Revolution in electric vehicles

Amandeep Sagwal¹, Paras Agrawal¹, Randeep¹, Mangladeep Bhullar¹  
¹Physics Department, DAV College, Sector 10, Chandigarh 160011, India.

Email: bhullarmangla@gmail.com

Abstract- Nowadays electric vehicles play an effective role in reducing greenhouse gases emission by the transportation sector. In recent times, electric vehicles such as battery, hybrid, plug-in hybrid, and fuel cell electric vehicles are becoming an advanced area of research related to the automobile industry. This article focuses on the latest emerging technologies in electric vehicles including various aspects of electric vehicles, their types, innovations in electric vehicle technology in terms of their motors, batteries as well as their applications, future perspectives, and different challenges associated with electric vehicles.

Keywords: Electric vehicles, Motor, Batteries, Ultracapacitors, Greenhouse gases

Abbreviations:

| Abbreviation | Description |
|--------------|-------------|
| EVs | Electric vehicles |
| ICEV | Internal combustion engine vehicle |
| BEV | Battery electric vehicle |
| FEV | Full electric vehicle |
| HEV | Hybrid electric vehicle |
| PHEV | Plug-in hybrid electric vehicles |
| FCEV | Fuel cell electric vehicle |
| Ni-MH | Nickel-metal hydride battery |
| Ni-Zn | Nickel zinc |
| SRM | Switched reluctance motors |
| PM | Permanent magnet |
| IM | Induction motor |
| BLDC | Brushless DC Motor |
| SynRM | Synchronous reluctance machines |
| PMSM | Permanent magnet synchronous motor |
| GHG | Greenhouse gases |

1. Introduction

As the number of vehicles keeps on filling in India, vehicles are resulting in being a wellspring of causing air contamination which is needed to be controlled down quickly [1]. The specialized measure that can be taken to reduce air pollution is the usage of electrically driven vehicles.

The concern towards the increasing global warming is not new to us. Back in 1996, the modern era began with the launch of EVs, such an EV was GM EV1 [2]. In comparison to ICEVs, EVs require new components such as supercapacitors, hydrogen fuel cells, hydrogen storage systems, automotive thermoelectric generators, charging technology for energy storage, etc. to provide smooth operating efficiency [3]. With time, we have witnessed the transition of motor design technology in electric vehicles. Moreover, future development trends are concentrated towards the improvement of motor performance by improving the insulation performance of magnet wires [4].
To meet the regulatory standards, the number of EVs such as BEV, HEV, PHEV, and FHEV has been introduced in the market. Though the aforementioned types have a significant role in reducing greenhouse gas emissions, each has its advantages and drawbacks. Understandably, FCEV has a much more promising potential in the transportation sector [1].

In near future electric vehicles will become more preferable than ICEVs, if research and development are successful in developing motors for EVs which are lighter, smaller, more reliable, have a more specific power, and are capable of offering maximum torque even at low speeds, etc.

This paper reviews the electrification of vehicles (cars) in the transportation sector. The paper discusses different models of electric cars in terms of components used. The review gives an understanding of the most recent achievements in terms of techniques and components used in the vehicles. Section 2 includes the various types of electric vehicles and cars models available in past and present days. Some futuristic trends in batteries and motors that are used and would be expected in the future in vehicles are reviewed in sections 3 and 4, followed by the conclusion.

2. Electric vehicles and their types
Landmarked reached after the appraisal of a survey done regarding the number of papers published on topics related to EVs during 1984 to 2020 is that continuous growth in development trends of various EVs has been marked. GMs EV1 was the first electric vehicle launched in 1996. Following this, Toyota Prius in 1997 was launched and witnessed a profuse response. Thereby, the increase in popularity of EVs as mass-produced cars was noticed. Amongst the prior labels mentioned, Tesla has been marked as the chief label since it has been extending the frontiers of innovation. Accordingly, the current report, EVs have reached the marked two million worldwide sales in the year 2019 and the growth in requirement for such cars is in continuity [2][5][6]. Also, a wide range of EVs is offered by automakers such as Tesla Roadster, Leaf, Mitsubishi i-MiEV, BMW i3, Renault Zoe, and many more [7]. The aforementioned models fit into the prime categories of EVs (figure 1) as follows:

![Figure 1. Various types of electric vehicles](image)

i) Battery or Full electric vehicle (FEV or BEV)
BEVs exhibit an electric propulsion system. These are completely based upon electric motors or in other words, the power to drive train is provided with only the batteries [7]. Merits of such systems are their simple construction, operation, and convenience to be brought into utilization. The emission of GHG, as well as, noise is completely declined in such systems. Even at low speed, electric propulsion provides instant and high torque. The practice of such an approach can be marked in Teslas [8].

ii) Hybrid Electric Vehicle (HEV)
The concept of HEVs was introduced first in 1997. To power the vehicle, utilization of both ICE as well as electric power train is in requirement. During low power demand scenarios, HEV uses electric propulsion. During the rest period engine remains off and thereby reducing the fuel
consumption like in case of traffic jams. In case of higher speed requirement HEV chop and change to ICE [3]. HEVs can be subcategorized into series, parallel, series-parallel, and complex hybrid HEVs and their properties are summarized in figure 2.

**Figure 2. Types of Hybrid Electric Vehicles**

a) **Series HEVs:** In series hybrid vehicle via transmission AC motor is contacted directly to the wheels or the differential. Into the bargain, DC/AC converter is needed to connect different power systems. Inthis, the DC link is responsible to decouple electrical machines and also, ICE from the wheels is mechanically decoupled with the help of an electrical system [7]. Due to the reason immensely large size of motor/generator, these find application in commercial heavy duty vehicles [1] [9].

b) **Parallel HEVs:** Since the electrical machine and ICE are connected to wheels/transmission, hence both contribute to the propulsion. Not only the reduction in fuel consumption in ICE is assisted by electrical machines but also it encourages regenerative function and battery charging [7]. Due to its compact size, it can be brought into utilization in small vehicles such as Honda Insight, Ford Escape, and Honda Civic, etc [1] [9] [10].

c) **Series-Parallel HEVs:** Both series and parallel paths for power are developed by two electrical machines when combining with ICE. For the generation of electricity, for charging batteries ICE is coupled with an electrical generator. Regenerative function in the present case is viable too [7]. Toyota Prius was the first industrially available vehicle that uses this framework [1] [5] [11]. It provides only unidirectional power flow [8].

d) **Complex hybrid HEVs:** Such a system provides bidirectional power flow. It is an appropriate choice to be brought into use where vehicles require dual-axle propulsion. The only drawbacks which accompany such a system are their high complexity and cost [8] [12]. The use of such systems has been observed in certain Toyota and Ford models [8] [13].

iii) **Plug-in Hybrid Electric Vehicle (PHEV)**
Mechanically, PHEVs configuration is also similar to HEVs for its operation [8]. PHEVs are able to utilize fully electrically driven mode because such systems have adequate high energy density, energy storage systems capable of being charged externally [7]. Moreover, in contrast to the HEVs, PHEVs have high energy density capacity, so such vehicle uses electric propulsions as the main driving force [7] [8]. Hence, such systems are also termed as range-extended HEVs [7]. Examples of such systems are Chevrolet Volt and Toyota Prius [8].

iv) **Fuel Cell Electric Vehicle (FCEV)**
The Fuel cell is mounted in such vehicles to produce electricity which goes into the electric motor and drives the wheels. The production of electricity in the fuel cell is carried out by the chemical reaction (redox reaction) between high-pressure hydrogen and oxygen [14]. The source of
hydrogen is high-pressure tanks carried out by the vehicle and the oxygen is obtained by the air sucked. FCEVs like Toyota Mirai or Honda Clarity are commercially available options [8]. These EVs are gaining more popularity in the transportation sector in recent times due to their properties [7] [8] (Table 1).

The electrified transport industry significantly relies on batteries and traction motors. The chief component in EVs and HEVs is the electric propulsion system and their energy storage system [1] [15]. The performance of electric machines in EVs can be considered up to par if it offers the needed high efficiency and high power density. To survive in the competitive world of automobiles sector the electric machine must not only fulfill the condition of high rated torque and wide speed range but also offer a fast dynamic response. Characteristics such as large capacity, reliability along with constant speed ability make such machines an enticing piece of technology [2] [16].

| Table 1. Electric Vehicles and their characteristics |
| EVs | Advantages | Drawbacks |
|-----|------------|-----------|
| ICEV | Highly commercial | Economically unfriendly |
|     | Easy functioning | Emit green house gases |
|     |               | Heavy framework [12] |
| BEV  | Work smoothly | Long charging period |
|      | Good Energy efficiency | Limited charging sources [8] [12] |
|      | No greenhouse gas emitted | |
| HEV  | Economically friendly | High Cost |
|      | Durable | Heavy |
|      | Less pollution | Complex Structure [8] [12] |
| PHEV | Quite and smooth operation | Complex structure |
|      | High fuel efficient | Initially expensive [8] [12] |
|      | Lower emission | |
| FCEV | Maximum efficiency | Costly |
|      | No petroleum products used | Complex electronic structure [8] [12] [14] |
|      | Highly Reliable and durable | |
|      | Emission less | |

3. Batteries
The most important component for an electric vehicle is the battery, serving as an energy source. The major concern regarding EVs is their driving range. An energy source is said to be perfect if it has maximum energy and power densities during the time of acceleration, fast charging, is inexpensive, and requires low maintenance [17]. The batteries with higher energy densities have the potential to drive vehicles a longer distance. The power to energy ratio is required more in HEV as compared to EV battery [18]. Many technological developments are being carried out to attain the desired goals. Some of the prominent types of batteries available are as follows [8]:

i) Lead-acid battery: One of the oldest batteries in use, for over 50 years. Their drawback includes the insufficient life cycle in case of deep rate of charge consumption with minimum power density. However, they are not highly expensive.

ii) Nickel-Metal Hydride battery: These batteries have almost double the energy density to what is in lead-acid batteries. At high voltages, NiMH batteries offer a safe operation. Unlike
lead-acid batteries, NiMH batteries have a longer life cycle and a longer range of operating temperature. However, these batteries suffer a reduction in useful power.

iii) Lithium-Ion battery: These batteries have almost doubled the energy density than in nickel-metal hydride batteries. The reduction in usable power is less due to the low memory effect. Lithium-ion batteries offer good performance even at high temperatures. These batteries have a longer battery life which is around 1000 cycles and offer high specific energy and power. But, these batteries are expensive and have a longer recharging duration. Lithium-ion batteries have the highest energy densities among the available options.

iv) Nickel-Zinc battery: Not only these batteries have high power and energy densities but are also capable of offering deep cycle. Such batteries have a wide temperature operating range. But at the same time offers a disadvantage due to the fast growth of dendrite, which makes it unfit to be used in vehicle applications.

v) Nickel-Cadmium battery: The most significant advantage of these batteries is that they can discharge fully without any damage. Moreover, these batteries offer a long lifetime and are recyclable. Cadmium used in these batteries should be disposed of properly to avoid pollution. These batteries are too expensive to be brought into application in electric vehicles.

Not only batteries but supercapacitors also supply energy to drive an electric vehicle [7]. Supercapacitors or ultracapacitors help in achieving fast charging goals [7]. However, because supercapacitors have low specific energy hence, cannot be solely used as an energy source to drive an electric vehicle [12].

4. Motors

After compatible batteries, another important component is transition motors. In EVs new topologies such as Switched Reluctance Motors and Synchronous motors are used because the previously used DC motors have maintenance issues. Presently, induction motors and permanent magnet synchronous machines are said to be the best contenders to serve the purpose. Not only these but hybrid excited or less rare-earth magnet synchronous reluctance machines (SynRM) and PM assisted SynRM can also be considered for future perspectives. In the recent development of vehicles, PMSM specifically axial and radial flux is utilized. Synchronous PM type is the utmost and most efficient choice to meet the demands of the automotive [2] [16] and properties of these motors are characterized in Table 2. Figure 3 shows different car models utilizing motors as their propulsion system. Depending upon the purpose of use, EVs are developed with a different number of motors as in Toyota Prius only a single motor is mounted whereas, in Acura NSX, three motors are fitted [8].
Table 2. Motors and their characteristics.

| Type of Motor                      | Benefits                                      | Drawbacks                                |
|-----------------------------------|-----------------------------------------------|------------------------------------------|
| Brushed DC Motor                  | Low speed offers high torque                  | Heavy                                    |
|                                   |                                               | Less efficient [8]                       |
| PM Brushless DC Motor             | Negligible copper loss                        | Expensive [8]                            |
|                                   | Efficient                                     |                                          |
|                                   | Lighter, compact, and Reliable                |                                          |
| Permanent Magnet Synchronous Motor (PMSM) | Working in various ranges of speed           | Maximum iron loss occurs at high speeds [8] |
|                                   | Productive and Compact                        |                                          |
|                                   | Low speed offers high torque                  |                                          |
| Induction Motor (IM)              | Can be used individually                      | High power losses                        |
|                                   |                                               | Less efficient than PM [8]               |
| Switched Reluctance Motor (SRM)   | Inexpensive                                   | Less power factor                        |
|                                   | Hazardless                                    | Less efficient                           |
|                                   |                                               | Bulky [8]                                |
| Synchronous Reluctance Motor (SynRM) | Highly efficient                             |                                          |
|                                   | Compact Size                                  |                                          |
| PM assisted SynRM                 | Good power factor                             |                                          |
|                                   | No demagnetization                            |                                          |
| Axial Flux Ironless PM Motor      | Light in weight                               |                                          |
|                                   | Efficient                                     |                                          |
|                                   | Minimal losses                                |                                          |

Some recent problems and their solutions regarding motors are discussed as follows [19]:

i) Even though IM is generally acknowledged for utilization by the majority of EV/HEV makers, still it has poor efficiency and power factor in comparison to Permanent magnet motors [20-22]. Many developments are being made to increase efficiency by introducing a new converter topology or a new control scheme. IM drives are the most cost-effective among the compared motor drives.

ii) Though PM motors are the most popular choice for electric traction drive systems but the idea is not epoch. Due to the possibility of a shortage of rare-earth metals and their high cost we need to shift the approach towards IM and SRM as an alternative for EVs/HEVs applications. In case of permanent magnet motors improvement in performance cannot be achieved with inexpensive magnets such as Ferrites [19] [23]. Research and development of materials may improve the functioning and properties of permanent magnet motors.

iii) The presence of torque ripples and acoustic noise cause problems in functioning of switched reluctance motor [9] [20]. Nowadays, the most preferred choice is the axial flux PM brushless DC motor drives [24].

Besides the fact that electric vehicles promise to reduce GHG emissions and save us from climate changes, but such systems may lead to power instability. With the help of technological development, such an issue can be resolved which will make EVs more reliable [8].
The depletion and shortage of rare-earth materials will not allow us to use PM motors. Shifting the approach from PM type, IM with internal PM are being utilized by Tesla in its models presently. Great research has already been carried out and will be carried out in near future. Such technological initiatives will make EVs more affordable, efficient, and reliable.

Better charging technologies must also be brought into consideration for research. Wireless charging technologies will also be a conspicuous development if worked upon [8]. The trend and pattern of the sales of EVs across the globe is shown in figure 4.

![Figure 4 Market shares of EVs car sales between 2014 and 2020 from ref [25]](image)

5. **Conclusion**

The advancement of technology used in motors and batteries having good capacities will favor the use of EVs in other areas of transportation.

The use of superconductors and ultra-capacitors are however able to help in achieving quick charging objectives and provide high-power required during acceleration. The objective of achieving high energy densities is being fulfilled using Lithium ion batteries.

BEV and HEV are the latest innovations in the field of electric vehicles successfully growing at a faster pace. FCEVs have long-term potential, have negligible emissions, and have a good driving range making them a contender to be used as the standard vehicle in the future.

Along with DC and PMSM traction motors, SRM and IM are significant motors used in the electric vehicle sector. Every type of motor is used as far as cost, effectiveness, power density, and manufacturability are concerned. Presently, Synchronous permanent magnet motors are the most productive electric motor in electric vehicle application. The exhaustion of rare earth materials, has led to a change from the PM type motor to IM.

An enormous rise in production of EVs is underway in the coming years. Further upgrades in EVs are required and expected in upcoming years.

**References**

[1] Alam S Md and Khan A 2020 *IJSART* 6 30-37
[2] Agamloh E, Jouanne A von and Yokochi A 2020 *machines* 8 1-17
[3] Farfan-Cabrera L I 2019 *Tribol. Int.* 138 473–86
[4] Sato A, Iiduka S and Kimura K 2020 *SEI tech. rev.* **90** 17-21
[5] Husain, I 2011 *Electric and hybrid vehicles design fundamentals* 2nd ed. (CRC Press BocaRaton, FL, USA)
[6] Schefter K and Zaccagnino M 2019 *Electric vehicle sales facts and figures* (EEI Pennsylvania Avenue, NW) 701
[7] Katić V A, Đumić B, Ćorba Z and Miličević D 2014 *Electronics and Energetics* **27** 299–316
[8] Un-Noor F, Padmanaban S, Mihet-Popa L, Mollah M N and Hossain E 2017 *Energies* **10** 1217
[9] Ehsani M, Gao Y and Miller J 2007 *Proc. IEEE* **95** 719-728
[10] A Emadi A, Lee Y J and Rajashekar K 2008 *IEEE Trans Ind. Electron.* **55** 2237 -2245
[11] Nagasaka A, Nada M, Hamada H, Shu H and Kikuchi Y 1998 *SAE trans.* **107** 1721-1730
[12] Chan, C.C. 2002 *Proc. IEEE* **90** 247–275.
[13] Miller, J.M 2006 *IEEE Trans. Power Electron.* **21** 756–767
[14] EG & G Technical Services, Inc. 2002 *The Fuel Cell Handbook*, 6th ed.; U.S. Department of Energy (Morgantown, 2WV, USA)
[15] Finch J and Giaouris D 2008 *IEEE Trans. Ind. Electron.* **55** 481-491
[16] Sun X, Li Z, Wang X, Li C 2020 *Energies* **13** 90
[17] Deng J, Bae C, Denlinger A, and Miller T 2020 *Joule* **4** 1-5
[18] Baskar S., V.Vijayan, Isaac Prem kumar, I. J., Arun kumar D., and Thamaran D. 2020 *Mater. Today: Proc.* 1-3
[19] Rind S J, Ren Y, Hu Y, Wang J, Jiang L 2017 *Chin. J. Electr. Eng.* **3**
[20] Kumar L and Jain S 2014 *Renew. Sustain. Energy Rev.* **29** pp. 924-940
[21] Zhu Z, and Howe D 2007 *Proc. IEEE* **95** 746-765
[22] Zeraoulia M, Benbouzid M and Diallo D 2006 *IEEE Trans. Veh. Technol.* **55** 1756-1764
[23] Riba J, Lopez-Torres C, Romeral L and Garcia A 2016 *Renew. Sustain. Energy Rev.* **57** 367-379
[24] Eldho Aliasand, A., and Josh, F. T. 2020 *Mater. Today: Proc.* **24** 1804–1815
[25] Sanguesa J.A., Torres-Sanz V., Garrido P., Martinez F.J. and Marquez-Barja J.M. 2021 *Smart Cities* **4** 372–404