International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2019): 7.583

Alternate Fuel Vehicle Technology - Energy Storage and Propulsion System

Amey Phatale

Process Engineer, Magna Exteriors Belvidere, Belvidere, IL, USA

Abstract: ***This paper addresses the urgent requirement for sustainable transportation solutions, considering the limited availability of Earth's resources. Focusing on the vehicle sector, traditionally reliant on petroleum, the study emphasizes the urgency to find alternatives. Among various options like Hybrid Vehicles, Bio - fuel Vehicles, and Hydrogen Vehicles, the paper specifically delves into Battery - electric vehicles. Highlighting Battery - electric vehicle recent surge, the discussion emphasizes their role in reducing emissions and reliance on finite fuels. Despite challenges like limited range, Battery - electric vehicle, and Plug - in Hybrid Electric Vehicle (PHEV) sales have consistently grown since 2010. The environmental impact, including reduced city pollution and varied greenhouse gas emissions based on regional energy mixes, is explored. Global sales figures of major electric vehicle manufacturers, including the Renault - Nissan Alliance, Mitsubishi Motors, and Tesla Motors, underscore the industry's momentum. Government funding initiatives, such as the U. S. 's $2.4 billion federal grants and China's $15 billion investment, reflect global motivation for the initiative. The paper then scrutinizes the core components of Battery - electric vehicles, starting with Electric Motors. Various types, like DC motors, induction motors, permanent magnet motors, and switched reluctance motors, are evaluated for their suitability in vehicular applications. Battery Packs, crucial energy carriers, are explored next. Lead - Acid, Nickel Metal Hydride, Sodium (Zebra), and Lithium - ion batteries are assessed based on energy density, efficiency, lifespan, and environmental impact. Despite limitations, the ascendancy of Lithium - ion batteries, evident in Tesla Motors' success, is acknowledged.***

Keywords: Battery Electric Vehicle, Electric Vehicle, EV, Electric Vehicle Motor, Electric Vehicle Batteries, Lithium Ion Battery, Lead - Acid Battery, Nickel Metal Hydrate Battery, Energy Storage EV

1. Introduction

There have been continuous efforts made to introduce and implement new technologies which help introduce alternative fuel. The reasons being obvious, limited resources on earth can last for coming generations. Utilization of energies that are available in abundance and which can be renewable are flourishing year by year. For vehicles, most of the energy that has been used for more than a century is petroleum. Petroleum, being fossil fuel, is limited and will finish off in the next few decades. Therefore, it has become crucial to find the right alternative that will satisfy the needs of the economy in the coming century. Numerous options, including Battery - electric vehicles, Hybrid Vehicles, Bio - fuel Vehicles, Hydrogen Vehicles, and Natural Gas Vehicles, have been in existence. This paper specifically concentrates on Battery - electric vehicles and their distinct components.

1.1 Battery - Electric

Battery - electric is a very interesting and enthusiastic alternative that has been gaining traction recently. A battery electric vehicle is an electric vehicle that uses chemical energy stored in rechargeable battery packs. Such vehicles use power from battery packs, eliminating the need for an internal combustion engine, fuel cell, or fuel tank. Battery electric vehicles use electric motors and motor controllers. Battery electric vehicles include forklifts, bicycles, scooters, cars, buses, and trucks. Despite the significant drawback in terms of range, the sales of battery electric vehicles and PHEV cars have shown an annual increase since their introduction in December 2010. By August 2014, 234, 502 electric cars had been sold in the US, and the Nissan Leaf, the top - selling all - electric car, achieved global sales of 130, 000 units by the same month.

An electric car is simply a plug - in battery - powered automobile that uses an electric motor for propulsion. Although electric cars usually provide good acceleration and have an acceptable top speed, the lower energy per unit mass of the batteries available in 2010 compared to conventional fuels means that electric cars will need batteries that constitute a large fraction of the vehicle mass, but they often can still provide a relatively low range between charges. Also, Recharging takes a significant amount of time. Electric cars are practical forms of transportation for shorter - range commuter - type journeys, rather than long journeys, and they can be recharged overnight.

Electric cars can significantly reduce city pollution by producing zero tailpipe emissions. Vehicle greenhouse gas emissions depend on how the electricity is generated. With the current United States energy mix, using an electric car will result in 30% fewer carbon dioxide emissions. Given the current energy mixes in other countries, it is predicted that emissions would decrease by 40% in the UK, 19% in China, and as little as 1% in Germany. Electric cars are expected to have a major impact on the automobile industry with less dependence on oil, advantages in city pollution, and an expected rise in gasoline prices. World governments are offering billions for funding the development of electric vehicles and their components. The U. S. has announced US$2.4 billion in federal grants for developing electric cars and batteries. China will provide US$15 billion to initiate an electric car industry.

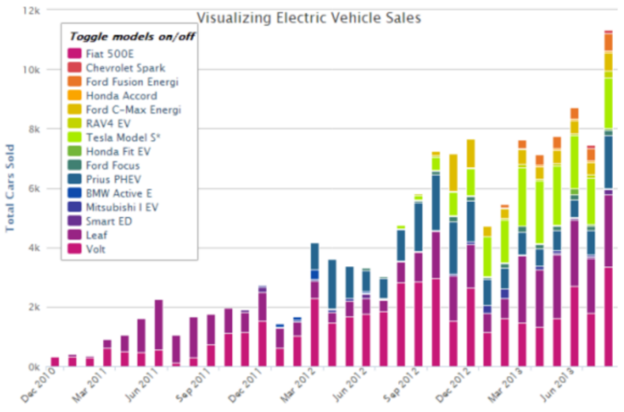

Figure 1: Visualizing EV Sales | Source: [24] motorreview. com

As of July 2013, the Renault - Nissan Alliance has been the top electric vehicle manufacturer, achieving global sales of 100, 000 all - electric vehicles since December 2010. This figure includes over 3, 000 Renault Fluence Z. E. electric cars, approximately 11, 000 Renault Twizy heavy quadricycles, 71, 000 Nissan Leafs, about 5, 000 Renault Zoes, and almost 10, 000 Renault Kangoo Z. E. utility vans. The Nissan Leaf holds the title of the world's bestselling highway - capable electric car, with global sales reaching 130, 000 units by August 2014. Following closely is Mitsubishi Motors, securing global sales of around 32, 685 electric vehicles from July 2009 through April 2013. Mitsubishi's lineup includes other all - electric vehicles such as, the rebadged Peugeot iOn, Mitsubishi i - MiEV, and Citroën C - Zero, along with the Mitsubishi Minicab MiEV utility van. Sales figures also encompass the Mitsubishi Outlander P - HEV plug - in hybrid.

Tesla Motors takes the third spot among the best - selling all - electric vehicle manufacturers. The company has sold almost 2, 500 Tesla Roadsters and over 25, 000 Tesla Model S cars through December 2013. Since their commercial introduction in 2010, sales of battery electric vehicles and PHEVs have seen consistent annual increases.

EVs specifically consists of two main components: the Electric Motor that drives the car, and the Battery Pack that stores energy. The selection of these components from a wide range of options is crucial, and these aspects are explained in detail below.

a) Electric Motor

Vehicles are required to undergo frequent starts and stops, and thus the electric motor must exhibit a decent range of acceleration and deceleration. This includes low - speed hill climbing and high - speed cruising, during which the vehicle needs to endure various environmental and hostile conditions. These motors differ from those used in industrial applications.

Therefore, an electric propulsion system should possess high torque for starting the car and climbing hills. It should also have high power to allow the vehicle to cruise at high speeds and achieve good acceleration. Additionally, the system should exhibit high efficiency over a wide range of speed and torque. It should incorporate regenerative braking, have overload capability for unexpected situations, and ensure high reliability and robustness at affordable costs. Other important considerations in the design should include minimum torque ripple, fault - tolerance capability, temperature management, and low acoustic noise.

The electric motor should adhere to the characteristics shown in Figure (a) below. Furthermore, the standard torque - speed characteristic of an electric propulsion system is illustrated in Figure (b).

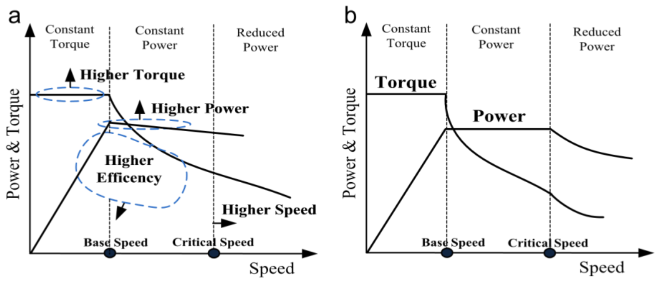

Figure 2: (a) Desired torque–speed characteristic of vehicle propulsion system, (b) Standard torque–speed characteristics of electric motors | Sources: [3]

The frequently used electric motors are DC motors, induction motors, permanent magnet motors, switched reluctance motors. Recently, the trend showed that Research & Development is focused on the concepts that do not require rare earth magnets and the exploration of less expensive materials that can be used for lamination and cores. Magnets like ALNICO and Ferrite are being worked upon for various applications. Also, materials that can reduce losses and improve efficiency are being researched.

1.2 DC Motor

This motor was once very popular and widely used, but recently, many decent alternatives for this type of motor have emerged. It has very high starting torque and simple speed controls. However, its bulky structure, low efficiency, and reliance on numerous mechanical commutators and brushes impose limitations, leading to the need for heavy maintenance. As a result, these days, it is mostly utilized in low - power operations. Eventually motors free from commutators (rotatory switch which controls the flow of electricity in the motor) were developed and are now used instead of DC motors.

1.3 Induction Motor

Induction motors are highly developed and widely accepted for electric propulsion systems. It is free from commutators and has multiple attractive features such as simplicity, higher reliability, wide range of speeds, robustness, low maintenance, low cost, low noise and is resilience in hostile conditions. High - speed operation can be achieved by weakening flux, which is a desirable factor in vehicles. However, its pullout torque limits high - speed operation and the constant power range. By keeping the starting current low, the supply voltage and frequency can be varied to achieve high starting torque, approaching the maximum torque. Despite these advantages, induction motor has several disadvantages including high losses, low efficiency, and an unsatisfying power factor. Additionally, their weight and volume are high for the same power output when compared to permanent magnet motors Researchers and developers are actively addressing these drawbacks through ongoing research and development, working on new methods to address these issues at the design level.

1.4 Permanent Magnet Motor

The Permanent magnet motor is the only type of motor that has the ability to compete against the Induction motor in the electric vehicle propulsion systems. Currently, Permanent magnet motor is used by almost all leading auto manufacturers and are also being developed for further systems. They are usually classified based on supply voltage and current as DC or AC. To maximize torque with low pulsation in BLDC (Brushless DC) mode, a trapezoidal back EMF waveform is preferred, while in BLAC (Brushless AC), a sinusoidal back EMF is preferred. Some of the inherent benefits it offers encompass high power density, diminished weight and volume for an equivalent power output when compared to alternative systems. As it reduces rotor losses, it provides high efficiency. Compact packaging delivers high reliability and low maintenance. It also offers effective heat dissipation, making it effective in cooling as well.

While it offers many exciting features, it also falls short in some areas, such as an unsatisfying region of constant power due to limited field weakening capabilities. Additionally, managing and controlling back EMF at high speed increases its size. The extended speed can range up to 3–4 times the base speed, and the efficiency of PM motors can be enhanced by applying suitable control algorithms of power converters above the bases speed. Important design considerations for PM motors associated with flux weakening capability, fixed excitation for EPS include torque density, stator iron losses, overload capability, rotor eddy current losses, and demagnetization withstanding capability.

Based on the location of PMs, the basic configurations of PM motors are classified. In conventional PM motors, PMs are mounted usually on rotor surface or buried within the rotor. Surface - mounted PM motors (SPM) are a widely used design and use less magnets, whereas interior PM motors are preferred for an extended speed range and constant power operations because they use more magnets and offer higher air gap flux density with a higher degree of ruggedness. To overcome the compromise made between low - speed torque and high - speed power, the concept of hybrid PM and field excitation has been adopted. This concept combines a PM motor and a reluctance motor, which limits the air gap field.

1.5 Switched Reluctance Motor

The Switched reluctance motor is gaining increasing attention for electric propulsion systems in vehicular applications. Features such as a rotor without magnets and windings provide simple and robust construction, making it desirable for very high - speed, high - temperature operations. It also exhibits excellent torque–speed characteristics, and the constant power region can be extended up to 3–7 times. Additionally, it has fault - tolerance capability and ensures smooth, hazard free operation. However, the limitations of SR motors include high acoustic noise, considerable vibrations, high torque ripple, a complex control mechanism and the requirement of a special converter topology. While the cost of SR motors is high, it is believed that mass production can render them as cost effective as induction motors.

A comparison of different motors based on desirable characteristics for EPS is shown in the image below. The suitability of a particular motor with specific characteristics is rated on a scale of 1–5, where 5 indicates the best suitability and 1 shows poor response. The comparison is measured on a relative basis and may vary based on factors such as the placement of the motor (in - wheel or out of the wheel), the design considerations of motor types, materials used for magnets, lamination, and core, as well as the relevant power electronics converter and their control algorithms. The primary purpose of the table below is to identify the most suitable motor technology for vehicular applications.

Characteristic	Motors with commutator	Motors without commutator		
		Induction motor	PM motor	SR motor
Controllability	5	5	4	3
Size and weight	3	4	4.5	4
Robustness	3.5	5	4	4.5
Reliability	3	5	4	4.5
Power density	3	4	5	3.5
Efficiency	3	4	5	4.5
Speed range	2.5	4	5	5
Life time	3.5	5	4	4.5
Torque density	3	3.5	5	4
Technical maturity	5	4.5	4	3.5
Cost	3.5	5	3	4
Over load capability	3	4	4.5	4
Torque ripple/noise	3.5	4.5	4	3
Manufacturability	3	5	3	4
Potential for improvement	2.5	3	4.5	5

Figure 3: Comparing Motors | Source: [3]

Electric motors being used by automobile models of electric and hybrid electric vehicles are given in image below.

Make	Model	Market release	Electric motor	Power (kW)
Tesla	Model s	2012	IM	215
	Roadster	2008	IM	215
Hyundai	Blueon	2012	PM	61
Honda	Fit EV	2012	IM	49
	EV Plus	1997	DC	100
Toyota	Reva 4	2012	IM	50
	Prius	2004	PM	30
Honda	Fit EV	2012	PM	100
	Civic	2013	PM	17
Ford	Focus Electric	2011	IM	107
	Transit Connect	2010	IM	
	Think City	2008	IM	34
	Ranger EV	1999	IM	67
	ECOstar	1992	IM	56
Renault	Fluence ZOE	2011	SM	70
Tata Indica	Vista EV	2011	PM	55
Fiat	Peogeot ION	2011	PM	35
	Panda	2009	IM	15
REVA	NXR	2011	IM	13
Nissan	Leaf	2010	PM	80
	Altra	1997	PM	62
Mitsubishi	Miev	2009	PM	47
GM	EV1	1999	IM	102
Chevrolet	Volt	2011	PM	111
	Silverado	2010	IM	301
Mahindra Reva	Reva e2o	2012	IM	20
Holden	Ecommodore	2007	SR	55
Lucas	Chloride	–	SR	–

Figure 3: Comparing Power of Car Models | Source: [3]

1.6 Battery Packs

Battery packs serve as energy carriers for electric vehicles, which are commonly referred to as battery vehicles. Various types of batteries are required for different operations. The widely used batteries in vehicles include lead - acid, nickel - metal hydride, zebra, and lithium - ion batteries.

a) Lead - Acid

Lead - acid batteries are the most affordable and cheapest among all the available options. Their battery life is reduced if discharged below 50% and they require frequent maintenance and replacement of water. Traditionally, most electric vehicles have used these types of batteries due to their availability in abundance, matured technology, and low cost. However, they have a significant environmental impact during construction, use and disposal. The efficiency of these batteries can be maximized to 70 - 75% and energy density up to 30 - 40 Wh/Kg. Such batteries were used in early modern EVs, including versions of the GM EV1 and the Toyota RAV4EV.

b) Nickel Metal Hydride

These types of batteries have a significant advantage in terms of energy density, with approximately 3080 Wh/Kg, which is considerably better compared to Lead - Acid batteries. However, they operate at a lower efficiency of 60 - 70%. Another advantage is their long lifespan, capable of operating without issues for more than 100, 000 miles. They are used widely in Hybrid Vehicles.

c) Zebra (Sodium)

Sodium batteries use molten chloroaluminate sodium ($NaAlCl_4$) as electrolyte. They have a good energy density of 120 Wh/Kg. However, a disadvantage is that they operate at very high temperatures of about 270 °C, leading to energy waste and creating difficulties in long - term storage of charge. Sodium batteries were introduced and used in Modec in 2006, with a charging cycle of around 3000 cycles.

d) Lithium Ion

Widely known for its use in laptops, lithium - ion batteries are now predominantly used in Electric Vehicles and have recently achieved huge success. They consist of a lithium cobalt oxide cathode and a graphite anode, boasting an impressive energy density of over 200+ Wh/kg and an efficiency of 80 - 90%. However, they have a relatively short lifespan of around 1000 cycles and can pose fire safety risks if not charge properly or if punctured. New variants have been developed using various elements to overcome the above limitations. For instance, Lithium Iron Phosphate batteries exhibit life cycles up to 7000+ cycles, while Lithium manganese spinel batteries have a lifetime almost four times that of Lithium Iron Phosphate. Various lithium battery variants are widely used in recent automobiles, including successful vehicles like the Tesla Roadster and Tesla Model S. Tesla Motors' success has driven increasing demand for these batteries every year, leading to the establishment of a Giga Factory by Tesla in collaboration with Panasonic. In the picture below, it shows the Lithium - Ion battery pack of the Tesla Roadster—an intuitive way of utilizing space while considering factors like the center of gravity and weight distribution.

Figure 3: Tesla Model S battery | Source: [12]

2. Conclusion

Battery Electric Vehicles (BEV) might be the most desirable shift towards alternate fuels. Despite range limitations, BEV can significantly reduce urban pollution. Evaluating diverse motor types—DC, Induction, Permanent Magnet, and Switched Reluctance by weighing their suitability for EV propulsion can help choose the right technology for the use case. Additionally, dissecting battery technologies—Lead - Acid, Nickel Metal Hydride, Zebra, and Lithium - Ion—highlighting their attributes and applications.

Apart from Battery Electric Vehicle, there is active research on other alternative fuels option such as Biofuels, Hydrogen and Natural Gas.

References

[1] C. Fleming, "Californians' purchases of plug - in electric cars top 100, 000", Los Angeles Times, Sep.2014. [Online]. Available: https: //www.latimes. com/business/autos/la - fi - hy - plug - in - electric - cars - sales - california - 20140909 - story. html

[2] "First, and second, Nissan LEAFs delivered in Puerto Rico", Nissan News Article, Aug.2014. [Online]. Available: https: //usa. nissannews. com/en - US/releases/video - report - first - and - second - nissan - leafs - delivered - in - puerto - rico

[3] L. Kumar and S. Jain, "Electric propulsion system for electric vehicular technology: A review", Science Direct, Oct.2013. [Online]. Available: https: //www.sciencedirect. com/science/article/abs/pii/S1364032113006734

[4] J. De Santiago, H. Bernhoff, B. Ekergård, S. Eriksson, S. Ferhatovic, R. Waters and M. Leijon "Electrical motor drivelines in commercial all - electric vehicles: a review", IEEE Journal, Dec.2011, doi: 10.1109/TVT.2011.2177873. [Online]. Available: https: //ieeexplore. ieee. org/document/6093982

[5] G. Nanda and N. C. Kar "A survey and comparison of characteristics of motor drives used in electric vehicles", IEEE Article, Jan.2007, doi: 10.1109/CCECE.2006.277736. [Online]. Available: https: //ieeexplore. ieee. org/document/4054701/authors#authors

[6] Z. Q. Zhu and D. Howe “Electrical machines and drives for electric, hybrid, and fuel cell vehicles”, Proceedings of the IEEE, Apr.2007, doi: 10.1109/JPROC.2006.892482. [Online]. Available: https: //ieeexplore. ieee. org/document/4168032
[7] S. A. Rogers “Advance Power Electronics and Electric Motors Program” APEEM Annual Progress Report, Dec.2013. [Online]. Available: https: //www.energy. gov/sites/prod/files/2014/04/f15/2013_apeem_report. pdf
[8] Raymond R. Fessler, “Final Report on Assessment of Motor Technologies for Traction Drives of Hybrid and Electric Vehicles”, Mar.2011. [Online]. Available: https: //info. ornl. gov/sites/publications/files/pub28840. pdf
[9] “Electric Vehicle”, Wikipedia. [Online]. Available: http: //en. wikipedia. org/wiki/Electric_vehicle_battery#cite_note - Barre - 5 (accessed Sep.2014)
[10] “Lithium - ion battery”, Wikipedia. [Online]. Available: http: //en. wikipedia. org/wiki/Lithium - ion_battery (accessed Sep.2014)
[11] “Molten - salt battery”, Wikipedia. [Online]. Available: http: //en. wikipedia. org/wiki/Molten_salt_battery (accessed Sep.2014)
[12] D. Noland, “Life with Tesla Model S: Battery Upgrade from 60 kWh to 85 kWh”, Green Car Reports, Dec.2013. [Online]. Available: https: //www.greencarreports. com/news/1089183_life - with - tesla - model - s - battery - upgrade - from - 60 - kwh - to - 85 - kwh
[13] N. Gordon - Bloomfield, “How much does a Tesla Model S Battery Pack Cost you? We do the math”, Green Car Reports, Mar.2011. [Online]. Available: https: //www.greencarreports. com/news/1056497_how - much - does - a - tesla - model - s - battery - pack - cost - you - we - do - the - math
[14] M. Balat and H. Balat, “Recent trends in global production and utilization of bio - ethanol fuel”, Science Direct, Apr.2009. [Online]. Available: http: //www.sciencedirect. com/science/article/pii/S0306261909000919
[15] S. R. Schill, “Economist: Ethanol Profits Face Decline”, Ethanol Producer Magazine, Oct.2014. [Online]. Available: https: //ethanolproducer. com/articles/economist - ethanol - profits - face - decline - 11581
[16] E. Voegele, “OECD - FAO Outlook Report Predicts Growth In Ethanol Production”, Ethanol Producer Magazine, Jul.2014. [Online]. Available: https: //ethanolproducer. com/articles/oecd - fao - outlook - report - predicts - growth - in - ethanol - production - 11264
[17] Solange I. Mussatto, G. Dragone, Pedro M. R. Guimarães, João Paulo A. Silva, Lívia M. Carneiro, Inês C. Roberto, António Vicente, Lucília Domingues and José A. Teixeira, "Technological trends, global market, and challenges of bio - ethanol production", Science Direct, Jul.2010. [Online]. Available: https: //www.sciencedirect. com/science/article/abs/pii/S0734975010000947#gr1
[18] P. P. Edwards, V. L. Kuznetsov, W. I. F. David and N. P. Brandon, "Hydrogen and fuel cells: Towards a sustainable energy future", Science Direct, Nov.2008. [Online]. Available: https: //www.sciencedirect. com/science/article/abs/pii/S0301421508004503
[19] “List of countries by natural gas proven reserves”, Wikipedia. [Online]. Available: http: //en. wikipedia. org/wiki/List_of_countries_by_natural_gas_proven_reserves (accessed Sep.2014)
[20] “Natural gas vehicle”, Wikipedia. [Online]. Available: http: //en. wikipedia. org/wiki/Natural_gas_vehicle#cite_note - NGVJournal - 1 (accessed Sep.2014)
[21] E. Loveday, “Pike Research predicts 68% jump in global CNG vehicle sales by 2016”, AutoBlog, Sep.2011. [Online]. Available: https: //www.autoblog. com/2011/09/26/pike - research - predicts - 68 - jump - in - global - cng - vehicle - sales - by - 2/
[22] “Worldwide Prius sales top 3 - million mark; Prius family sales at 3.4 million”, Green Car Congress – Hybrid, Sales, Jul.2013. [Online]. Available: http: //www.greencarcongress. com/2013/07/prius - 20130703. html
[23] “Hybrid electric vehicle”, Wikipedia. [Online]. Available: http: //en. wikipedia. org/wiki/Hybrid_electric_vehicle (accessed Sep.2014)
[24] Tobias Buckell, “Electric car sales Break new monthly sales records in US”, Motor Review, Sep.2013. [Online]. Available: https: //motorreview. com/electric - car - sales - break - new - monthly - sales - record - us/