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A Comprehensive Review on Hybrid Multiport Converters for Energy Storage Devices Control and Performance of Electric Motor in EVs

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ABSTRACT

Multiport converters are a promising approach for Electric Vehicles (EVs) in hybrid energy sources (HES). These converters are highly suitable for a single conversion when interfaced with different input energy sources. Later the power converters are developed for continuous power supply to the load by utilizing fewer switches and energy storage systems like i.e., battery, fuel cells, and super capacitors. In case of hybrid multiport converters, the battery can be charging and discharging with quickly, the power quality in the EV powertrain can be enhanced and consequently, it increases the life-span of the battery management. Because of the flexibility in the bidirectional power flow in multiport converters become more efficient in relating to the traditional converters. Therefore, it improves the battery state of charge (SOC) performance under load conditions. This article presents the Multiport converter for EVs with bidirectional power flow from source to load and parallelly it controls the electric motor drive.

Key words: Battery, Electric Vehicles, Multiport converters, Switched Reluctance Motor, Ultra-Capacitors.

1. INTRODUCTION

Due to day by day increasing of population in the world the energy sources are highly demanding for transportation. In 1900's bullock cart, horse cart, and camel cart are used for shipping. This vehicle does not produce any pollution to the environments, but these carts are used for the limited purpose with small distance transport and fewer weights. To overcome these issues developed a conventional vehicle (CV), these are operated by using fossil fuels like oils, natural gas, and coal. However, by using fossil fuels the CVs are operated. Since 1990 to 2000's transportation consumes huge energy to run a vehicle. That energy is available with fossil fuels and utilization factor is also high. So that the global warming and carbon emissions are increased, and the availability of fossil fuels are drastically decreased in the earth. With increasing non- renewable energy prices, a rapid increase in environmental issues, cleanness, and tolerable energy clarifications are in demand. Therefore, these CVs can produce carbon emission, CO_2, global warming, and temperature rise in the environment. By igniting the fossil fuels, it produces toxic particles into the atmosphere, due to this it injects the diseases to humans like asthma, cancer, and respiratory.

Because of the increasing emphasis on environmental problems and energy sovereign, different CVs can be altered by EVs. To mitigate these problems, usage of renewable sources as input to the vehicles. Most of the vehicles have Internal Combustion Engines (ICE). Presence of ICE in CVs the CO_2 is drastically increased. To reduce the available CO_2 in an environment, the CVs could be replaced by EVs. Significant challenging developments in EVs are Power converters, Battery management, and Motor, etc. The input sources are renewable and non-renewable energy sources and these sources can be controlled using power converters efficiently with fewer conversion losses. The EVs can hold highly attractive for upcoming years, because of the depletion of fossil fuels and environmental preservation air pollutants in urban areas [1], [2]. To minimize the global environmental issues, renewable energy sources are used compared with non-renewable energy sources, that will secure the emission of gas exhausts, energy-saving concerns. For uninterrupted power supply to the motors with effectively we are using power converters and energy storage devices i.e., batteries, fuel cells (FC), ultracapacitors (UC), and solar cells.

Batteries are the primary energy storage devices for the storage of electricity. Under braking conditions, the batteries will store the mechanical energy into electrical energy. EVs are discriminated by electric drive systems; meanwhile, energy conversion is realized by converters such as ac-dc converters and dc-dc converters [3],[4]. Significant switching frequencies of similar converters can create electromagnetic interference (EMI) which prompts considerable serious issues such as common-mode currents along with stray capacitance of the device, shaft voltage, bearing currents and life- time depletion for motor insulation, etc. [5]. Motors are the dominant part of EVs and it converts electrical energy to mechanical energy for the propulsion of wheels. For this, high-performance engines are needed. So, the Switched reluctance motor (SRM) has been developed for EVs, with their features like low cost, less fault tolerance, widespread range, simple and robust construction. Finally, researchers explained the current hotspots of the vehicle performance. In EVs the motors have significance peripherals for their applications, it must be designed with the following requisites.

- Huge torque density and high-power capacity
- Good efficiency over widespread torque-speed territory
- Widespread torque-speed proficiency
- With good reliability and robustness
- Very least amount of fabrication and maintenance.

Therefore, in an electric motor, the torque effectiveness is commonly embarrassed by the allowable current fed into the windings. Therefore, the windings can be connected magnetically with inductive coils. Then it creates the self-inductance and mutual inductance, because of this inductance the current flowing through the winding coils can create huge heat/loss [6]. For the rotation of wheels or transmission system, it requires energy, i.e. the energy will get from the electric machine (EM). Mainly EMs were chosen by their advanced features like the ruggedness of the motor, vast torque-inertia ratio, considerable torque consistency, with extensive vehicle speed range, less noise, low maintenance cost, small size, its simple to monitor, and less cost [7].

Nomenclature

- r - Radius of the flywheel
- w - Rotational velocity
- k - Inertial constant
- M - Mass of the wheel
- I - Flywheel moment of inertia
- T_l - Torque at the load side
- T_e - Total electromagnetic torque
- J - Moment of inertia for combined Motor and Load
- U_g - Capacitor voltage from rectification of Ground control unit output
- U_{by} - Voltage at battery
- i_{dc} - lower dc-link current
- θ - Rotor position
- w - Angular speed

To reach the above advantages, it is needed to design an advanced power-controlled converter. In the provision of motor drive configuration, Permanent Magnet (PM) motors are suitable for EVs with high-performance rating, but it has unfeasible for rendering mass for EVs market by the reason of shortage of rare- earth materials [8]. In the present scenario, the EVs demand has been increased, because of their features, i.e., fewer environmental effects. By enhancing the efficiency and economy of fossil fuel, both government regulations and consumer insistence manufacturers are continued to pursue novel technologies. For large-scale market penetration of EVs, a lot of research and development is ongoing at day by day. Especially, there are three main categories: energy storage, power electronics, and electric motors. Section II explains the different categories of Electric Vehicles. Section III is a brief explanation of energy storage devices like Batteries, UCs, and FCs. Section IV explains the main consideration of SRM drives apart from the remaining motors. Finally, Section V deals with different power electronic converters. This paper deals with the evolution of these technologies and road map of layouts for future development and realization of EVs

2. ELECTRIC VEHICLE CATEGORIES

Electric vehicles are broadly classified depends upon the propulsion of vehicle electricity used.

1. Hybrid Electric vehicle (HEV)
2. Battery Electric Vehicles (BEV)
3. Plug-in-hybrid electric vehicle (PHEV) and
4. Fuel-cell electric vehicle (FCEV)

2.1. Hybrid-Electric Vehicles (HEVs)

HEVs are drive with ICE and electric Generator/Motor with a configuration of series or parallel connection. To extending the driving range by endowing ICE there by electric machine efficiency is increased. Under the braking condition, the regenerating energy is stored in batteries due to this fuel economy is improved [9].

HEVs again classified as different types, that are

- Series Hybrid electric vehicle
- Parallel Hybrid electric vehicle
- Series-Parallel Hybrid electric vehicle

2.1.1. Series hybrid electric vehicle (Series HEV)

In series HEVs, the ICE output is mechanical energy, by using a generator the mechanical energy can be converted into electricity. The available converted electricity is utilized to battery storage or it can bypass through the battery to wheel with the same motor and transmission system, as shown in figure.1. Compared with conventional vehicles, the ICE-aid EVs driving range is increased. For the drivetrain, it requires three propulsion gadgets. i.e.

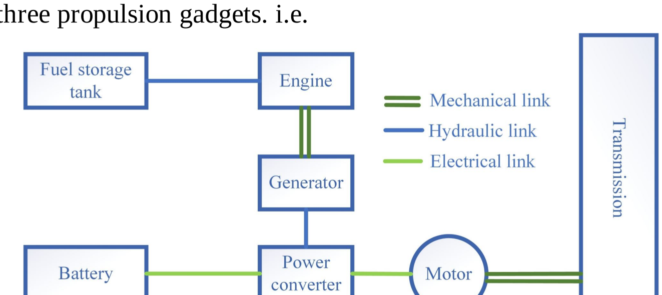

Figure 1: Series hybrid electric vehicle power train prototype

The ICE, generator and electric motor. In generally Series HEVs efficiency is less. It exists six possible operations that are, 1) battery mode alone: battery only supplies the power to the vehicle, the engine is off. 2) engine mode alone: power flowing through ICE and generator(G). 3) dual-mode: combine ICE/G and battery supplies the power to the traction motor. 4) power split mode: ICE/G split the power to drive the vehicle and additionally, it charges the battery. 5) regenerative braking mode: Kinetic energy can be converted to electricity by using generator and it can be converted into chemical energy by the batteries. 6) stationary charging mode: Battery can be charged by utilizing grid supply [10].

2.1.2. Parallel hybrid electric vehicle (Parallel HEV)

In parallel HEV, it allows power from both ICE and in parallelly electric motor to drive the wheels. Via two clutches, both ICE and electric motor are coupled to the shaft to drive the wheels detailed in figure.2. By the electric motor alone or the ICE or by both can be supplied power for propulsion of the system. Under regenerative braking, the electric motor can act as a generator to charge the

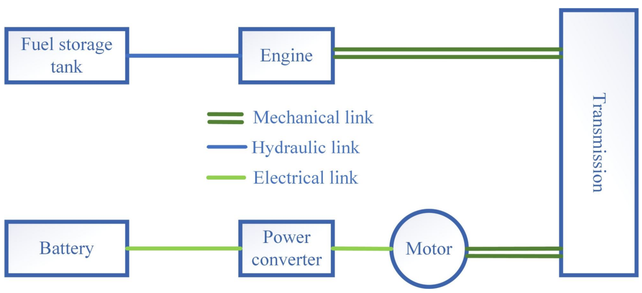

Figure 2: Parallel HEV power train prototype

battery or when ICE output power is greater than the absorbing power is required to drive the wheels. Parallel HEV required two propulsion gadgets- the electric motor and the ICE only. For general trip operation, the ICE only required to maintain maximum sustainable power while the electric motor may still be about a half. There are different possible modes of functions in the case of parallel HEV. 1) motor mode alone: motor only powered to the vehicle, the engine is under off condition.2) only engine mode: engine only provides the power to the vehicle.3) dual-mode: to drive the vehicle, both motor and ICE can provide power. 4) power split mode: under this condition, the motor can act as a generator, then the battery is charging and driving the vehicle with the ICE power split. 5) regenerative braking mode 6) stationary charging mode.

2.1.3 Series-Parallel HEV

This type of model is also called as dual-mode HEV or power-split HEV. The series-parallel prototype, as shown in figure.3. It needs a subsidiary generator contrast with parallel HEV and an additional mechanical link contrast with series. It holds power split gadgets to transfer ICE power from mechanical or electrical to the propulsion of vehicle wheels [11]. The merits of this type of vehicles will run both in series and parallel mode. For under slow speed situations the vehicle will run in series. Under the far-away and high-speed circumstances, it will run in parallel mode.

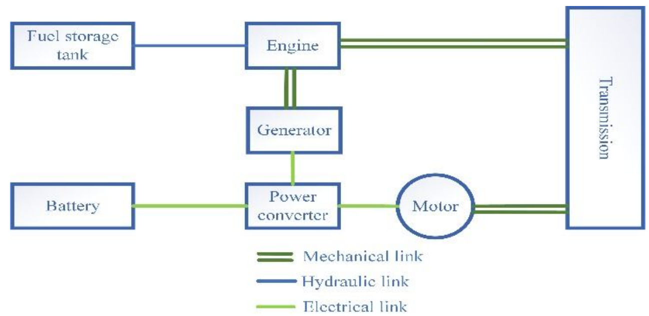

Figure 3: Series-Parallel HEV power train prototype

2.2. Battery Electric Vehicle (BEV)

BEV is also called as pure EVs or all-EVs. Batteries are the primary energy storage elements in BEV; batteries can store chemical energy in rechargeable battery packs. Instead of ICE, BEVs consist motor controller and electric motor for the propulsion of vehicle wheels. Nowadays the fuel price is drastically increased, and additionally, it produces CO_2 emission in the environment, to protect these, use rechargeable batteries in EVs. Lithium-Ion (Li-ion) battery having large energy density and power compared to Lead-Acid batteries, etc. Li-ion has a large energy density. The energy density of petroleum-based fuels

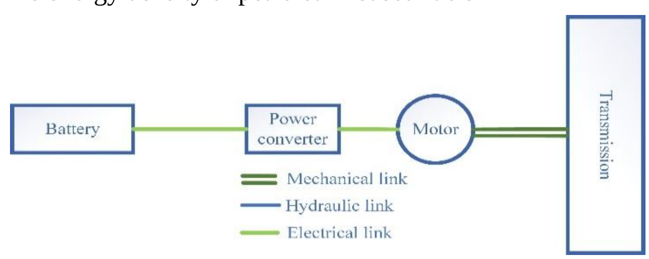

Figure 4: Power train prototype of BEV

is 34.2MJ/L, ethanol having the energy density of 24MJ/L, the energy density of lead-acid is 0.36 MJ/L, Li-ion energy density is 0.9-2.63MJ/L. 50-60% of CO_2 emissions can be saved by using electric vehicles compared with CVs.

The demerit is the initial cost of the vehicle is very high compared with other vehicles. From the grid energy or any other power sources, the batteries are charged using a socket [12] the power train prototype of BEV as shown in figure.4. For BEVs, the vehicle weight and conversion losses, i.e., electrical to mechanical conversion is also very loss. For high torque traction drive BEVs are used, due to this decrease in the efficiency of the system. BEVs are sustainable for a short duration trip. Recharging time including battery management is the significant demerit of BEVs. Examples of BEVs are Tesla Model S, Ford FOCUS electric, BMW i3, and Nissan LEAF.

2.3. Plug-In-Hybrid Electric Vehicle

PHEVs are also one type of HEVs. It contains rechargeable batteries and ICE as shown in figure.5. The rechargeable batteries can be charged by grid energy through an external socket or by regenerative braking process [13]-[14]. PHEVs shares both electric and CV characteristics. It was mainly appealing in certain conditions where it daily uses within a short duration of miles. The operation cost is less, and greenhouse gas emission moderate per mile while connected by electricity apart from gasoline [15].

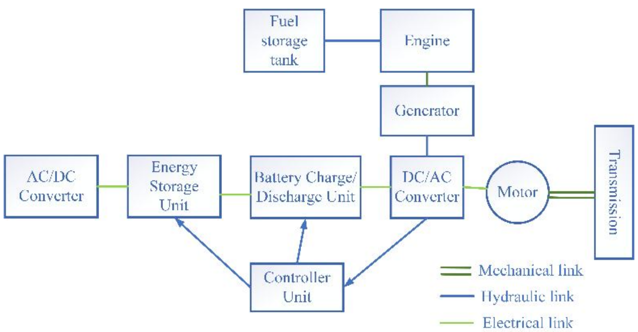

Figure 5: Power train prototype of PHEV

The significant challenging technical issues in PHEVs are energy storage capacity improvement of Li-ion batteries, reduce the cost of the vehicle and reliability of automotive uses. It produces less emission and requires less fuel compared with HEVs. Demerits are the high cost of batteries. Chevy Volt, Toyota Prius and Ford C-MAX are examples of PHEVs.

2.4. Fuel Cell Electric Vehicle (FCEV)

It is also one type of EV, and it contains a fuel cell instead of a battery as shown in figure.6. A battery or supercapacitor combination to power an onboard electric motor. A fuel cell is made up of an electrolyte, anode, and cathode. The function of the fuel cell is like a battery, and it produces electricity to run an electric motor. Fuel cells are attained from reformed natural gas. FCEVs are zero-emission vehicles, and it releases only heat and water.

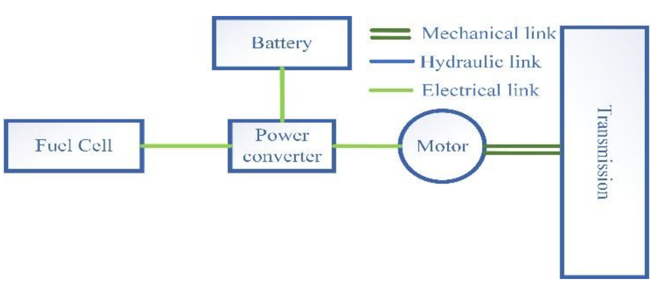

Figure 6: Power train prototype of FCEV

There are different kinds of fuel cell vehicles. However, it mainly uses in indoor applications because it requires clean emission and essential for air quality. Hydrogen vehicles cluster pollutants at the site of the hydrogen pro- duction compared with ICE [16]-[19]. Demerits are hydrogen cost high. Examples of FCEVs are Honda FCX Clarity, Hyundai Tus- can, and Toyota Mirai. Characteristics of various electric vehicles mentioned in table.1

Table 1: Various Electric Vehicle Characteristic

Vehicle Type / Constraints	FCEV	HEV	BEV	PHEV
Power supply & Frame Work	Fuel cell / Battery	UC/ Battery / ICE	UC/Battery	UC/ Battery / ICE
Energy Scheme	Fuel cell / Battery	Battery/ UC	Battery/UC	UC/ Battery
Advantages	Emission is Zero, Efficiency is high	Emission is moderate, Drive range is long	Emission is Zero, Crude oil is Independent	Emission is less, driving range is long
Propulsion	Drive is EM with-out ICE	Drive is EM with ICE	Drive is EM without ICE	Drive is EM with ICE
Disadvantages	High Cost of Hydrogen	It is dependent on crude oils, cost is high	It has huge initial cost and battery managemen t	It is dependent on crude oils and high cost

3. ENERGY STORAGE DEVICES

Energy storage is a process of conversion to electrical energy from various energy sources. The electrical energy can be stored in devices. That is

I. Battery
II. Fuel cell
III. Flywheel and
IV. Ultracapacitor etc.,

3.1. Battery

For the applications of electrical energy storage, batteries are ideally suitable. It provides not only environmental benefits and fuel flexibility but also useful for electricity utility operation [20]. It has high efficiency because standby losses are very less. For ample scale applications energy storage of battery is rare up because energy density is less, short duration of life cycles, power capability is small, and maintenance cost is high. Almost all batteries are hold of toxic materials [21].

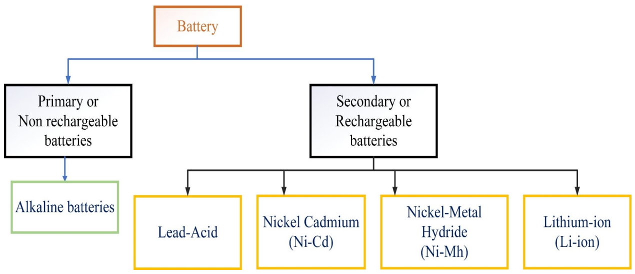

Figure 7: Different types of Batteries

Various categories of batteries are detailed in figure.7. Batteries are suitable for the applications of energy storage utilities, i.e., lead-acid, sodium nickel chloride, nickel-cadmium, sodium-Sulphur, nickel-zinc, nickel-metal hydride, nickel-cadmium, and Li-ion batteries are used in EVs [22].

3.2. Fuel Cell

It is a conversion of the electrochemical device which converts fuel into electricity as shown in figure8. Air and fuel are the inputs, and then it converts water and electricity via chemical reaction [23],[24]. The fuel cell will work like ICE up to fuel is available. The late 1950's develops an alkaline fuel cell with a 12kw for space- craft in NASA. In remote areas, fuel cells are adopted as a backup and primary power source, especially in industrial, residential, and commercial towers. For automobile industries, fuel cells are altered commercial towers. For automobile industries, fuel cells are altered for developing ecofriendly vehicles. There are various types of fuel cells depending upon the electrolyte type substance, namely phosphoric acid fuel cell, alkaline fuel cell, solid oxide fuel cell, and molten carbonate fuel cell [25],[26].

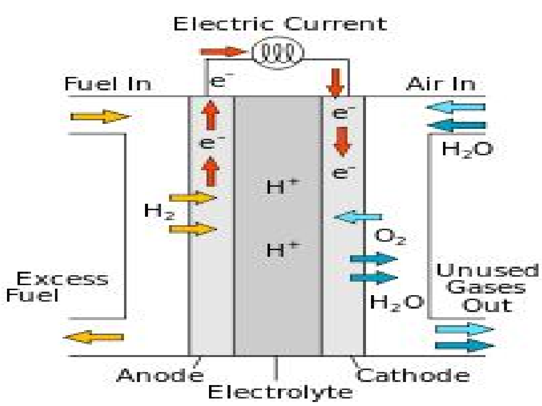

Figure 8: Fuel cell prototype

3.3. Flywheel

It is an old concept to store energy by utilizing flywheel. Since 1950's, this concept is used for the storage of energy. Due to wheel inertia, it was continuously rotating with the required effort. This could be sighted at a bus shelter for public transport charging, because of excessive weight and bulkiness. The schematic diagram of the flywheel energy storage system, as shown in figure.9. The amount of stored energy in flywheel can be manipulated by using below formulae

$$\frac{1}{2}(Iw^2) \text{ or } \frac{1}{2}((KMr^2)w^2) \quad (1)$$

where,

r = Radius of the flywheel
w = Rotational velocity
k = Inertial constant
M = Mass of the wheel
I = Flywheel moment of inertia

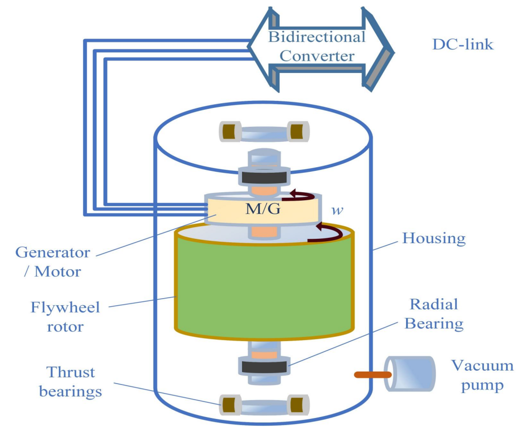

Figure 9: Flywheel energy storage device prototype

With modern technology, flywheels are more elegant. In the present scenario, the novel flywheels hold the kinetic energy in a quick movable rotary drum, and it acts as a rotor of a generator. The rotors are made up of high strength: thickness ratio such as carbon fiber materials. Generally, the rotor revolves with an average speed of 50,000 revs/minute and should deliver high centrifugal force activity [27]. These types of the rotor are seated in the vacuum cavity to nullify the losses due to air friction.

3.4. Ultracapacitors (UC)

The energy density of the ultracapacitor is large, and it developed in the capacitor domain. It is also called as super-capacitor or electrochemical-capacitor [28]-[29]. The range of the fuel cell is milli farads to picofarads, in case of UCs the range is farads. The UCs power density is 10^6 w/m^3 and 10^4 wh/m^3 for energy density. For traditional capacitor energy density range is 50 wh/m^3, and power density is 10^{12} w/m^2. The traditional capacitor or battery surface area is very less compared with UCs surface area. Charging and the discharging ratio of UCs are efficient, and life cycle duration is also large. For the traditional capacitor, the dielectric materials are aluminum oxide, ceramic, and polymer film. In the case of super-capacitors dielectric material is activated carbon. Depends on the electrode materials UCs are subdivided into three categories, as shown in fig.10, i.e., pseudo-capacitor, electrostatic double-layer capacitor, and hybrid capacitors are detail in figure.10 [30],[31].

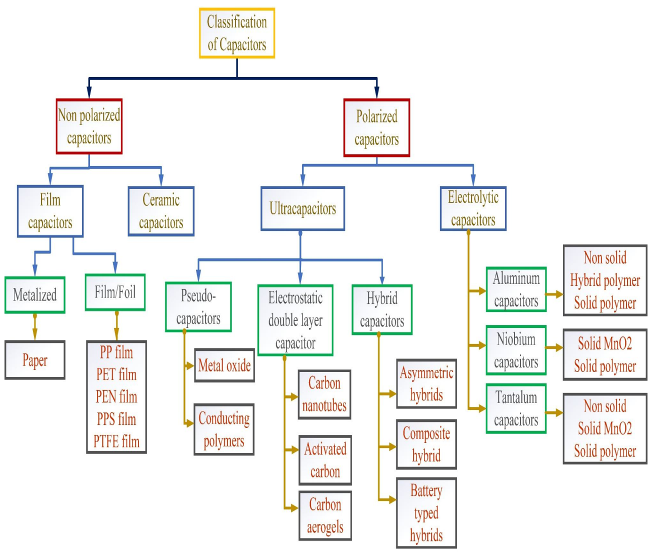

Figure 10: Various types of UCs

4. MOTOR DRIVES IN EVs

Permanent magnet synchronous motor (PMSM) has prevailed in EVs/ HEVs for traction motor applications recently, it tends to be operated over a vast torque speed range along with preferable torque density and power capacity. The obstruction of these motors is the availability of rare-earth materials and costs utilized in a permanent magnet. Therefore, alter these motors by advance developed motors like Induction motor (IM) as well as switched reluctance motor. In the case of IM, it does not have a magnet that symbolized a sturdy structure. The drawback of this technique might lose the cooling entity. So, initially, heat is created on the stator after some time, the rotor also started to heat due to no magnet [32]. This paper deals with the merits and comparison of a few motor architectures of EVs/HEVs models. Scientists in [33],[34] has explained the efficiency outlines of IM, PMSM, and SRM with standards. SRM drive does not depend on permanent magnets, and it has been particularly robust, it is convenient for rigged environments and fault tolerance region. Still, with high noise and less power factor has a few main objectives for construction and modeling of machines. In parallel, SRM drives might require essential personalized converters and many power sources to aid unconventional on stator part with phase windings [32]. A novel arrangement is required for developing electric vehicle charging points at transportation with available renewable energy sources. To achieve this, a novel multiport converter is needed for the control of the motor drive with multiple energy sources [35]. For an electric drivetrain, SRMs have become ambitious choices and attractive for recent applications of EVs and research associations. Presently, one of the aspects of reducing EV applications with their high capital cost and framework. This can be significantly achieved by the fabrication of universal charging points across the transport highways with existing fossil fuel stations. The difficulty is proposing by replacement of SRM-based charging or driving topology utilized which associates on-board charger. The SRMs can contribute to outstanding performance on fault tolerance and electro-magnetic isolation [EMI], that are compatible with EVs/HEVs applications [36].

Historically, EV charging points are mandator when the solar is in adequate as well as battery SOC is less than the 20%. Under this circumstances EV charging points are required across the high-way sides. To achieve this charging features, it needs a novel converter design. To design these types of converters, it significantly increases the cost. [37],[38]. To implement EVs with few onboard charging develop a converter with the load as a motor the motor windings can be connected to the output of the converter, which is utilized in a wide SRM charging scheme. In EVs dc source would typically be arranged with Lithium-ion battery staircase due to this it gives tremendous energy and power density. It generates large ripple currents at stator windings of the SRM, it will cause many complications:1) enormous temperature rise will happen in the battery pack which needs larger cooling scheme and thermal management demand.2) Depletion capability can result in enormous temperature rise and reduce the SOC of battery with this damage the Li-ion batteries attainment. Recent effects are the reliability of the battery SOC and life cycle of the battery, which has additional running to the battery safety concerns. As a result, battery pack thermal management typically from price and volume in the significant role of the system.

Table 2: Comparison between three types of electric motor drives

Motor Drive	Power Factor	Maximum Speed	Rated Speed	Constant Power range
SRM	0.6	20000	4000	1:3 rest in natural mode
IM	0.82	8750	1750	1:5
BLDC	0.93	9000	4000	1:25

Traditionally, massive electrolytic capacitors were familiar to govern this unwanted power ripples. Despite this, a theoretical span of electrolytic capacitance is a way briefer than the life span of semiconductors and alternative passive peripherals. Furthermore, the SRM permits for bidirectional power flow, which suggests that it will serve in each driving and regenerative braking process. This will facilitate to improve the driving extent of vehicles by gathering and convert kinetic energy into the batteries throughout the braking span. Consequently, it is vital to the engineers with a logical and versatile power flow control in SRM drive as utilized in EVs/HEVs appliances. Newly, several researchers are launched in numerous fields to alter with passive compensation scheme or active methods to destroy the inconvenient power ripples for batteries in place of enormous electrolytic capacitors. This generating power ripple and propagation in fuel-cell power grids are surveyed [39].

Table 3: Efficiency comparison of Different Electric motors

Drive Type	Efficiency at Peak Load (%)	Efficiency at 10% Load (%)
Induction Motor	>90	>90
Synchronous Motor	>92	80 to 85
DC Brushless Motor	>95	70 to 80
DC Brushed Motor	85 to 90	80 to 85
SRM	>91	>93

4.1. Photovoltaic with SRM Drives

A photovoltaic (PV) panel as an additional input of the EVs and the SRMs is connected across the wheels for the propulsion of the vehicle. PV panels can be fixed on the head of the EVs. Different energy sources are available. In the present scenario, a classic railcar has sufficient surface to build a PV panel at 250 watts. Then, SRM does not require rare-earth PMs and is additionally sturdy so that it highly attractive in EVs. Although PV panel has a less-power capability for traction systems. Battery is charged at utmost by connecting with PV cells. Hybrid EVs having the ICE, the ICE are interchanges with PV-fed EVs with modern features as shown in figure.11. Its key element is holding an off-board charging point, batteries, Solar and power converters [40]-[42]. So, as to reduce the energy conversion mechanism, straight to integrate the motor to restore some onboard charging functions

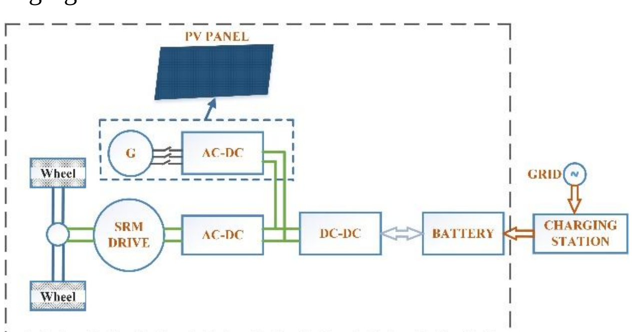

Figure 11: Photovoltaic panel-fed Hybrid Electric Vehicle

In [43] a 20-kilowatt split-phase PM motor for EV charging. However, it deteriorated from vast harmonic contents with back electromagnetic force (EMF). To overcome that, conventional SRM is predicting. Power factor correction and on-board charging achieve during a 2.3-kilowatt SRM by using windings because of the inductor filter at input. The concept of standard driving topologies is projected in [44].

A four-phase half-bridge converter, Sustained Intelligent Power Modules (IPMs) are utilized for grid-charging under driving conditions. The utilization of half-bridge or full-bridge topologies can diminish the systems reliability. PHEV supports versatile energy flow. The grid will be associated with the generator, by using conventional rectifiers the energy conversion losses are reduced drastically and reduces charging effectiveness. However, a better converter topology and management of PV-fed electric vehicles are not established [45].

$$J\frac{dw}{dt} + \mu w = T_e - T_l \tag{2}$$

T_l – Load torque
T_e – Electromagnetic torque
J – Moment of inertia for combined Motor and load

At present scenario, in Hyundai kona electric car having a PMSM with a torque of 395 n-m with moderate speed. In Tata Tigor uses 3-phase IM having 105 n-m torque and at a speed of 2500rpm. BMW i8 run with hybrid synchronous motor with 250n-m with high speed. Tesla model-3 is running with dual motor for all wheel drive (SRM at rear and IM at front). Many researchers are working on SRM with reduction in high-noise, high torque ripple and vibrations of the system.

5. POWER CONVERTERS

By utilizing Power Electronic Converters ((PEC) in distributed power generation and transportation, the hybridizing storage system (HES) is accompanied. PEC is promising for HES to reduce the size of the part and multiple inputs. It does not have any systematic approach for multiple input converter to synthesis them. By using of switch blocks, it achieves the multiple inputs systematic perspective. For hybrid and conventional vehicle distribution system, Electrochemical Capacitors (EC) are projected. During regenerative braking, acceleration, and hill-climbing, the energy storage unit is used for an intermediate level of ECs at high specific power. ECs are a better choice compared with batteries of HES in future EVs [46].

5.1. Conventional converters

A reliable and righteous rectifiers or inverters are needed for electric vehicle traction drives in general. A few converter techniques are supported for SRM drive. A modern 3-Phase

SRM drive for charging functions can be developed newly, as well as ICE and grid charging is conferred [47]. In parallelly, the rapid excitation and quick demagnetization cannot be attained, and this device comes from a C-dump converter that has zero fault-tolerance ability because of non-isolated phases within this circuit. DC-DC converter shown in figure.12 is utilized for SRM drives, and a voltage-boost converter is meant to reinforce the SRM winding current and vigorous speed responses [48].

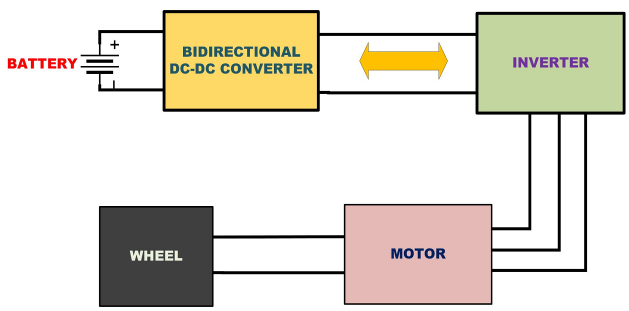

Figure 12: Bidirectional converter interfaced with Battery and Motor drive

Initially, DC-DC converters enclose capacitors and inductors to diminish the power density. SRM drive among Miller converter by victimization 3-Phase intelligent power module is conferred for driving or charging in [49] for application of powered vehicles, but it is not furnished with fault-tolerance ability. With flexible battery charging as well as discharging for an SRM drive motor has been designed a two-level converter and asymmetric bridge converter [50]. The management patterns are implemented with extraordinary acceleration, retardation, and regenerative braking virtue. To penetrate versatile charging activities in both dc and ac sources, a split converter is intended for a 4-Phase SRM drive [51] in EV applications, but it cannot produce a multilevel voltage in motoring condition, undesirable on three-phase motor drive appliances. A passive boost power converter is projected for SRM drive, which enhances the passive circuit to the front-end asymmetrical conventional converter to upgrade the voltage at dc link for high negative bias within the activity stage. Current rising and falling times are nullified in SRM drive by utilizing a quasi-three- level converter is designed. This convertor needs double as several power switches compared with standard converters, which highly increase the price and size of the motor drive [52].

An integrated multilevel converter fed to the SRM drive for EHV is compatible with the front-end circuit. Use on-off control technique switches for front-end circuit, and distinct operating modes are attained. The battery unit exalts phase voltage for quick excitation and demagnetization under generator driving stage. The converter has been redesigning with 4-level converter with quick excitation, and demagnetizations are developed for battery driving stage by the extra charge capacitance. However, due to structural voltage, the torsion capability is developed. The battery charging will be flexibly attained in standstill conditions. By controlling suitable switches, the energy transformation amid the generator, battery unit, peripheral ac source, and traction is flexibly accomplished [53].

An integrated multilevel converter is having more compact with an improved power density, multiple purposes, and different working modes are attained. Thereafter the efficiency of the motor system is increased by (2 to 4)%. Additionally, under motoring, braking and standstill conditions, the battery could be charged flexibly, without appeal to off-board charging availability. For the inductance ascending zone, the current conducted, and therefore, positive torque is generated and under inductance descending zone, the current is supplied, because of this negative torque is attained. A typical half-bridge asymmetrical converter with front-end power converter diagram as shown in figure.13.

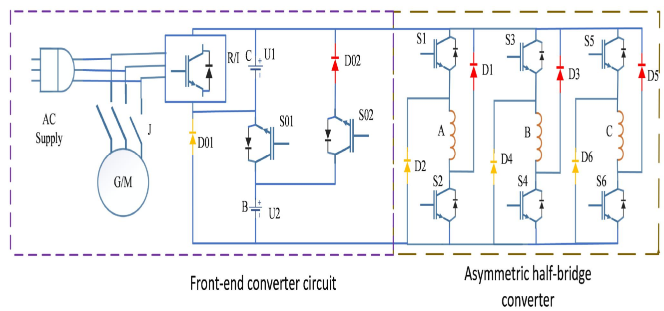

Figure 13: Half-bridge Asymmetrical converter with front-end power converter circuit

The strategy of the generator, as well as battery functions at distinct speeds, are shown in figure.14. The battery and generator can operate simultaneously or individually subjected to speed contrast, to ascend the acceleration, steady-state, and starting system performances.

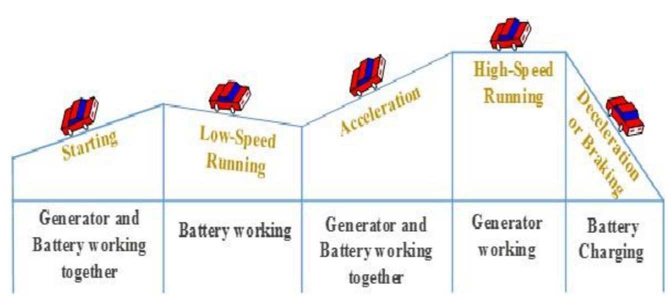

Figure 14: Strategies of the generator, battery roles at different speeds

Fast demagnetization and excitation in multilevel voltage can be attained in battery and generator driving modes for torque capability enhancement.

To develop flexible energy conversion on multiple electrical energy components, it requires two converters for the board, i.e., generator, motor, and battery unit. The limited on-board area is needed to drive the trucks at high-power converters that should be utilized. By achieving ac grid connection charging, an additional converter is required. On-board power electronic converters are difficult for the above converters. For SRM depending on plugin hybrid electric trucks, a standard tri-port high power converter has been investigated to meet the several electrical energy components into the single converter. It supports both flexible energy, series parallel winding connections according to various circumstances. For instance, ac grid connecting stages are also sophisticated in the drive, which permits the projected converter to operate as a grid concerning charger except for additional amenities. For traditional EV application, the combination of dc-dc converter along with the bidirectional ac-dc charger, on-board energy transformation can be solved. In this method, energy drift between the battery bank and high voltage bus can be controlled by the charging system. This circuit having more complexity due to integration [54].

For two intelligent power modules, a frontend dc-dc boost converter and miller converters are designed for improving the driving performance by considering convenient control techniques. The new technique is suggested for reducing the price and weight effectually for hybrid vehicles by integrating DC-DC converter processing through the traction drive system [55]. By using inverter along with the machine to develop an isolated DC-DC full-bridge converter for primary bridge leg. The tri-port schematic diagram of 3-Phase SRM based HEV is represented in figure.15.

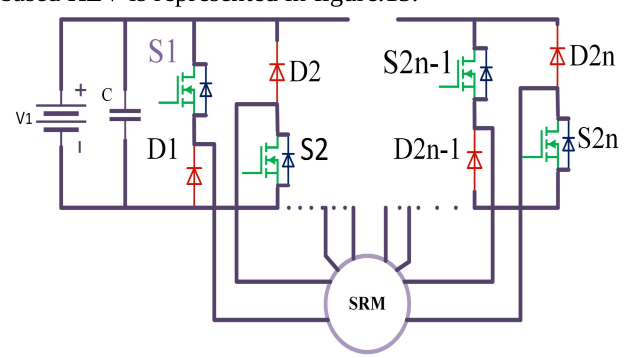

Figure 15: Tri-Port schematic diagram of three-phase SRM-based HEV

Table-4 represents the comparison between modular tri-port converter, and other tri-port converters for SRMs, that demonstrate the benefits of modular tri-port converter apart from the-state-of-art converters. Due to the symmetrical and salient configuration of the motor, the rotor is balanced because of tangential force whenever the 3-Phase windings are connected parallelly. While charging progress, the SRM keeps on standstill conditions. Under the hysteresis control method, the phase current waveforms are high quality, and consistent total harmonic distortion is assuring in [56].

To diminish the dc-link capacitance, allow the wide-speed process and boost the dc voltage, a Quasi -Z-source integrated multilevel converter as implemented for SRM drives [57],[58]. The C-dump converter can be utilized for hybrid vehicles along charging capabilities that have been improved in SRM drive, despite it has poor fault tolerance facility, owing to with Non-Isolated phase in the circuit, in additionally the improved DC voltage should not be attained [59]. For four-phase SRM-based, a split converter topology is designed for pure battery-powered vehicles to reach battery charging operations with flexible, while the midpoint of the phase windings is associated.

For reducing the dependence on charging stations and fuels/batteries to develop the self-charging capability thereby increasing the driving miles. By integrating the electrical devices into a single converter, a bidirectional front-end circuit along PV fed circuits are developed. To enhance the torque capabilities on SRMs converters along additional boosted dc-link voltages are introduced. To degrade the current ascending and descending times by implementing a Quasi-three-level converter [60]. For SRMs, a Quasi-Z-Source integrated multiport converter is manufactured, to increase the dc voltage, to decline the dc-link capacitance and to permit the wide-speed operation. To attain both charging and driving services for EVs, the state-of-the-art SRM drives have been introduced in [61]-[66]. To develop the motoring performance and control the current ripple suggest a three-port converter is recommended for battery-powered SRM drives in recent EV applications.

5.2. Integrated Multiport Converter

A multiport converter is vital for transferring energy between input sources, the battery pack and SRM drive. The Asymmetrical H-bridge [ASHB] methodology in figure.16 is usually used because of its integrity. Waveforms of phase current infused to SRM appears in figure.17 and the relationship between the magnetic energy storage in one phase of SRM and through current commutation periods cannot be dealt with by the ASHB.

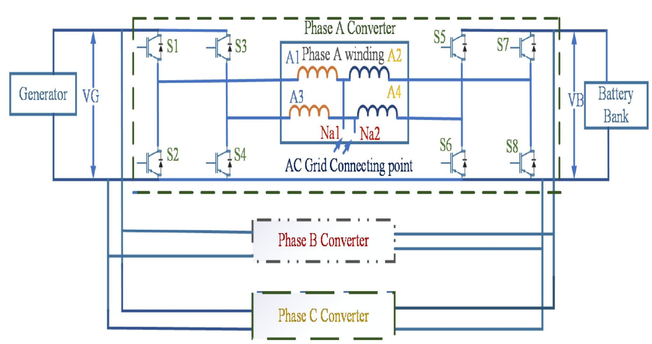

Figure 16: Asymmetrical H-bridge converter with SRM drive system

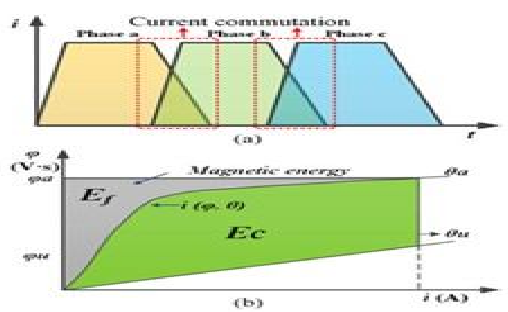

Figure 17: Current commutation in SRM (a) Phase current, (b) Magnetic energy stored in SRM versus current.

These lead to a drastic change in the output power of the battery pack, causing periodic high peak current and highly di/dt for the battery. In order to diminish this current ripple, Cai and Yi [67] presented a novel Integrated Multiport Converter (IMPC).

Compared to the asymmetrical H-Bridge converter, the presented IMPC has few advantages incorporates.

- ★ The dc voltage source is not influenced by the capacitor, because the capacitor is isolated from the DC source.
- ★ Voltage ripple and average capacitor voltage can be expansive, which takes a reduction of capacitor necessity virtually expected.
- ★ The current flowing in the DC source is filtered by an inductor; in this way, the electrolytic capacitors are not connected in parallel with the DC input source necessary. Moreover, the necessity for dc input source voltage is release and can be lesser than what the SRM needs.
- ★ By expanding DC-link voltage, the conduction angle should be expanded with time de-energizing phase moderates, and large torque can be acquired. Speed range can be enlarged with particularly engaging for large speed appliances.
- ★ It has five-switches, 3-diodes, one inductor, and one small capacitor are needed for IMPC in a 3-phase SRM drive it implies less cost and larger power density in motor drive.
- ★ If SRM holds N phase, then legs are N+1 are essential, N+2 switches and N diodes are required in total.
- ★ To drive N-phases of SRM drive exclusively, N+1 wire was essential, which implies bulky wire harness is less.

In an urban environment, HEVs are familiarized it requires a more significant number of charging stations. The manufacturing costs are considering if conventional ICE-based vehicles are altered by updated electrified ones. In addition to that for pure battery power mode, the desirable driving distance very less, because of the constraints of the existing battery technologies.

To overcome these problems, PV panels could be engaged to benefit the main power source in the driving stage and attain battery charging that will greatly decrease the dependence on batteries, charging stations and fuels. In aircraft and electrified transport applications, PV panels have been implemented in [68],[69].

$$\frac{1}{2}(IW^{2}) or \frac{1}{2}((KMr^{2})w^{2})$$

5.3. Hybrid Multiport Converter with SRM Drive

Solar-assisted hybrid electric vehicles, a multiport bidirectional SRM drive is designed for multisource operation, it accesses flexible self-charging, and enhance the motoring performance functions. Due to multisource operation, the torque is increased. The circuit diagram of powertrain SRM-based solar-assisted hybrid electric vehicle (SHEV) is shown in figure.18. It consists of the stored of energy component, i.e., a GCU, a battery unit, a power control section as well as multiport converter unit and controller section, then rectification of AC-DC converter part, PV panels, and SRM drive used in the traction motor drives. At the top of the vehicle, PV panels are installed to maintain feasible power supply, by using this not only defeat the demerits of very less driving provided in pure battery operating stage due to the constraint of modern battery technologies; additionally, it achieves self-charging flexibilities to decrease dependence on charging stations. Bidirectional Multiport SRM drive technique for the SHEV application that consists of a front-end PV-fed circuit, front-end bidirectional circuit, and traditional half-bridge asymmetrical converter as shown in figure.19.

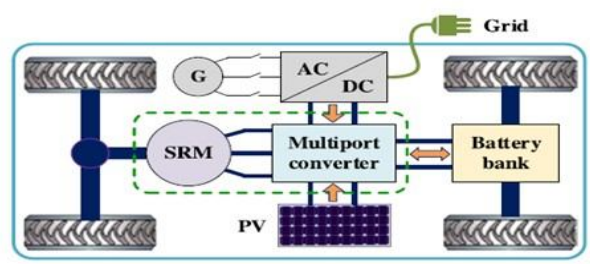

Figure 18: Solar assistant hybrid electric vehicle propulsion system with self-charging function

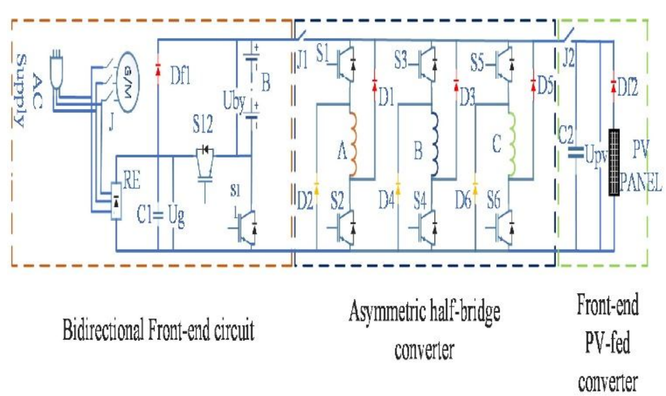

Figure 19: Bidirectional multiport converter SRM drive topology

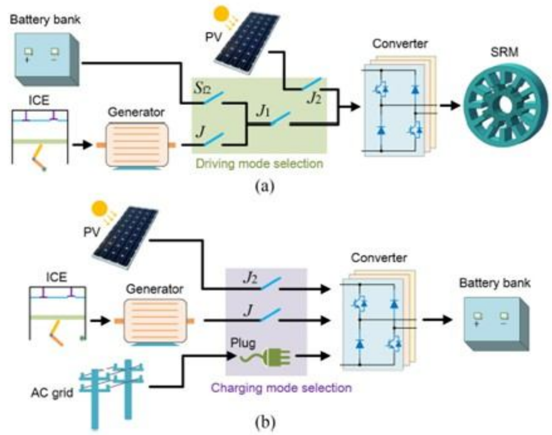

Figure 20: Schematic diagram for the proposed SRM drive (a) Motoring mode (b) Charging mode

Figure.20 represents the basic diagram of the SRM drive for charging and motoring sections, correspondingly. For providing three-phase ac power rectification, the GCU is mechanically attached to an ICE

Table 4: Modular tri-port converter comparison with other tri-port converters

Converter type	Modular Tri-Port	Integrated Charging	Integrated Multilevel Tri-Port
Power level	More	Less	Moderate
Energy flow workability	High	Low	Moderate
Fault tolerance	feasible without absence of	Without fault tolerance	Without fault tolerance
Modular topology	Yes	No	No
Grid connecting charging	Charging stations are not needed	Charging converter is used	charging converter is used

In motoring mode, by monitoring the switch S_{f2} and relay J in a bidirectional converter the GCU and battery can operate individually. Corresponding to the solar irradiance, the PV is erected for utilization by governing the J_2 relay. It attains six driving stages, along with the battery driving stage, GCU driving stage, GCU- battery driving stage, PV-GCU driving stage, PV driving stage, PV-battery driving stage as displayed in Fig. 20(a). By monitoring the relays J_2 and J in battery charging stage, it achieves three charging stages, apart from this it includes GCU charging stage, ac grids charging stage and PV charging stage as presented in Fig. 20(b). When phase A winding is under demagnetization voltage. Current and voltage at phase A are given below

$$U_a = -U_g - U_{by} = R_a i_a + L_a(\theta, i_a)\frac{di_a}{dt} + \frac{\partial L_a(\theta,i_a)}{d\theta}(w\, i_a) \qquad (3)$$

$$i_a = i_{dc} + i_b \qquad (4)$$

where U_g is capacitor voltage from rectification of GCU output, U_{by} is voltage at battery, i_{dc} is lower dc-link current, θ is rotor position and w is angular speed Demagnetization current i_a is smaller than the excitation current $i_{b.}$ A-phase voltage is demagnetization for capacitor C_1, current and voltage equations are given below for phase A

$$U_a = -U_g = R_a i_a + L_a(\theta, i_a)\frac{di_a}{dt} + \frac{\partial L_a(\theta,i_a)}{d\theta}(w\, i_a) \qquad (5)$$

$$i_a = i_{dc} + i_b \qquad (6)$$

Demagnetization current i_c is higher than the excitation current i_a during this mode phase A voltage and current equations are as follows below

$$U_a = U_g + U_{by} = R_a i_a + L_a(\theta, i_a)\frac{di_a}{dt} + \frac{\partial L_a(\theta,i_a)}{d\theta}(w\, i_a) \qquad (7)$$

$$i_a = i_{dc} + i_b \qquad (8)$$

Whenever solar irradiance is available, the battery is charged by using solar panels. By the less power level of solar panels, it exists only one phase of the converter at any moment in solar powered charging mode. In this state, the current is flowing through the winding can be given as

$$i_{k1}(t) = \mathrm{I}_{k0} + \frac{(I_{km} - \mathrm{I}_{k0})}{\mathrm{DT}}t \qquad (9)$$

The phase winding current feeds back to the battery B through diodes. In this mode the battery is charged by the solar panels then the charging current is given by

$$i_{k2}(t) = \mathrm{I}_{k0} + \frac{(I_{km} - \mathrm{I}_{k0})}{(1-\mathrm{D})\mathrm{T}}t \qquad (10)$$

The maximum and minimum total of three-phase currents are given as

$$\mathrm{I_{max}} = \mathrm{I_{am}} + \mathrm{I_{bm}} + \mathrm{I_{cm}} \qquad (11)$$

$$\mathrm{I_{min}} = \mathrm{I_{ao}} + \mathrm{I_{bo}} + \mathrm{I_{co}} \qquad (12)$$

The charging current for the battery bank in this mode is given by

$$i_{by}(t) = \mathrm{I}_{max} + \frac{(I_{max} - \mathrm{I}_{min})}{(1-\mathrm{D})\mathrm{T}}(t\text{-}DT) \qquad (13)$$

The bidirectional multiport converter is connected with several sources i.e., grid supply, energy storage devices, solar system and SRM drive. One side of the multiport converter is connected with grid supply. The grid supply can be controlled by use of rectifier mode (AC to DC). Battery is connected across the output of the rectifier. The available DC energy can be charged by use of battery if battery SOC is less than 100%. If battery SOC reaches to100% then it does not allow to charge the battery, then the DC energy can be converted to AC with inverters. The inverter can be control the motor drive with appropriate switching operation. Multiport converter another side solar system can be connected. These system produces the DC. The DC is not constant values because it various depends upon the irradiance and temperature. So, capacitor is connected in parallel to the solar cells. Here by utilizing diode charge the battery. Six driving stages are attained. The solar-assisted HEV has been operated with the GCU driving stage, Battery-GCU driving stage, and pure battery driving stage, with different running circumstances. Whenever solar irradiance is adequate, PV can operate with the GCU/Battery simultaneously as an assisted feasible energy source to subsidize for driving the motor, which diminishes the dependence on fuels or batteries significantly. The solar can serve the energy individually to the motor drive in downhill motoring conditions. Without additional charging converters it exists five stages of charging functions. In the GCU driving stage and solar driving stage, in demagnetization current, the battery bank can be charge marginally. The energy can be reclaimed to the battery under braking progress. Moreover, at SHEV rest condition, the BB can quickly charge by the solar, ac grids and GCU this will reduce the charging station reliance. Multilevel voltage and the boosted dc voltage can be acquired by the BB in the GCU driving stage. By boosted dc voltage, both demagnetization and excitation processes are accelerated. Without increasing torque ripple, the torque capability can be drastically improved because of the multiport topology [70]. Wireless charging converters also available in the present scenario, but it will be limited for suitable applications. Bi-directional DC-DC converter having a high efficiency with advanced switching operation by connecting with electric drives [71]-[73]. Table-5 represents the Comparison of bidirectional multiport SRM drive and state-of-the-art.

Table 5: Comparison of bidirectional multiport SRM drive and state-of-the-art

Constraints	[56]	[57]	[59]	[48]	[47]	[66]	[70]
Multiport Converter	Not Accomplished	Not Accomplished	Not Accomplished	Not Accomplished	Not Accomplished	Not Accomplished	Accomplished
Dependence on batteries / fuels	More	More	More	More	More	Less	Less
Fault tolerance Ability	Available	Unavailable	Unavailable	Available	Available	Unavailable	Available
Energy flow flexibility	Very Low	Moderate	Low	Moderate	Moderate	Moderate	Huge
Self-Charging Ability	Not obtained	Not obtained	Not obtained	Not obtained	Not obtained	Obtained	Obtained
Dependence on charging station	Very High	High	Very High	Very High	High	Less	Less
Enrich DC voltage	Attained	Attained	Not Attained	Not Attained	Attained	Not Attained	Attained
Grid Charge connection	Charging converter not necessary	Charging converter not necessary	Charging converter not necessary	Charging converter not Necessary	Charging converter not necessary	Charging converter is necessary	Charging converter not Necessary

6. CONCLUSION

In this review, the article explains the multiport converter techniques for flexible charging and discharging of the battery and controls the SRM drive for E-Vehicles models. For solar-assisted hybrid electric vehicle applications, a bidirectional multiport SRM drive is implemented, not only for control of the motor at running situations, apart from this it accomplishes adaptable charging capability, various charging, and driving stages are developed. To increase the torque capacity in the drive system a multilevel voltage is required. Solar is suggested to enlarge the driving range and visualize self-charging capability. To enhance the multilevel voltage, battery charging and driving capacities, a novel bidirectional multiport converter is designed for SRM drive for the propulsion of the wheels. There are six driving stages are accomplished. If solar irradiance is not adequate, SHEV can operate in a pure battery driving stage, GCU driving stage, and Battery-GCU driving stage at running conditions. Solar can operate with Battery/GCU together at sustainable sources of energy to operate the engine driving at the point of solar irradiance adequate, which fundamentally reduces the dependence on batteries/fuels. Solar panel can give energy to the drive engine at downhill motoring conditions. Without additional charging converters, five charging stages are experienced. Under the GCU driving stage and PV driving stage, the battery bank can marginally charge by using demagnetizing current. During the braking process, the mechanical energy can be converted to electricity to charge the battery by using the bidirectional multiport converter. SHEV at rest condition, the battery bank presented in the vehicle to starts the charging immediately with the energy sources, which are Solar, GCU and AC networks, decreases the dependence on charging stations. To achieve a flexible energy control system a novel converter strategy is presented. In the GCU driving stage the battery bank and under pure battery driving stage the charge capacitor, by these two stages, it achieves multilevel voltage and dc boost voltage. Because of dc boost, voltage magnetization and excitation operations are accelerated. Because of the adaptability of a multiport converter, it gives a few interest points. It tends to be utilized in sustainable energy sources for continuous power supply without large capacity, or by using hybrid sources it may be utilized for energy capacity in electric vehicles. Although the work has focused on energized vehicle applications, the developed innovation techniques can be connected to high-torque, as well as high-speed applications, for example, electric ships, traction drives, and electric aircraft, etc.

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