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RESEARCH ARTICLE

The Role of Power Electronics in Shaping the Future of Electric Vehicles: A Comprehensive Survey

P. Mallikarjun[1]*, V Srinivasa Chary[1], M Kondalu[3] and G Venu[1]

[1]Assistant Professor, Department of EEE, Malla Reddy Engineering College (Autonomous), (Affiliated to Jawaharlal Nehru Technological University) Hyderabad, India.
[2]Assistant Professor, Department of EEE, Malla Reddy Engineering College for Women,(Affiliated to Jawaharlal Nehru Technological University)Hyderabad ,India.

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***Address for Correspondence**
P. Mallikarjun
Assistant Professor,
Department of EEE, Malla Reddy Engineering College (Autonomous),
(Affiliated to Jawaharlal Nehru Technological University)
Hyderabad, India.

ABSTRACT

In today's world of expanding environmental concerns and rising oil prices, the importance of and interest in EVs is growing. Electrifying the conventional transportation system can help to reduce the usage of dwindling fossil fuels while also improving performance and lowering emissions. Power electronics will be critical in developing highly efficient electric vehicles with reduced emissions and improved fuel efficiency. This study provides a detailed assessment of current power electronics technology in electric vehicles, concentrating on both semiconductor devices and material technologies. It also goes through the various power electronics systems seen in electric vehicles. The examination of anticipated future trends in power electronics technology that will enhance the markets for electric vehicles in the upcoming years finishes the study.

Keywords: Power electronics, electric vehicles, semi-conductor devices, wide band gap semiconductors

INTRODUCTION

ICE) vehicles during the first few decades of the 19th century Electric cars coexisted peacefully with traditional Internal Combustion Engine (Ilah, 2023). Due to a number of factors, including improved ICE vehicle research and development, the discovery and exploration of new oil reserves that lowered oil prices, improved ICE vehicle performance, immature EV technology, etc., the popularity of electric vehicles (EVs) has drastically decreased over the years. Due to a variety of factors, such as the harm that ICE engines caused to the environment, the steady depletion of fossil fuels that resulted in an increase in oil prices, the rise in the number of vehicles on the road that caused significant air and water pollution, etc., EVs once more attracted interest by the 1970s. There are also strict rules in place. Power electronics will play a significant role in the development of future energy technologies [1]. In areas like entertainment, safety, sensors for smooth operation, battery charging, etc., electronics have always been a part of the vehicle system over time. However, recent years have seen enough interest in the use of electronics in power trains for better engine propulsion and their control. It was observed that an EV's efficiency was significantly increased by switching from traditional mechanical and hydraulic systems to electric systems. This has prompted extensive research on the subject of power electrical components in electric cars. The areas where power electronics and semiconductor devices have been heavily utilized in an EV are briefly examined below.

Electric propulsion

Through several phases of power conversions, the electric supply from the source (batteries, ultra capacitors, fuel cells, etc.) is transmitted to the wheel and vice versa. This section, which is frequently referred to as the heart of EVs, has a significant amount of power electronics components. You can further divide electric propulsion into the following groups:

1. Electric sources (Batteries, ultra capacitors, fuel cells, etc., are examples of electric sources.
2. Power converters (such as inverters and DC-DC converters)
3. Transmission and Motor (DC motor, induction motor, etc.)

A battery serves as the vehicle's only power source in a BEV. The literature [3] has a study on various battery types appropriate for EV applications. The source does not contain any power electronic components; instead, it produces electricity exclusively using the electrochemical (for batteries and fuel cells) or electrostatic (for ultra-capacitors) qualities to move the vehicle. A battery has the capacity to store a lot of energy, but it's not designed to deliver a lot of power quickly. This is brought on by a poor power output density. A small amount of energy can be stored in an ultra-capacitor, but it can deliver a lot of power in a short period of time [2].

Systems for Hybrid Energy Storage in EVs

The difficulty that the majority of manufacturers encounter when choosing the source for EVs is the lack of high-specific energy and high-specific power devices that can meet all the performance requirements. For the majority of EVs, creating a hybrid energy storage system (HESS) that combines two or more storage units and modules to realize the necessary energy and power characteristics would be the best option[2]. How to connect battery and ultra-capacitor units to the DC bus presents one of the major challenges in a HESS design. For vehicular applications, which are covered in the literature [4], various converters, including Buck-Boost, Cuk, SEPIC, Half-Bridge, and Full-Bridge, may be used as the interface in HESS. Different HESS

Power converters (inverters, DC-DC converters, etc.)

Complex automotive electrical systems with many forms of energy conversion are present. An EV needs both On-Board (placed in the vehicle) and Off-Board (installed outside the vehicle, typically at charging stations and power distribution networks) power electronics. Converters are essential for operating and managing the electric motor, which drives the wheel. In essence, an electric vehicle (EV) requires a DC-DC converter, a DC-AC inverter, and an AC-DC rectifier. Figure 3 illustrates and further explores the specific applications of power electronic converters in EVs. Power electronics converters unquestionably increase the volume and weight of an EV. Therefore, the choice of any converter and its architecture should be made to reduce these characteristics without sacrificing the vehicle's performance. Plug-in Hybrid Electric Vehicles (PHEVs) are often charged using a bidirectional AC-DC converter [4]. Integrating the onboard charger with the bidirectional DC-DC converter is one way to reduce the number of switches and passive components . In order to integrate an onboard charger and a DC-DC converter with fewer switches and greater performance than current charger topologies, Dusmez et al. suggested a new interface [5]. There are various bi-directional AC-DC and bi-directional DC-DC converter topologies for EV chargers available in

Dual-direction AC-DC converters

The weight and volume of an EV are undoubtedly increased by power electronics converters. Therefore, it is important to choose any converter carefully and consider its topology in order to reduce these characteristics without sacrificing the vehicle's performance. For plug-in hybrid electric vehicle (PHEV) charging, a bidirectional AC-DC converter is typically utilized [4]. By combining the on-board charger with the bidirectional DC-DC converter, you may cut down on switches and passive parts. A new interface that delivers greater performance in comparison to current charger topologies was proposed by Dusmez et al. for the combination of an on-board charger and a DC-DC converter with fewer switches [37]. various converter topologies for EV chargers, including bidirectional AC-DC and bidirectional DC-DC kinds.

Converters from one DC source to another

As with the back-end DC-DC converter previously described, a bi-directional DC-DC converter connects the AC-DC converter (from the onboard charger) to the energy storage unit [4]. It transforms the AC-DC converter's DC output voltage into a voltage that is adequate for charging batteries and converting battery power. based on the requirements of the system, for transmission. There are many topologies for DC-DC converters that can be found in the literature [5]. For DC-DC converters, full-bridge converters with high efficiency and a wide output voltage range are frequently used [6]. Additionally, input and output are isolated when a transformer is present, which is a benefit. The Half-bridge type converter topology, which has lower switching losses, is another often-used converter topology

Induction Motor

Traditional DC motors have been widely used in EV propulsion because of their straightforward control strategy. Due to the armature and field fluxes' intrinsic decoupling, speed, and torque control in separately excited DC motors was achievable on an individual basis. Recent technical advancements have brought about a new era for AC motors, giving them distinct advantages over DC motors like improved efficiency, higher power density, cheaper cost, more reliability, and nearly maintenance-free operation. Induction motors are the greatest option for EV propulsion, according to research on several EV motor types and their evaluations [7] Figure 4 depicts various standard electric motor types. Due to the armature and field fluxes' inherent connection, controlling AC motors like DC motors was previously not possible. However, technologies like vector control have made this possible. Additionally, ac machines completely eliminated the issues that commutator machines had. Ac induction motors are gaining popularity because they offer excellent durability and maintenance-free operation, two important factors in EV propulsion. In recent years, attention has also been drawn to the usage of Permanent Magnet (PM) motors and Switched Reluctance Motors (SRM) in EVs. Power electronics play an indirect influence in motor design because it is difficult to visually observe any power electronics components connected to electric motors. However, in the current environment, motor control without power electronics is virtually unthinkable. Schael et.'s comparison of electric vehicle power train designs using distributed induction motors revealed that the performance of the power train concept utilizing two doubly-fed induction motors is superior.

Energy Management and Their Control Methods

An effective EV design relies heavily on control. In the literature, there are numerous control methods that can be applied to EV applications. A very small amount of an energy management control method directly involves power electronics components. In order to regulate the operation of the system's available converters and equivalent power circuits, the control techniques instead use low-power analog or digital electronic systems. New applications can now be created thanks to technological developments in power electronics, and old applications can perform better as well. These developments heavily rely on the efficacy of the controls; as a result, in order to get the converter to operate as wanted and the system to function as intended, the proper control scheme must be used. Depending on a number of factors, including switching frequency, heating effects, the type of power semiconductor device being utilized, preferred architecture, etc., a suitable control strategy must be implemented. The main function of control circuits is to generate gate signals for turning on and off power semiconductor switches, detect and analyze feedback signals, control and safeguard the electrical vehicle system, etc. Control circuit creation typically makes use of contemporary microelectronic components including digital signal processors (DSPs), microprocessors, and microcontrollers. Proper software technique selection is just as important to the successful operation of EVs as choosing the right hardware.

V. Power Semiconductor Device Version

One of the important components that affect how well hybrid electric cars (HEVs) and pure electric vehicles (EVs) function is a power-switching device. A power electronic switching device's performance is generally determined by its switching frequency, switching losses, operating temperature, range of operation (both in terms of voltage and current), and other factors. It also depends on the device technology and semiconductor material used in its fabrication. Below, both of these factors are briefly explored.

Power semiconductor switches

In converters for electric vehicles, semiconductor switches with high operating temperatures, high voltages, high powers, quick switching, and extremely low on-resistance are of utmost importance. The development of the thyristor, also known as a silicon-controlled rectifier, in the late 1950s gave rise to the solid state power electronics. Other semiconductor devices including the insulated gate bipolar transistor (IGBT), static induction transistor (SIT), and static induction thyristor (SITH) will gradually be added. It was first introduced to use MOS-controlled thyristors (MCT) and integrated gate-commutated thyristors (IGCT). Chan et al. 1996 [14] performed a comparison of EV power devices. The majority of power semiconductor switching devices on the market are silicon-based. The power devices GTO, BJT, MOSFET, IGBT, and MCT are readily available and are particularly well-suited for EV propulsion. Because it combines the conductivity of a BJT with the high input impedance and quick speed characteristics of a MOSFET, the IGBT is now the most attractive device. MOSFET and IGBT comparisons were done. Shenai . studied power devices for vehicle electronics together with their packaging and thermal considerations. Discrete power device methods and other low-power microelectronics were briefly explained. Nakayama et al. also addressed the problems with thermal management for electrical and electronic components in a vehicle environment. . Kumar et al. [8] compared power semiconductor devices for various components of an electric vehicle system.

Materials for Power Semiconductors

The material qualities of the semiconductor used to construct a power semiconductor device have an impact on both the device's performance and its capabilities[14] . Its theoretical limits of operation, including those related to higher thermal conductivity, higher breakdown strength, higher maximum operating junction temperature, higher switching frequency, etc., have forced researchers to look into newer wide band-gap semiconductor materials for production. electrical switching devices for power .Stefanskyi et al. explored the effects of semiconductor material qualities on the operation of power devices and looked at the benefits of employing silicon carbide (SiC) in power electronics. SiC is shown to have an advantage over other power semiconductor materials in the future.SiC is shown to have an advantage over other power semiconductor materials in the future . Majumdar et al. reviewed recent technologies and trends in power devices and discussed several power module technologies, concluding that the 4H-SiC MOSFET is the best switching device for future applications. Acharya et al. have presented a bidirectional DC-DC converter for PHEVs that uses SiC devices and delivers greater performance at higher operating temperatures and switching frequencies [10]. Kachi et al. investigated the automotive applications of gallium nitride (GaN) power devices and determined that while the technology currently requires significant advancement, it may one day provide an alternative. Letellier et al. [11] compared a conventional Si-based semiconductor switch to a GaN-based switch and discovered that the latter exhibits superior performance. compared SiC and GaN power electronics for automotive systems and determined that both are promising materials for upcoming HEVs and EVs. Gueguen examined the market shares and industrial trends of SiC and GaN devices and predicted a bright future for these technologies [13]. For wide band-gap power semiconductor devices, there are still issues with cost and wafer quality, steady processing, and performance reliability of the devices.

CONCLUSION

This work discusses in detail the various power electronics converters used in EVs, including as DC-DC converters, inverters, and their topologies. The numerous converter topologies and power electronic devices are also reviewed in the literature. With a focus on power electronics for EV propulsion, battery charging, and power accessories, this article has assessed the current state of interdisciplinary technologies in EVs. That means power electronics. The development of EVs is greatly influenced by technology. IGBTs (Insulated Gate Bipolar Transistors) are projected to fundamentally alter on-board converter technology in switching devices. IGBTs will be able to replace GTOs and enable manufacturers to create better, more affordable inverters with less harmonics thanks to three primary advantages: high switching frequency, straightforward gate control, and maybe a lack of snubber circuits. IGBT usage lowers switching losses and harmonics. Wide band-gap semiconductor materials like SiC and GaN will decrease loss in the HEV power circuit and increase overall efficiency when used as semiconductor switches[18] .

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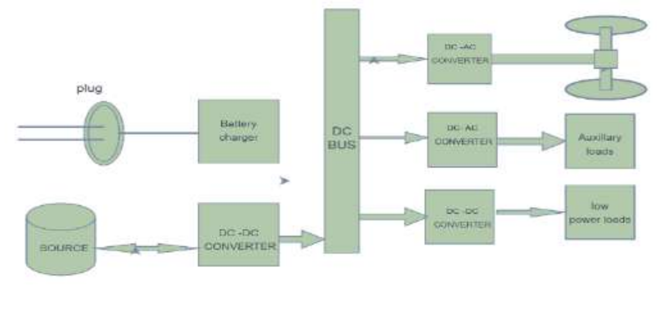

Fig.1.Role Of Power Electronics Converters In EV Applications

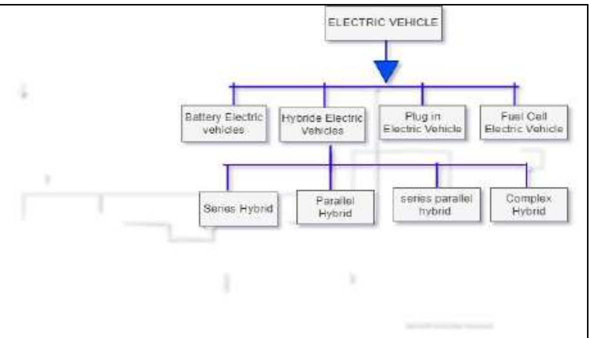

Fig .2. Broad Classification of Electric Vehicles

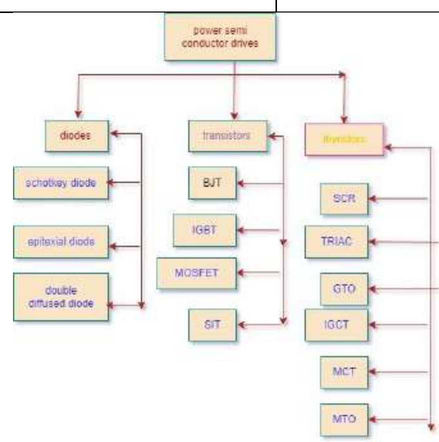

Fig .3. Classification Of Power Electronics Switching Devices