Overview of Electric and Hybrid Vehicles

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***Abstract*—Introduction of electric vehicles (EVs) signal the beginning of the end for traditional engine vehicles. The major motivators for shifting to EVs are the need for reducing polluting engine emissions and reducing dependence on costly oil fuels. By the end of 2016, the global stock of EVs crossed the two million mark. The growing acceptance of EVs is the outcome of several factors: technological advancements, rising storage capacity of traction batteries coupled with their falling cost, increased public charging facilities and Govt. incentives. The two EV technologies currently remain at the top are the battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEV). This paper gives an overview of various EV technologies, their features, limitations and challenges in their bulk deployment as a replacement to conventional vehicles.**

I. INTRODUCTION

THE development of automobiles powered by internal combustion engines (ICE) was one of the greatest engineering achievements towards the end of the nineteenth century. The availability of low-cost fuels, ease of use, increased reliability and long driving range boosted the acceptance of these vehicles. However, vehicles propelled by heat engines are very poor in fuel efficiency (~ 20-25%), besides the combustion of hydrocarbon fuels in these vehicles release many toxic gases. Today, after more than a century, the automotive industry and the large number of vehicles in use around the world are causing serious concerns for the public and the environment.

The transport sector is a major contributor of air pollution besides electricity and heat generation industries. As shown in Fig. 1, the power and heat generation sectors contribute to 42% of the global CO_2 emissions, while the transport sector alone contributes to 24% of CO_2 emissions in 2015 [1]. Road transport accounted for 75% of transport emissions.

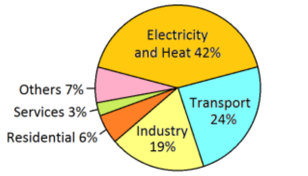


Fig. 1. World CO_2 emissions from fuel combustion by sector (IEA report 2017).

Depending upon the fuel type, driving style and road conditions, a typical medium size vehicle on an average emits about 411 grams of CO_2 per mile of travel, leading to about 4.7 metric tons of CO_2 yearly [2].

Besides CO_2, liquid fuel engine vehicles also emit nitrogen oxides (NO_x), carbon monoxide (CO), sulphur oxides (SO_x), and unburned hydro-carbons (C_xH_y) from the tailpipe and hydro-fluorocarbon (HFC) emissions from leaking air conditioners. The shares of these gases are small as compared to CO_2; however, the impact of these emissions can be significant because they have a higher *Global Warming Potential* (GWP) than CO_2. The global warming potential of a gas relates the impact of that gas relative to an equivalent amount of CO_2. Various *Green-House Gas* (GHG) emissions from automotive and their GWP are shown in Table 1. CO_2 emissions account for more than 95% of the total GHG emissions from a passenger vehicle.

Table 1. VEHICLE LINKED GASES & GLOBAL WARMING POTENTIAL

Greenhouse Gas	GWP
Carbon Dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous Oxide (N_2O)	298
AC Refrigerant (HFC-134a)	1,430

The major challenges automobile sector needs to address today are (i) how to reduce impacts on climate change and (ii) how to lower dependence on oil fuel. Several strategies are being considered for addressing these issues. These include switching over to eco-friendly biofuels, improved engine design and use of electric vehicles. Biofuels have the potential to decarbonize the transport sector. In the early 2000, it was projected that biofuels would be the answer to the issues of fuel security and emissions. However, the sustainability and the anticipated reduced emissions from biofuels have been questioned in recent years in connection with food versus fuel trade-offs, carbon accounting and land use [3].

EVs hold the promise of reducing carbon emissions from transport sector significantly. Many countries have set targets to stop the production and sale of petroleum fueled vehicles. In terms of market share till Dec. 2016, Norway has 29% electric cars followed by the Netherlands (6.4%), Sweden (3.4%) and China (1.5%) [4]. The Electric Vehicles Initiative (EVI), a policy forum focusing on the adoption of EVs recently launched the *EV30@30 campaign*, setting the EV targets of 30% by 2030 [5]. In Germany, all new cars will be electric by 2030 and in France and Britain; sales of petrol and diesel cars will be banned by 2040. China, the world's biggest car market, plans to ban the production and sale of diesel/petrol cars and vans 'in the near future'.

India is targeting to have an all-electric car fleet by 2030 with an objective of lowering the fuel import and running cost of vehicles. As a starting point in this direction, Govt. of India launched the *National Electric Mobility Mission Plan* (NEMMP)-2020 in 2013. It aims to achieve national fuel security by promoting hybrid and electric vehicles in the country [6]. The ambitious target is to achieve sales of 6-7 million hybrid and EVs per year starting from 2020, out of which 4-5 million are expected to be two-wheelers.

II. HISTORY OF ELECTRIC VEHICLES

The first electric vehicle powered by non-rechargeable batteries was built in 1834, much before the development of IC engines [7]. Electric vehicles were very popular during the 1890 to 1920 period despite their very high cost. In 1912, EVs have reached their prime, making up nearly 28% of the cars on the road. The advances in IC engine technologies coupled with mass-production resulted in low-priced lightweight vehicles. By 1920, the availability of cheap oil, electric starters, and a superior ability to travel long distances helped petrol cars to dominate the auto market and eventually led to the collapse of the EV market. The downfall of EVs was attributed to a number of factors, including the need for long travel range, limited motor power and the easy availability of cheap petrol. In the 1970s, however, worries about the rising price of oil due to the *oil shock* of 1973 together with the growing concerns of global warning resulted in renewed interests in EVs.

III. Electric Vehicle Technologies

Electric vehicles use electric motors for propulsion in place of conventional IC engines. Engine driven vehicles work on the principle of combustion get their energy from carbon based fossil fuels. In contrast, EVs can use electricity generated through a wide range of resources such as fossil and non-fossil hydrocarbons, hydro/nuclear power and renewables. Electricity is transmitted to the vehicles through overhead power lines, direct connection through cables or wireless energy transfer. By using a storage system, the energy may then be stored onboard the vehicle.

Basic structure of an EV is shown in Fig. 2. Major components of an electric vehicle include storage battery, drive motor, motor controller, power electronics converters, charge controllers and battery management system (BMS). Depending upon the complexity of design, drive motor of the EV can be a single reversible motor/generator or individual motors and generator.

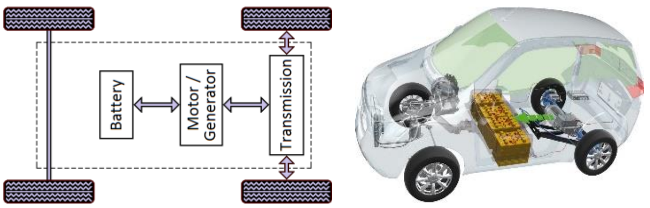


Fig.2. Basic structure of an electric vehicle.

EVs have relatively shorter driving ranges as compared to engine powered vehicles due to limited energy storage capacity. A brief comparison of IC engine vehicles vs. electric vehicles is shown in Table 2. Various terminologies associated with electric vehicles is described in Table 3.

Table 2. Comparison of Engine Vehicles vs. Electric Vehicles

IC Engine (ICE) Vehicles	Electric Vehicles (EV)
• Powertrain: IC engine	• Powertrain: Motor (+ Engine)
• High specific energy of fuel	• Low specific energy of battery
• Power density: High	• Power density: Low
• Emits greenhouse gases	• No tailpipe emissions
• Travels > 300 miles / fill	• Travels < 100 miles / charge
• Short refilling time (< 5 min.)	• Long charging time (0.5-8 hr.)
• Fuel tank takes less space	• Battery takes large space
• Fuel weight is very less	• Batteries are very heavy
• Higher maintenance costs	• Lesser maintenance costs
• Braking energy not recovered	• Can recover braking energy
• Running cost: high	• Running cost: low
• Engine efficiency: ~ 30%	• Motor efficiency: ~ 80%
• Needs complex gear system	• Needs only one gear
• Noisy operation	• Quiet operation
• Ample refilling infrastructure	• Lacks charging infrastructure
• Need to pick up some speed to deliver maximum torque	• Produce maximum torque instantly after starting of motor
• Uses only hydrocarbons	• Uses electricity from many resources

Table 3. Terminologies associated with EVs

kW	1. Drive motor power, similar to *hp* of IC engine. 2. Rating of battery charger, which gives an idea of how quick to recharge.
kWh	Size of battery: it gives the idea of how far the EV can be driven (travel range), similar to petrol tank capacity
km/kWh	How far EV can be driven with a unit of electricity, similar to ‘km/litre’.
$/kWh	Cost of electricity, determines the cost of travelling and charging.

Based on *how* and *where* the electricity is produced, EVs can be classified into three categories [8]:

1. Vehicles using continuous electric supply from an external power source. These include trolley buses and electric trams supplied by overhead line (shown in Fig. 3). Since they need continuous electricity, these vehicles are suitable only for very limited tasks.
2. Vehicles based on stored electricity from an off-board power source. These include vehicles using battery, flywheels, super capacitors etc.
3. Vehicles using on-board electricity generation to meet their needs. These include series electric hybrids, parallel electric hybrids, and fuel-cell electric vehicles.

Fig.3. (a) A trolley bus and (b) An electric tram.

The drive train of an EV (Fig. 4) consists of three major subsystems: motor propulsion, energy source and auxiliary. The propulsion system consists of the controller, power electronic converter, motor, torque transmission and wheels. The energy source section includes the energy source, energy management unit and the energy refilling unit. The auxiliary subsystem consists of power steering unit, climate control unit, and auxiliary supply unit [9].

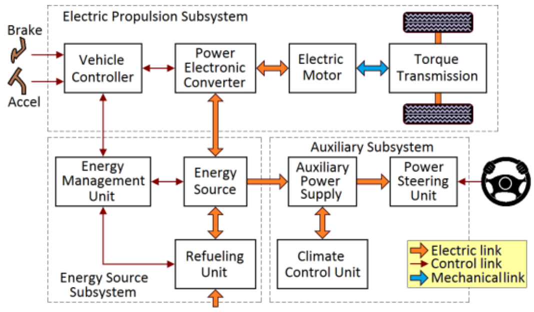


Fig. 4. Basic arrangement of an EV drive train.

EVs can be classified as Battery Electric Vehicles (BEV) and Hybrid Electric Vehicles (HEV). Pure EVs have only battery as their energy source. A vehicle that has two or more energy sources and energy converters is called a hybrid vehicle (HV). A HV with an electrical power train is called a hybrid EV. The sources of energy used in HEVs can be a combination of many resources such as battery, petrol, bio-fuels and fuel cells. Battery-powered EVs usually have larger storage batteries than HEVs. Travel range is one of the most important differences between BEVs and HEVs.

A common feature of all electric vehicles is the capability for *Regenerative Braking* (regen-braking). Regen-braking is a process by which kinetic energy (KE) of the moving vehicle is converted into electricity by reversing the operation of the motor into generator. Conversion of KE in to electricity slows the vehicle, which otherwise would have lost as heat by friction in the mechanical brakes.

a. *Battery Electric Vehicles*

Battery electric vehicles are propelled by electric motors by using energy stored on board in batteries. There are many similarities between an IC engine vehicle and a battery EV, a brief list of which is summarized in Table 4. To recharge the batteries of a BEV, periodically they must be plugged into an external source of electricity.

Table 4. COMPARISON OF SYSTEMS AND FUNCTIONS OF ICEV & BEV

Function	ICE Vehicle	Bat. Electric Vehicle
Energy storage	Fuel Tank	Battery
Replenish the energy	Petrol Pump	Charger
Production of motive force	IC Engine	Electric Motor
Controls speed and power	Carburetor	Electronic Controller
Auxiliary power supply	Alternator	DC/DC converter

Based on the type of transmission, clutch, gearbox, differential and the number of motors, a variety of EV configurations are possible. This is shown in Fig. 5, starting from the oldest design (a) to most advanced design (f).

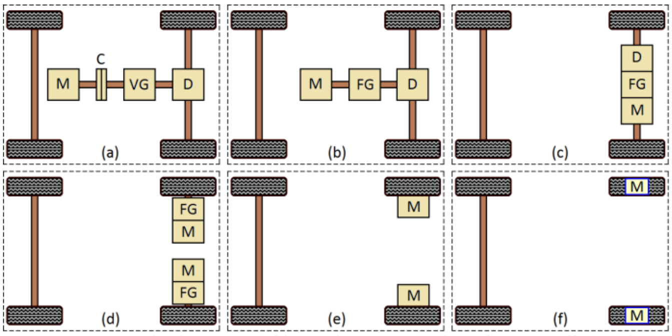


Fig. 5. Various configurations of Electric Vehicles.

a. Vehicles with a clutch, a multi-speed gearbox and a differential. These EVs are modified versions of ICE vehicles with motors in place of engines.
b. EVs with a fixed ratio gearbox and a differential. They do not use clutch as the electric motor that has constant power in a long speed range. This resulted in reduced size, weight and increased driving easiness.
c. Similar to the drive train in (b) but the motor, fixed gearing, and the differential are integrated into a single assembly. Result is a further simplified drive train.
d. The differential is replaced by using two traction motors to drive front wheels and operate at different speeds when the vehicle is running along a curved path.
e. The *in-wheel* drive with a thin planetary gear in which the traction motor is placed inside the wheel. The gear is used to enhance the drive torque.
f. Similar to the drive train in (e) except that the motor is placed inside the wheel without any gear. This design is relatively less complex than in (e).

The latest innovation in electric vehicles is the in-wheel configuration. In this design, as shown in Fig. 6, separate motors (known as in-wheel motors) are installed at each wheel. Mounting the motor and power electronics within a wheel assembly can improve efficiency, save space and give designers more flexibility in body design. It is possible to regulate drive torque and braking force independently at each wheel without the need for any complex transmission or drive shaft. Regen-braking capability of in-wheels is very high, about 85% [10]. This design will require drive motors with higher torque to start and accelerate the vehicle. In-wheel motors of capacity up to 75 kW is currently available.

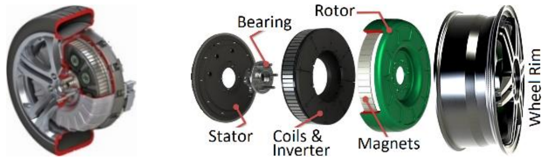


Fig. 6. Arrangement of an in-wheel motor.

b. *Hybrid Electric Vehicles*

The biggest advantage of IC engine vehicles is the long driving range due to the high energy-density of petroleum fuels. Though battery EVs possess many advantages over conventional engine vehicles such as zero pollution, high efficiency etc., their travel range per battery charge is much less than engine vehicles due to the lower energy content of batteries. Hybrid electric vehicles have the benefits of both ICE vehicles and electric vehicles, and overcome their individual disadvantages.

An HEV typically houses a petrol engine with a fuel tank, a motor and a battery bank. The electric propulsion provides higher acceleration performance at low speed, which cannot be achieved in engine vehicles due to several mechanical constraints. The power flow in ICE drive is unidirectional from engine to wheel whereas in electric drive, power flow can be bidirectional: from motor to wheel and from wheel to battery. The concept of a hybrid vehicle drive train and the possible power flow routes is shown in Fig. 7. There are five unique features generally common in hybrid EVs: idle-off, regenerative breaking, power assist, electric-only drive, and extended battery-electric range.

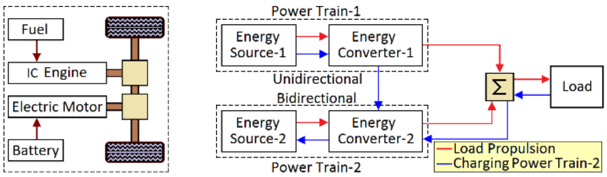


Fig. 7. Arrangement of a HEV with power flow paths.

In order to represent how much is the share of electric power in an HEV in comparison with the overall power, a *hybridization factor* (*HF*) is defined as

$$HF = \frac{\text{Sum of Power of Electric Motors}}{\text{Sum of Motor Power + Engine Power}} \qquad (1)$$

On the basis of the degree of hybridization, hybrid electric vehicles can be classified as (i) Micro Hybrid, (ii) Mild Hybrid and (iii) Full Hybrid

Micro Hybrid (μHV): Micro hybrid is the least electrified type of HEV. It is a conventional ICE vehicle with an oversized starter motor of about 3 to 5 kW at 12 V to assist the starting of IC engine. The motor cannot propel the vehicle, but can be used to assists accessories such as power steering and air conditioning. This type EV is generally used for frequent idle-stop or stop-start mode operations. During idling of a μHV, the engine is shut down and during regenerative braking; the motor works as a generator to charge the battery. Regen-braking, however, may not be a standard feature in all µHVs. Micro hybrids usually have a hybridization factor of 5%-10% with an energy savings of about 3%-10% in city driving. µHV design is usually found in light vehicles, and is most suited for urban applications. Example:-Mercedes Smart.

Mild Hybrid (MHV): This hybrid uses motor of 7-15 kW at 60-200 V. Motor does not alone propel the vehicle but only supports starting of the engine, regen-braking, and also provides supplementary torque when peak power is needed during acceleration. In MHV, the IC engine will be always running, unless the vehicle has stopped or the speed is very low as it is coming to a complete stop. The hybridization factor of mild hybrids is about 10%-30%. Battery size is higher than micro hybrid. Energy savings in city driving is about 20%-30%. Example: Honda Civic and Honda Insight.

Full Hybrid (FHV): A hybrid EV which can move by electricity alone is a full hybrid. Since a FHV can run in *only electric mode*, it needs a large capacity motor, about 30-50 kW at 200-600 V. Energy saving is of the order of 30%-50%. Example: Toyota Prius.

A brief comparison of various levels of hybrids is shown in Table 5. When the engine of an HEV is in operation, intelligent controls ensure that the engine always operate at its optimum performance zone directing the excess energy to the battery. Although regen-braking is a common feature in all HEVs, vehicles in the micro and mild category cannot absorb the complete KE of the vehicles during a rapid stop. This is because micro/mild HVs have smaller hybridization factor, which means small generator; and hence they cannot convert all the available KE into electricity. For recovery of full braking energy, hybridization factor must be about 40% or higher. This is the reason for increased energy saving with increasing level of hybridization.

Table 5. Comparison of Hybrid Levels of EVs

Hybrid Type	Micro Hybrid	Mild Hybrid	Full Hybrid
IC Engine	Conventional	Downsized	Downsized
Motor Power	3-5 kW	7-15 kW	> 30 kW
Motor Voltage	12 V	60-200 V	200-600 V
Hybridization	< 10%	10-30%	> 40%
Energy Saving	5-10%	20-30%	30-50%
Functions	Start/Stop Reg. Braking Accessories powering	Start/Stop Reg. Braking Electric Assist	Start/Stop Reg. Braking Electric Traction
Relative Cost	Low	Medium	High
Examples	Mercedes Smart	Honda Insight	Toyota Prius

Architecture of Hybrid EVs

Hybrid EVs are popular for their enhanced efficiencies as compared to conventional vehicles. The improved efficiency of HEVs is attributed to the following reasons:

1. Operating ICE optimally independent of vehicle speed
2. Regenerative braking
3. Shutting off the ICE at low speeds to reduce idling loss
4. Minimising vehicle accessory load and road load

Based on the way the energy converters (i.e. IC engine, electric motor etc.) of an HEV are combined to propel the vehicle, many powertrain configurations are possible:

i. Series Hybrid (SHEV)
ii. Parallel Hybrid (PHEV)
iii. Series–Parallel Hybrid (SPHEV)
iv. Complex Hybrids (CHEV)
v. Fuel Cell Hybrids (FCHEV)
vi. Plug-in Hybrid Electric Vehicles (PHEV)

The major configurations of HEVs are shown in Fig. 8.

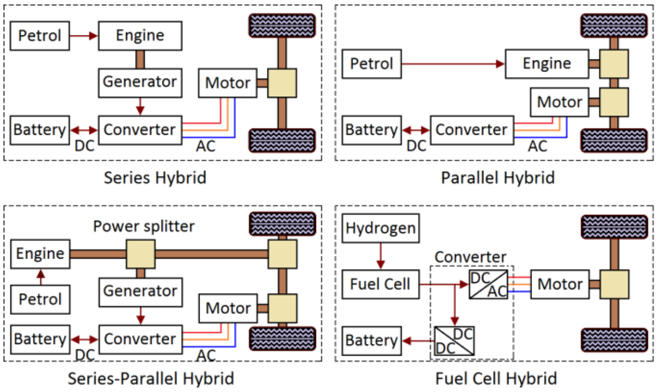


Fig. 8. Architecture of Hybrid EVs.

Series Hybrid EVs (SHEV)

Series drivetrain is the simplest hybrid configuration. In this design, the electric motor alone delivers the vehicle traction power as the engine is not connected to the drive train. The traction motor is powered by a battery or by an electric generator driven by the downsized IC engine. The generator powers the drive motor when the traction load demand is large or charges the batteries when the motor load demand is small. The motor can also operate as generator during braking and coasting. Series hybrids are the most efficient in driving cycles that require frequent stops and starts such as for delivery vehicles, urban buses and stop and go city driving. The drawbacks of SHEV: (i) needs separate generator and motor sections (which means increased cost and reduced efficiency due to more systems), (ii) needs large size drive motor rated for maximum power needs such as climbing uphill. However, since series hybrids use a bigger electric machine in the propulsion system, their energy recovery capability is much higher than other HEVs. Example: Nissan e-Power.

Parallel Hybrid EVs (PHEV)

In parallel hybrids, both IC engine and motor are directly connected to the drive system so that they can individually (during low traction power demand) or jointly (during high power demand) propel the vehicle. Most PHEV designs combine the generator and motor into one unit. In parallel drive mode, the supplied torques are added together. When only one of the two drives is in service, the other will be disconnected through a clutch. PHEVs are relatively more compact as they use a smaller battery pack than other hybrids and needs a smaller traction motor. The drawback of PHEV is the need for complex mechanical systems and control algorithms. Example: Honda: Insight and Civic.

Series-Parallel Hybrid EVs (SPHEV)

Series–parallel hybrids (or power-split hybrids) combine the benefits of both series and parallel architecture. The power-split device divides the output from the engine into mechanical and electrical transmission paths. This design is capable of providing continuous high output power as compared to series or parallel powertrain. They use smaller motors. Series-parallel hybrids can achieve similar operating modes as series hybrid vehicles. However, it requires very complex control system. Example: Toyota Prius.

Complex Hybrid EVs (CHEV)

The complex hybrids are similar to series-parallel hybrids but use more complex designs depending on the number of motors/generators and their configuration. Motor power flow in these designs is bi-directional as compared to unidirectional flow in the series-parallel hybrid. Example: Ford Escape.

Fuel Cell Hybrid EVs (FCHEV)

A fuel cell (FC) HEV is a series hybrid configuration in which fuel cell is the energy conversion system and a battery (or a supercapacitor) is the energy storage system to deliver peak acceleration power. The operating principle of fuel cells is the reverse process of electrolysis in which hydrogen and oxygen gases combine to generate electricity with water and heat as byproducts. FC vehicles are true zero-emissions vehicles as they do not emit any greenhouse gases. Since fuel cells can offer high specific energy but cannot accept regenerative energy, it is usually combined with battery or other storage systems. At present, FCHEV technology is very premature and they are very expensive as compared to other HEVs. Example: Honda Clarity.

Plug-in Hybrid Electric Vehicles (PHEV)

The basic difference between a standard HEV and a plug-in HEV is shown in Fig. 9. Plug-in hybrid EVs are full-hybrids which use a smaller engine, a larger battery and a larger motor. Batteries of PHEVs can be recharged from any external power source unlike in standard HEVs in which batteries are recharged only by means of the engine driven generator or regen-braking. This feature of PHEV has the advantage of drawing electricity from any resource such as grid power including household supply, autonomous systems or even renewable energy. PHEVs have a shorter all-electric driving range per recharge as against battery EVs, but have a larger all-electric range as compared to standard HEVs because the engine-generator drive can assist the system when the batteries are depleted. Also, owing to the large electric motor, PHEVs have higher regen-braking capability compared to traditional HEVs.

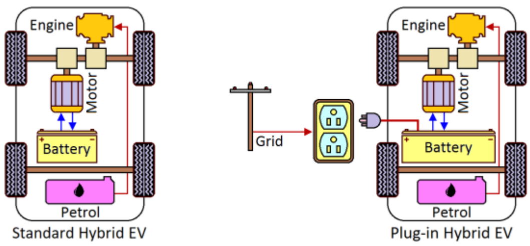


Fig. 9. Comparison of a standard HEV and a PHEV.

Benefits of PHEV include: better fuel efficiency than regular HEV, long driving range than EVs, potential for distributed energy storage, low running cost compared to petrol, and environmentally friendly. Major disadvantages are: high cost and non-availability of fast charging stations. Examples: Chevy Volt, Toyota Prius, Ford CMax Energi.

A hybrid vehicle is much more complex since it has two powertrains. This makes the vehicle more expensive besides increasing maintenance costs compared to both battery vehicles and petrol vehicles that rely on a single powertrain. Hybrid EVs are attractive because they are capable of all-electric short distance trips (20-50 km) per battery recharge, such as daily travel to work place, or occasional long-distance driving in regular hybrid mode (> 500 km). Typical application of a pure EV and a PHEV is shown in Fig. 10. Classification and comparison of various features of hybrid EVs are shown in Fig. 11.

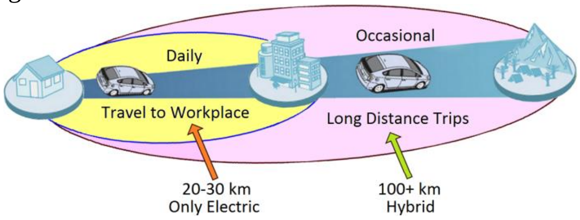


Fig. 10. Travel range of a typical PHEV in different modes.

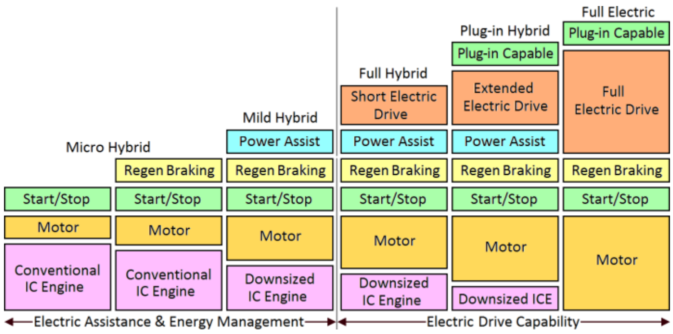


Fig. 11. Classification and features of Hybrid EVs.

IV. Batteries for Electric Vehicles

Traction battery in an EV is the counterpart to the petrol or diesel in an engine vehicle. It is the most critical single component of the EV with the highest weight and volume. Battery rating defines the travel range, acceleration ability, recharge time and cost of the EV. Besides the drivetrain, since the batteries also need to power the accessories of the vehicle, they must be capable enough to handle high power (up to a hundred kW) and high energy capacity (few tens of kWh). Depending on the driving style, road condition, type and age of vehicle, driving range of EVs vary between 5 to 7 km/kWh. Typical energy consumption of a mid-size EV ranges between 165 Wh/km (e.g. BMW i3) to 240 Wh/km (e.g. Tesla S85). Small EVs come with batteries of capacity 12–18 kWh, the mid-sized ones have 22–32 kWh pack, and the luxury models can have batteries of 60–85 kWh to provide extended driving range and high performance [11].

Batteries possess very low energy density (Wh/kg) as compared to liquid fuels. Energy density for Petrol is 12500 Wh/kg, whereas the same for Lead-Acid (LA) batteries is 35-45 Wh/kg, and for Lithium-ion (LI) batteries, it is 200 Wh/kg. Batteries are both large in mass and volume compared to a petrol/diesel tank carrying the equal amount of energy. To get the same energy output from a battery as that from a fuel tank, a very large battery pack is required. As an example, to get the equivalent energy output of 4 liters of petrol, it needs a 275 kg LA battery pack. This is a major drawback of EVs affecting the maximum all-electric range of these vehicles.

A number of traction battery technologies exist today. The LA batteries, being the cheapest, are used in very small EVs such as golf-carts, e-rickshaws etc. To a lesser extent, Nickel-cadmium (NiCd) batteries are also used. However, the current two major battery technologies used in EVs are nickel-metal hydride (Ni-MH) and lithium ion (Li-ion). Due to the higher specific energy and energy density potential, the adoption of

Li-ion batteries is expected to grow fast in EVs. The volume energy density and mass energy density for various battery types is shown in Fig. 12 [12]. Li-ion batteries are relatively smaller in size and lighter in weight in comparison with identically rated other battery types.

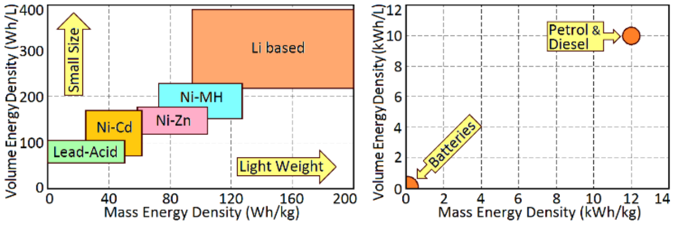


Fig. 12. Volume energy density and mass energy density for various battery types and liquid fuels.

Besides Li-ion, other battery technologies which are being investigated include: Solid state batteries, Aluminum-ion batteries, Lithium-Sulphur batteries and Metal-Air batteries. Solid state batteries can operate at super-capacitor levels, as they can be completely charged or discharged in just less than about 8 minutes, making it ideal for EVs. However, these technologies are still in the laboratory level and will take many more years to become commercially available. Based on the current battery technology, it is not practical to consider a pure BEV with a driving range of 300-400 miles with single charge since it would require a battery larger than 100 kWh that can weigh over 900 kg. Various battery generations and their expected driving range with single charge are shown in Fig. 13.

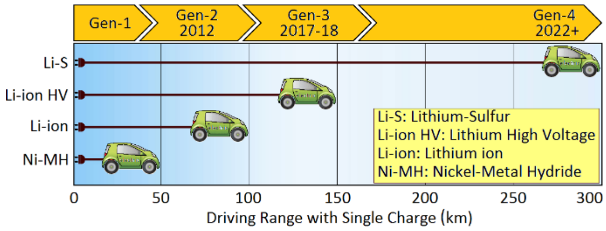


Fig. 13. Batteries for electric vehicles and their driving range.

V. EV Battery Charging Methods

EV charging is analogous to filling the fuel tank of an ICE vehicle. Batteries can be charged through *Conductive* and *Inductive* (or *Wireless*) methods. Conductive charging using cables is the current industry standard and for this purpose EVs have an onboard charger. Vehicle receives AC supply through an *Electric Vehicle Supply Equipment* (EVSE), usually known as EV charging station.

EV chargers are available in three different power levels: Level 1 (L1), Level 2 (L2) and Level 3 (L3), as summarized in Table 6. Charging stations can be of AC or DC type, their differences is shown in Fig. 14. Level 1 chargers are generally portable devices that can be carried in the vehicle. Level 2 chargers are usually wall mounted. Charging through on-board L1 charger replenishes driving range of about 6-8 km/hr., while a L2 charger delivers driving range of 14-35 km/hr. [13]. A DC fast charger can provide about 150 km of range per 20-30 minutes of charging. Type of charging will affect the battery life. L1 charging produces the least amount of stress on a battery whereas L3 fast charging results in maximum stresses on the battery.

Two types of AC connectors are generally used with EVs. Type 1 (SAE J1772), a single-phase connector used in the US and Asia, and the Type 2 (IEC 618515), a 3-phase connector used in Europe. A Combined Charging System (CCS) is available for fast charging (DC) and slow charging (AC). For DC fast charging, CHAdeMO is the most common connector standard. These are shown in Fig. 15.

Table 6: EV Charging Levels and Capacities

Level	Connector	AC/DC	Max. V & I	Power (kW)
Level 1	Type 1	1 phase AC	120 V/16 A	1.9
Level 2	Type 1	1/3 ph. AC	240 V/80 A	14 - 19
Level 3	Type 2	3 phase AC	480 V/63 A	43 - 52
Level 3	CHAdeMO	DC	500 V/125 A	63
Combo	Type 3	AC and DC	1 kV/400 A	36 - 200+

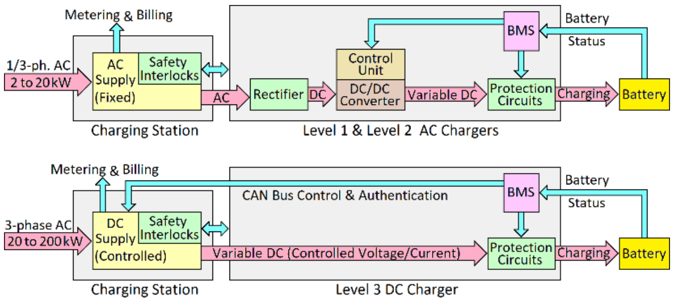


Fig. 14. Basic arrangement of AC/DC charging stations of EVs.

Type-1 Connector (1-ph AC)

Type-2 Connector (3-ph AC)

Combo Charging System (AC/DC)

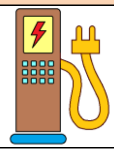
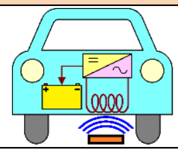
CHAdeMO Connector (DC)

Fig. 15. Connectors and Inlets for EV charging.

Agencies such as *Society of Automotive Engineers* (SAE) and *International Electrotechnical Commission* (IEC) etc. are working on defining EV charging features.

The latest in EV charging is the Wireless (or Induction) charging (WC). Unlike conduction charging (CC), which requires a conductor to feed electricity, energy in WC is transmitted through electro-magnetic induction. In WC, energy flows from a transmitter coil housed in a pad that sits on the pavement to a receiver coil in a pad underneath the vehicle. WCs are in the early stages of development and are very expensive. Table 7 compares various features of conduction and induction charging.

Table 7: Comparison of Conduction & Induction EV Charging

	Conduction	Induction
		
Power Rating	2 – 50 kW	3 – 40 kW
Typical Efficiency	90 – 95%	80 – 90%
Charging Time	Fast: 20 – 30 min. Slow: 6 – 8 hr.	Fast: ~ 30 min. Slow: 6 – 8 hr.
Weight added to EV	Nil (for Level 3)	4 – 20 kg

Majority of the current EV charging systems are located at residential areas. Other potential locations for EV charging include workplaces and public places. A charging pyramid, as shown in Fig. 16, represents the relative position of residential, workplace, and public charging infrastructure. It shows that most charging will occur at residences, followed by charging at the workplace, and the least possible time for charging in publicly accessible locations.

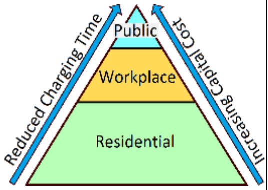


Fig. 16. Charging pyramid of electric vehicles.

VI. Way Forward and Conclusions

The future is electric for surface transport as the Earth will run out of petroleum fuels within 50 to 60 years. Electric vehicles offer many advantages: increasing nation's energy security by reducing oil consumption, supporting to climate-change initiatives by reducing harmful emissions, reduced public health risks on account of poor air quality and long-term economic growth through the introduction of new technologies and infrastructure. There are, however, many technical and socio-economic challenges to overcome before the widespread acceptance of EVs. This include high capital cost, shorter driving ranges, long charging time, heavy weight and large size of batteries, and the need for fast charging facilities.

Electric vehicles are clean only at the point of use. Reduction in vehicular pollution through EV deployment will be more meaningful if they are powered by electricity produced from clean resources to avoid pollution otherwise caused by generating stations based on fossil fuels.

Thus, the role of renewable energy in transport sector is the need of the hour. In order to increase the share of RE in the transport sector, solar PV powered recharging stations are being developed by many nations. Several of these L1 or L2 recharging stations have already been deployed at highly concentrated areas including office premises, shopping malls and other public places where cars might be parked for long periods. Various initiatives to increase the share of RE in the road transport is shown in Fig. 17. This include solar PV and wind turbine powered charging stations, both at residential areas and workplaces.

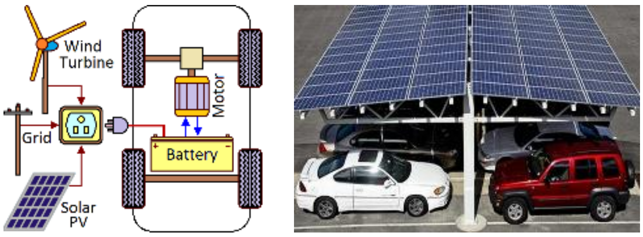


Fig. 17. Initiatives to increase the RE share in road transport.

An upcoming technology in EV charging is the *charging on the go*. This scheme, as shown in Fig. 18, uses dynamic charging of EVs through induction while they are moving over dedicated lanes. The advantage of this design is that EVs can have smaller batteries leading to a lighter and efficient vehicle besides saving of time for charging [15].

Fig. 18. Charging on the go (Inductive) [15].

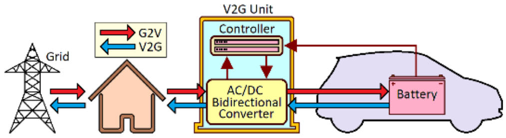


Fig. 19. The concept of G2V and V2G potential of EVs.

A smart application of EVs is the Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) concepts (Fig. 19), in which energy flows to and from the vehicle, turning it into a distributed energy storage system. During lean hours of power demand, EV batteries are charged using grid power (G2V) and during peak hours, batteries discharge power to the grid (V2G). By these modes of operations, EV can act as either a load (charging) or a generator (discharging) as needed. When aggregated in large numbers, this capability of EVs will become an important part of the smart grids.

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