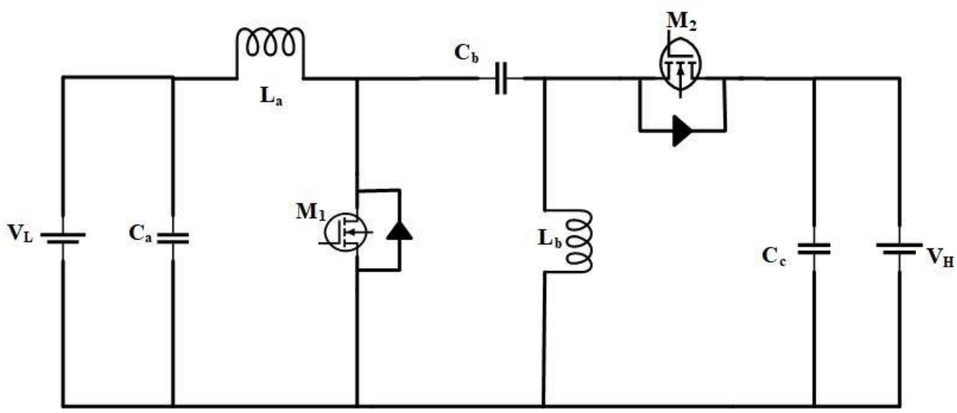

Figure 5: Bidirectional SEPIC-ZETA DC-DC Converter

CONCLUSION

Smart control algorithms provide a transformative solution for the enhancement of energy economy as it pertains to the power electronic systems of electric cars. Algorithms of this kind make it possible to implement adaptive strategies and real-time power management, which in turn reduces energy waste, improves thermal performance, and extends the life of batteries. According to the findings of the research, it is possible to substantially boost the overall system efficiency and driving range of electric vehicle power converters and inverters by using control systems that have been upgraded. In order to maximize the potential of intelligent energy optimization, future research efforts should focus on addressing concerns such as cybersecurity, large-scale deployment, and seamless integration with networks that link cars to the grid and renewable energy sources.

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