A Comprehensive Review on Selection of Hybrid Vehicles and Power Converters for Hybrid Electric Vehicles

Md Shahbaz Khan [1], Chirag Gupta[2] and Abhimanyu Kumar[3]
Electrical Department, Vedica Institute of Technology, Bhopal, M.P, India
[1]shahbaz.khan809@gmail.com, [2]cgupta.011@gmail.com, [3]ies.abhi@gmail.com

* Corresponding Author: Md Shahbaz Khan

Abstract: *A global transition toward cleaner, lower-emissions energy will need significant advancements in energy production and use. Factors such as pollution-induced climate change, constantly stricter vehicle emissions standards, depletion of petrol/diesel and price volatility for transportation systems all play a part in the advancement of technology in conventional cars. Hybrid electric vehicles (HEVs) are at the top of the list of clean vehicle technologies accessible. This study focuses on the various HEV designs as well as hybrid vehicle techniques. The design requirements and optimization approaches are also discussed in relation to the driving cycle. This document discusses the different electric drives used in HEVs. The various electric propulsion technologies are also described. Control techniques are critical for improving the fuel efficiency and emissions of hybrid power systems. Researchers are focusing on improving the performance of HEVs.*

Keywords: *power converters, energy management strategy, hybrid electric vehicle (HEV), hybrid energy storage source, hybrid hydraulic vehicle (HHV).*

I. Introduction

Due to the continued growth of global warming, the world energy issue has sparked interest in the vehicle industry during the previous two decades. The transportation industry is the leading source of greenhouse gas (GHG) emissions globally. Internal combustion engines (ICE) powered by fossil fuels are used in traditional cars. Carbon dioxide, hydrocarbons, carbon monoxide, and nitrogen oxides are all produced by these vehicles. Hybrid electric vehicles (HEVs) and electric vehicles (EVs) are two options for reducing global GHG emissions. However, both EVs and HEVs confront significant challenges in terms of battery deployment. Because of the human influence on GHG emissions and its link to global warming, vehicles with alternative powertrains are gaining a lot of attention these days. Alternative fuels, such as compressed natural gas, are used in a wide range of cars, as are sophisticated powertrain architectures that frequently integrate several propulsion systems. Energy generators such as fuel cells, solar panels, regenerative braking, and any other appropriate generators (such as flywheels, ultra capacitors, and wind energy) may be combined with EVs to achieve higher performance in the transportation domain [1] – [3].

Despite different developments in automobile technology, there is still a significant need for hybrid car optimizations in terms of consumption and CO_2 emissions. Fossil fuels are finite in supply, and finding alternative sources of energy is becoming increasingly challenging. Climate change is also attributed to CO2 emissions. Figure 1 shows a comparison of emission sources in percent in the EU-15. Figure 1 shows that transportation emits nearly a quarter of all CO_2.[4] – [5].

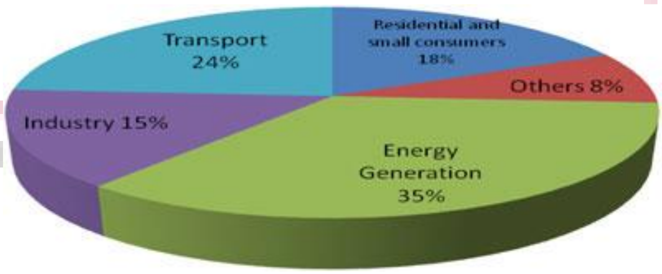

Figure 1: Amount of CO_2 emissions in percentage.

II. Types of Hybrid Vehicle

The automotive vehicle may be named as a hybrid vehicle when the vehicle depends on the following 3 factors.

1. Drive train structure
2. The traction power contributed by electric motor
3. Nature of the nonelectric source

II-A Depending on drive train structure

The vehicle construction can be classified as series, parallel, combination, or complex hybrid based on the linkage between the engine (ICE) and the electric motor (in the case of a battery as a source). The drive train structure explains the differences between all of these HEVs.

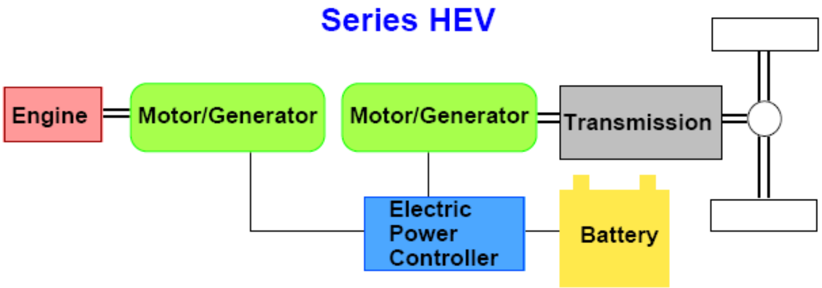

Figure 2: Series drive train structure

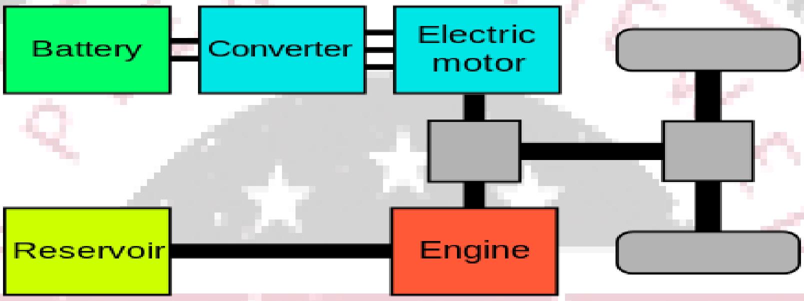

Figure 3: Parallel drive train structure

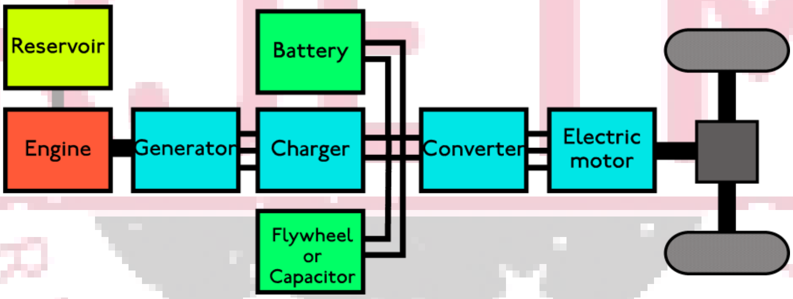

Figure 4: Series-Parallel drive train structure

II-B Depending on share of traction power by electric motor

Based on the distribution of traction power from the electric motor, the vehicle can be classified as mild or micro hybrid, medium or power assist hybrid, full hybrid, or plug-in hybrid. Hybridization is classified according to the degree of hybridization.

II-C Depending on the nature of nonelectric energy source

Unlike an internal combustion engine (ICE), which runs on gasoline or diesel, a fuel cell runs on hydrogen. Thus, a vehicle is categorised as an ICE, fuel cell, hydraulic, or pneumatic powered vehicle based on the fuel it receives. These vehicles are known as HEVs because they use electrical energy stored in batteries to power the motor (electric motor) that propels them.

The size of the electric motor is critical for greater fuel efficiency and dynamic performance in a HEV.

A factor called as the hybridization factor or ratio characterises the hybridization. The hybridization factor (HF) is the ratio of the electric motor's maximum power (P_{em}) to the ICE's maximum power (P_{ICE}). [6]

$$Hybridization\ Factor\ (HF) = \frac{P_{em}}{P_{em} + P_{ice}} = \frac{P_{em}}{P_{hev}}$$

The HF classifies a vehicle as either mild, micro hybrid, medium, or full hybrid. The basic phenomenon or methodology behind hybrid vehicle design is to operate the electric motor first, then add the engine (gasoline) only when it is required, as well as to operate the gas engine at a minimum state to achieve minimum fuel consumption, thereby increasing the hybrid vehicle's efficiency.

III. Types of Degree of Hybridization

In traditional automobiles, just one power source, namely the internal combustion engine (ICE), is used to provide power or push the wheels. A hybrid car is one that runs on a different energy source than an internal combustion engine. A vehicle's characteristics and function are represented by the degree of hybridization. The degree of hybridization refers to whether the alternative energy source aids the ICE or pushes the car alone, or, in certain situations, if the alternate energy source drives the vehicle without gasoline or ICE for a set period of time[7]. Mild or micro hybrid, medium hybrid, full hybrid, and plug-in hybrid cars are all classified as a result of these occurrences.

III-A Micro hybrid

The micro hybrid system is the lowest degree of hybridization conceivable in the car industry. The energy collected during regenerative braking action is a hallmark of this hybridization, as is the automated engine startstop operation. During regenerative braking, the micro hybrids only recover a little amount of energy. This sort of hybrid car can cut CO_2 emissions and fuel consumption by up to 4% depending on the vehicle drive train and driving circumstances.

III-B Mild hybrid

Mild hybrids are conventional vehicles that have some degree of hybridization in their hardware. In certain ways, the parallel system can be mildly hybrid. The functions of a mild hybrid may be limited to startstop simply, or they may be combined with or switching off the engine automatically when it is idle.

Conventional automobiles with an enlarged starting motor are essentially mild hybrids, allowing the ICE to be shut off when the vehicle is in the following modes: coasting, braking, and stopping; nonetheless, the vehicle is started instantly when necessary. The Volkswagen Lupo 3L, for example, is a mild hybrid that switches off its engine when the ICE is stopped. The electric motor that switches off the engine also catches energy while braking, i.e. regenerative braking. There is no motor assist or EV mode [8], though. In mild hybrid cars, the electric motor will not help the ICE for a length of time in the first mode, and in the second mode, the electric motor will not move the vehicle entirely by itself with the ICE turned off. Mild hybrid cars are frequently referred to as mini hybrid vehicles due to the availability of features and performance of the hybrid vehicle. When both regenerative braking and a start-stop technology are integrated, BMW achieves a successful outcome in their vehicle.

III-C Medium hybrid or motor assist hybrid

There are two power sources in the medium hybrid car. The engine provides the primary power, while a torque-boosting electric motor provides the secondary power, also known as engine assist power. As a result, the medium hybrid features an ICE in addition to an electric motor. Unlike mild hybrids, medium hybrid vehicles offer the option of running in electric mode for a limited time. The electric motor is big and sits between the engine and the transmission. When the ICE has to be shut off or when the ICE demands more power, the bigger starting motor kicks in. During regenerative braking, the electric motor serves as a generator, charging the battery. When the engine is at idle, the battery powers the accessories, and the engine is restarted by the electric motor.

IV. Nature of Energy Source

Based on the energy storage source utilised in the vehicle, hybrid vehicles are classified as HEV, battery powered electric vehicle/EV, hydraulic hybrid vehicle (HHV), pneumatic hybrid vehicle, fuel cell electric vehicle, and flywheel energy recovery hybrid vehicle. This section goes through the many types of hybrid automobiles. Figure 5 depicts the categorization of various hybrid cars.

IV-A Modes of operation of HEV

The series hybrid electric drive train vehicle can be operated in the following various modes [9]:

1. Pure engine mode. The vehicle is driven by engine. The ICE provides the power to the generator and motor. Battery does not provide any power.
2. Pure electric mode. The vehicle is propelled by the energy provided by the battery. The ICE is stopped or shut off.
3. Hybrid mode. The power to the electric traction motor is provided by both the ICE generator and the batteries.
4. Battery charging mode. The propulsion of vehicle is done by the ICE. The energy from ICE is not only used to propel the wheels or vehicle but also to charge the batteries.
5. Battery charging mode. The energy from ICE and generator charges the batteries. Unlike the earlier mode, the battery alone is charged in this mode while the energy is not supplied to the electric traction motor.
6. Regenerative braking mode. The kinetic energy obtained while applying brakes are used to charge the batteries. For this to happen, the motor acts as a generator and the ICE is turned off.

7. Hybrid battery charging mode. The electric traction motor acts a generator to change the battery, and simultaneously, the ICE generator also charges the batteries.

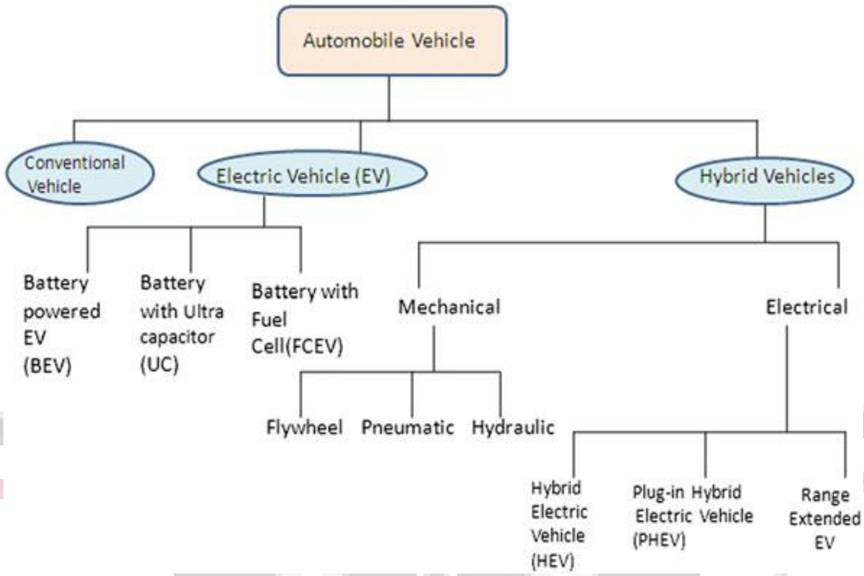

Figure 5: Different types of hybrid vehicles

In the following different modes, a parallel HEV drive train can be operated.

1. ICE only. The motor is freewheeling; the power required is supplied by the engine alone.
2. Electric mode. The engine is disengaged. The battery supplies the power and the motor propel the vehicle all alone without engine being operated.
3. Power assist mode. Along with ICE (T_{ice}), the motor (T_{em}) provides the required torque (T_{req}) to the wheel. In this mode the motor assists the ICE by providing the extra power.

$$T_{req} = T_{ICE} + T_{em}$$

The various modes of operation in series - parallel HEV is described below:

1. Pure ICE mode. ICE alone propels the wheels.
2. Pure electric traction mode. The vehicle is propelled by the battery at low speed.
3. Hybrid mode. In this mode, both the engine and the electric traction motor provide the total power to wheels.
4. Engine traction and battery charging. The ICE propels the vehicle and electric machine (motor) charges the battery.
5. Regenerative braking. When brakes are applied, the kinetic energy is used to store the charge in the battery. During this mode, the motor acts as generator.

IV-B Battery Technology

The electrical energy is stored in energy storage devices such as batteries, ultracapacitors, and fly wheels while they are charging (regenerative braking). Primary and secondary batteries are the two types of batteries. The first kind is non-rechargeable, whereas the second is rechargeable. In automobile applications, secondary batteries that can be recharged are employed. Figure 6 shows how rechargeable batteries are further categorized [11] – [13].

Lead-acid batteries have been a successful commercial product for over a century. They are low-cost and require no upkeep. Nickel-based battery technologies are progressing. Despite this, the specific power of leadacid, Ni–Fe, and Ni–Zn batteries is quite low. Ni–Cd and NiMH batteries are ideal for EV/HEV applications. Lithium batteries that are operated at or near ambient temperature can be either lithium polymer or lithium ion. Lithium metal is one of the electrodes of lithium polymer batteries, whereas lithium ion batteries do not include any lithium metal.

IV-C Pneumatic Hybrid Vehicle

Electric hybrids' primary drawbacks are the need for an auxiliary motor system and huge batteries. As a result, the price rises. Pneumatic hybrid vehicles are a cost-effective alternative to electric hybrid vehicles. The pneumatic hybrid differs from previous hybrid setups in that it only utilises ICE to propel itself.

V. Electric Motor Driving Force System

Electric motors, power electronic converters, and electronic control are the main components of the electric propulsion system for EVs and HEVs. The electric motor turns electrical energy into mechanical energy, which is used to move the automobile (Figure 6). To enable regenerative braking for battery charge, the mechanical energy is also transformed back to electrical. Power electronic converters are primarily used to supply the electric motor with the necessary voltage and current, i.e. to power the electric motor [14]. There are four primary types of electric motors used in EV, HEV, and fuel cell EV applications: DC motors, PM brushless motors (also known as PM synchronous motors), induction motors, and switching reluctance motors (SRMs).

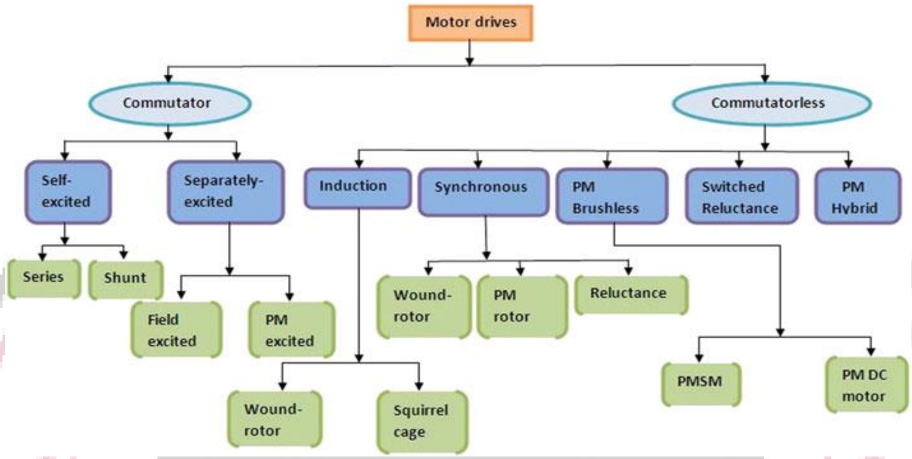

Figure 6: Classification of electric motors used for propulsion of hybrid electric vehicle

V-A DC Motors

A stator and rotor make up a DC motor. The former has a stationary field, whereas the latter has a wound rotor with brush commutation. Despite the fact that permanent magnets are employed for small machine excitation, the stator winding, i.e. field coils, are often induced by an external source. The field winding can be linked to the rotor armature coils in series or shunt depending on the needed characteristics. DC motors were the favoured alternative in variable speed operating applications prior to the invention of sophisticated power electronics. The main advantages of this sort of motor are that the technology is well-known, dependable, and fairly priced, and that the control is simple and durable. When compared to alternative technologies, the primary disadvantages are that it has a poor power density and brush maintenance is expensive and inefficient. Because of their infrequent use, the brushes are almost maintenance-free for private automobiles. However, DC motors have a large market for lower and intermediate range commutation.

V-B Induction Motor

Asynchronous motors, often known as squirrel cage motors, are induction motors. The most significant advantage of the IM is its ease of construction. Induction machines with squirrel cage motors, in addition to DC machines, are among the most technically advanced machines. The IMs are inexpensive, exceedingly durable, require very little care, and are dependable. The ohmic losses are the most significant losses in IM machines. At high speeds, IM gives a large range of options while also being substantially more efficient. Field-oriented control is used in IM to decouple torque control from field control (FOC).

This allows the motor to perform similarly to a separately excited DC motor (extended speed range operating is accomplished with constant power beyond base speed using the flux weakening approach). 40 When compared to DC motors, the speed control of IMs is substantially more complicated. Variable voltage variable frequency controls and FOC, also known as vector control, decoupling control, and pole shifting control, are the two types. To gain better efficiency of IM drives for electric propulsion in EV and HEV, FOC is favoured over variable voltage variable frequency control. The FOC transforms an induction machine into a DC machine.

V-C Permanent Magnet Brushless Motor

The three forms of permanent magnet brushless motor drives are pm synchronous motor drives, pm brushless DC motor drives, and pm hybrid motor drives. Because brushes, commutators, and slip rings are not used in PM brushless motors, they are referred to as synchronous motors. PM brushes DC motors are fed by rectangular AC waves, whereas Pm synchronous motor drives are supplied by sinusoidal or near sinusoidal AC waves. To regulate commutation, the former employs continuous rotor position feedback signals, whilst the latter uses discrete rotor position feedback signals.

For electric propulsion of HEVs, advanced pm hybrid motor drives have been developed. Permanent magnet motor drive systems are a cost-effective alternative for real-world automotive and naval performance.

V-D Switched reluctance motor

Electric propulsion for electric cars and hybrid electric vehicles, often known as SRM, has gained popularity in recent years. This is owing to its sturdy yet simple structure, ability to operate at extremely high speeds, ease of control, and hazard-free operation.

In comparison to other machines, SRM's remarkable advantages have made it more appealing for the application of traction. A research group at Texas A&M University carried out a serial design and simulation in SRM, resulting in the conclusion that SRM have an extraordinarily large constant power range. Design and control, on the other hand, are difficult, and acoustic noise is still an issue. Various electric motors used for traction are compared in Figure 7 (which was adapted from the literature52) on the basis of efficiency, controllability, dependability, power density, technological maturity, and cost. Table 1 summarises the electric propulsion for HEVs used in the automobile sector.

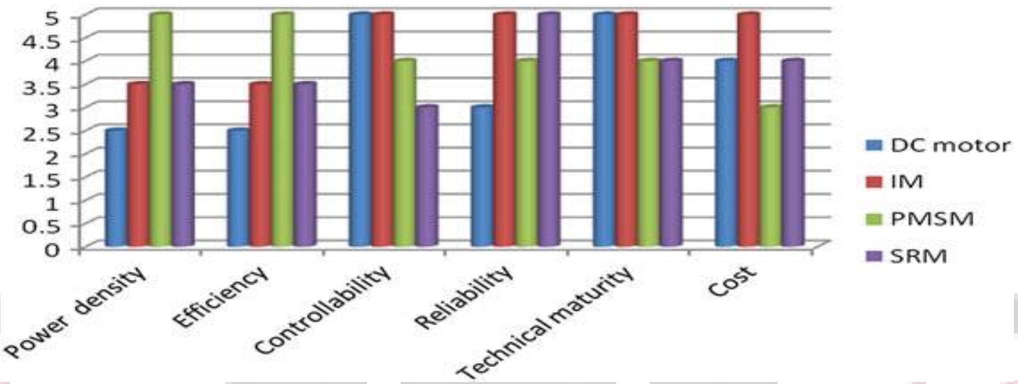

Figure 7: Evaluation of different electric propulsion motors used in hybrid electric vehicle. IM, induction motor; PMSM, permanent magnet synchronous motors; SRM, switched reluctance motor

Table I: Application of different electric motors for electric propulsion adopted in the automotive industry

Hybrid Electric Vehicles Models	Propulsion Motors
PSA Peugeot-Citroen Berlingo	DC motor
Renault Kangoo	Induction motor
Chevrolet Silverado	Induction motor
Daimler Chrysler Durango	Induction motor
BMW X5	Induction motor
Nissan Tino	PMSM
Honda Insight	PMSM
Toyota Prius	PMSM
Holden ECOmmodore	SRM

Abbreviations: PMSM, permanent magnet synchronous motors; SRM, switched reluctance motor.

VI. Power Converter

Power electronics look to be enabling technologies that will accelerate the transition from conventional vehicles to HEVs. Apart from gaining the characteristics of both present and future technologies, the vehicle industry has a significant hurdle in developing HEVs. The difficulties are to provide the most consistent, dependable performance while also allowing the car to provide the most relaxing driving experience at a reasonable price. Advanced power electronics devices and electric motors are used to attain the aforementioned characteristics [14]. This combination is critical for HEVs to be commercially viable on the market. According to reports, more and more power electronic gadgets will be used in the development of HEVs in order for them to have a more electric-intensive structure. As a result, small power electronic device design, as well as concerns of efficiency and reliability, have become key difficulties.

In the automobile sector, power converters are incredibly efficient circuits built using high-power electric switches and analogue and digital control circuitry [15]. These power converters convert an unregulated DC voltage level to a regulated and variable DC voltage level or regulate an uncontrolled DC voltage level to an AC voltage level. The former is accomplished by a DCDC converter, whereas the latter is accomplished by a frequency inverter (DCAC converters).

Isolated and nonisolated power topologies are also available. DCDC converters may be categorised into unidirectional and bidirectional converters, as shown in Figure 8.
In HEV systems, power converters play an important role. As previously stated, a HEV system's drive train consists of a battery, a power converter, and a traction motor/generator. If the power converter is an inverter, it can either be an inverter coupled to an AC motor or an inverter with a DC to DC converter [16]. In the latter architecture, the DC-DC converter connects the battery to the inverter's DC bus. The DC-DC converter used to run the inverter at its optimal working point is usually a variable voltage converter. In the majority of commercial HEVs, boost converters are employed as DC-DC converters. The use of a DC-DC converter and an inverter together improves system performance and flexibility. During regenerative braking and coasting, the converters in HEVs replenish the battery pack from the gasoline tank. In an electric vehicle, energy is stored in the battery pack or ultracapacitor (UC) [17].

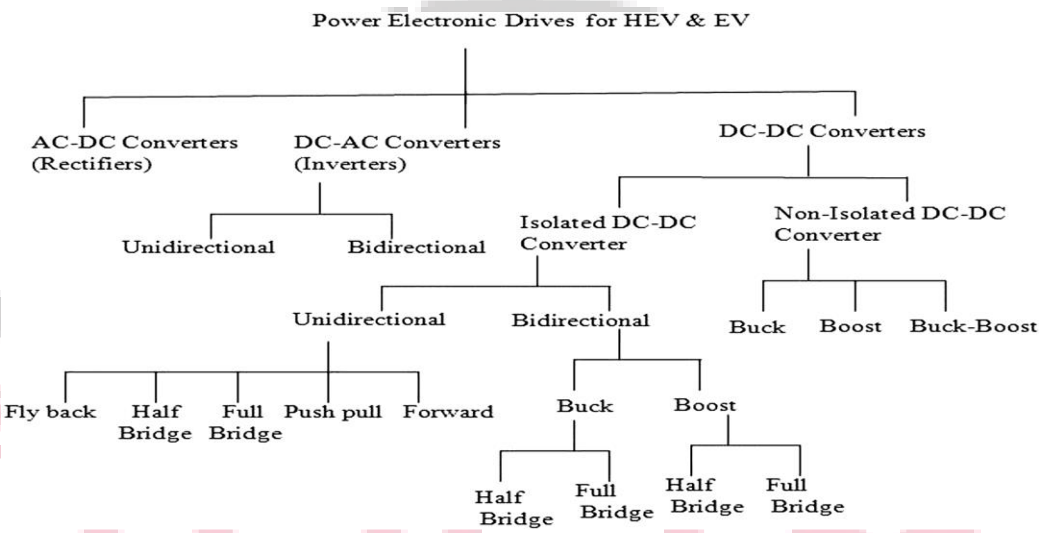

Figure 8: Classification of power converters used in hybrid electric vehicle (HEV)

VI-A Switching Technology

Hard and softswitched converters for inverters and DCDC converters are divided into two categories based on how they are switched. Softswitching methods have been widely employed in high-power bidirectional DCDC converters of all types, including isolated and nonisolated DCDC converters. The softswitching58 technology is used to produce zero voltage and zero current switching of power semiconductor switches or devices. HEV, power electronic devices in DCDC converters, and inverters employ softswitching topologies. Softswitching strategies for an EV or electronic concentrated vehicle (series, parallel, or seriesparallel HEV) are recommended by the researchers [18].

The advantages of soft - switching techniques are as follows.

1. Reduced switching stresses on power devices in its turn - on and turn - off transients.
2. The electromagnetic interference that occurs because of rigorous dv/dt or di/dt is limited efficiently.

VI-B Switching Device

For the drive system, high-power converters are necessary. These converters regulate high electric power in various hybrid topologies, and power electronic switches such as insulated gate bipolar transistors (IGBTs) and MOSFETs are utilised depending on the voltage, power, and switching requirements. IGBTs are the switching devices that manage the high voltage and power. MOSFETs (metal oxide semiconductor field effect transistors) are utilised for low and moderate voltage and power levels, as well as power design. The enhancement type of transistors, such as nchannel enhancement power MOSFETs and 1GBTs, are widely employed. Because of the substantial electric power loss, these high-power devices necessitate a cooling system, which is a major disadvantage. In the future, power switching devices with extremely low on resistance are predicted to simplify the cooling system. In comparison to IGBTs, power MOSFETs have faster switching times, but IGBTs can resist or handle higher currents than power MOSFETs. To control the electric motors and generators, voltage source inverters (VSI) are used in HEVs.

VI-C Types of Converters and Drives for HEV/EV

In a boost converter, the output voltage is greater than the input voltage, whereas in a buck converter, the output voltage is lower than the input voltage. Buckboost converters reduce or raise output levels in relation to their inputs, and these converters are dependent on the control signal duty cycle delivered to power semiconductor switches.

There are two types of power electronic circuits with electric motor/generator utilised in EV and HEV: DC drive and AC drive.

When a DC drive is utilised in an EV or HEV, a DCDC boost converter is typically employed to raise the battery voltage to meet the DC motor's voltage.

Bidirectional buckboost converters with DC motors are also employed as DC drives, albeit they are more commonly referred to as energy management converters. This DCDC converter connects the battery to the DC bus. To put it another way, the converter matches the voltage of the battery to the voltage of the electric motor or generator. HEV motors are either IM or permanent magnet synchronous motors, and the system is powered by an AC drive. Dual inverter drive is used when a permanent magnet synchronous motor requires two inverters. Control signals based on space vector pulse width modulation methods are used to operate the inverters linked between the battery and the electric motor.

Figure 9 depicts the variable DCDC converter utilised in HEV. Figure 10 shows a bidirectional DCDC converter with two power electronic switches, S1 and S2. Switch S1 is for boost conversion while switch S2 is for buck conversion. During engine starvation, i.e. pure ICE mode, the buck converter mode is employed in this circuit. The energy sent back from the wheels to charge the batteries through the motor/generator is regulated by the boost mode switch during regenerative braking or coasting. The VSI supplies the necessary voltage to the AC motor in order for it to drive the HEV. As seen in Figure 11, the VSI translates the DC voltage from, which is then boosted by a DCDC converter.

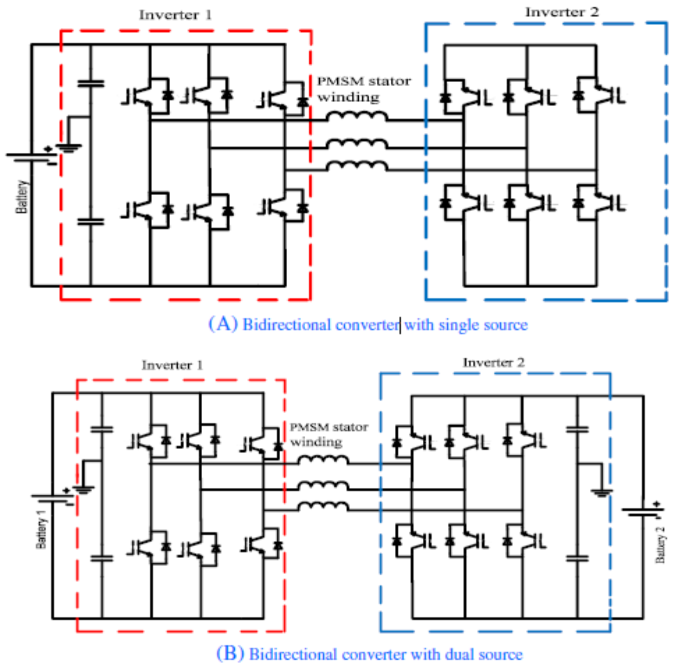

Figure 9: A, Bidirectional converter with single source. B, Bidirectional converter with dual source, configurations of isolated bidirectional DC‐DC converter. PMSM, permanent magnet synchronous motors

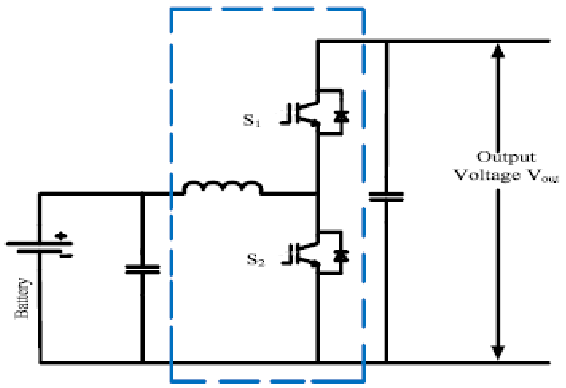

Figure 10: Bidirectional DC‐DC converter

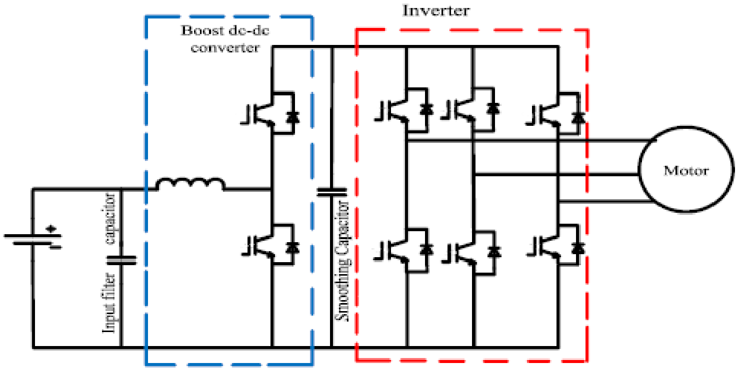

Figure 11: Power control unit for hybrid electric vehicle

VII. Conclusion

The need for further breakthroughs in alternative means to provide energy for automotive vehicles owing to insufficient fuel-based energy increases global warming and limits on pollutants emitted by cars has prompted researchers to look into HEV innovations. Although electric vehicles (EVs) are an alternative mode of transportation that mitigates the aforementioned disadvantages, battery recharging is a key problem for lengthy trips. This study provides an overview of HEVs, concentrating on various hybrid designs, electric propulsion motors, and power electronic converters, as well as various energy management systems. Different HEV power train setups' diverse modes of operation are presented. The HEV control techniques are grouped and explained. The control approach based on fuzzy logic is more stable and trustworthy. By fine-tuning the settings, it may be further tuned for real-time driving cycles.

References

[1] Tie SF, Tan CW. A review of energy sources and energy management system in electric vehicles. Renew Sustain Energy Rev. 2013;20:82-102.

[2] Ferreira HL, Garde R, Fulli G, Kling W, Lopes JP. Characterisation of electrical energy storage technologies. Energy. 2013;53:288-298.

[3] "Pollution control technologies", UNESCO-EOLSS Publishers Co. Ltd., Oxford, U.K, Volume-III, 2009, Chapter, "Hybrid Vehicles".

[4] Han SB, Chang YH, Chung YJ, Lee EY, Suh B, Frank A. Fuel economy comparison of conventional drive trains series and parallel hybrid electric step vans. Int J Automot Technol. 2009;10(2):235-240.

[5] Daniel Sigmund, et.al. "Simulation-based development of an energy-management-system for a drive train of a parallel hybrid electric vehicle", International Power Electronics and Motion Control Conference and Exposition, IEEE, 21–24 Sept 2014.

[6] Pourhashemi AP, Mehdi Ansarey Movahed SM, Panahi MS. Application of the fuel-optimal energy Management in Design Study of a parallel hybrid electric vehicle. J Fuels. 2014;2014, Article ID 417172:12

[7] Kulkarni P. Review of hybrid electrical vehicles. Int J Emerg Res ManagTechnol. 2015;4(3, March)

[8] Karden E, Ploumen S, Fricke B, Miller T, Snyder K. Energy storage devices for future hybrid electric vehicles. J Power Sources. 2007;168(1):2-11.

[9] Katrasnik T. Analytical framework for analyzing the energy conversion efficiency of different hybrid electric vehicle topologies. Energ Conver Manage. 2009;50(8):1924-1938.

[10] Schaltz E. Electrical vehicle design and modeling. In: Soylu S, ed. Electric Vehicles-Modelling and Simulations. 1st ed. Croatia: INTECH:1-24, Chapter 1.

[11] Cao J, Emadi A. A new battery/ultra-capacitor hybrid energy storage system for electric, hybrid and plug-in hybrid electric vehicles. IEEE Trans Power Electron. 2012;27(1):122-132.

[12] Chau KT, Chan CC. Emerging energy-efficient technologies for hybrid electric vehicles. Proc IEEE. 2007;95(4):821-835, April.

[13] Adrian Baltatanu, Leonard Marin Florea, "Comparison of electric motors used for electric vehicles propulsion", International Conference of Scientific Paper (AFASES) 2013, 23–25 May 2013.

[14] A. Hridaya and C. Gupta, "Hybrid Optimization Technique Used for Economic Operation of Microgrid System," *Academia.Edu*, vol. 5, no. 5, pp. 5–10, 2015, [Online]. Available: http://www.academia.edu/download/43298136/Aditya_pape_1.pdf.

[15] Khan S, Gupta C. An optimization techniques used for economic load dispatch. Int J Adv Technol Eng Res (IJATER). 2014;4(4).

[16] A Hridaya; C Gupta, "AN OPTIMIZATION TECHNIQUE USED FOR ANALYSIS OF A HYBRID SYSTEM ECONOMICS," *Int. J. Curr. Trends Eng. Technol.*, vol. 1, no. 6, pp. 136–143, 2015, [Online]. Available: https://www.academia.edu/22728404/AN_OPTIMIZATION_TECHNIQUE_USED_FOR_ANALYSIS_OF_A_HYBRID_SYSTEM_ECONOMICS.

[17] P. Verma and C. Gupta, "A Survey on Grid Connected Solar Photovoltaic System," *Int. Conf. Contemp. Technol. Solut. Towar. fulfilment Soc. Needs*, pp. 106–110, 2018, [Online]. Available: https://www.academia.edu/37819420/A_Survey_on_Grid_Connected_Solar_Photovoltaic_System.

[18] R Kumar; C Gupta, "REVIEW OF SHUNT ACTIVE POWER FILTERS CONTROL STRATEGIES FOR ELIMINATION OF HARMONICS," *IJESM*, vol. 8, no. 2, pp. 225–230, 2018, doi: 10.17148/ijireeice/ncaee.2017.03.