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Present and Future Challenges of Electric and Hybrid Electric Vehicles Battery

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Abstract: ***Now a days air pollution produced by use of petroleum products are major concern.Majority of this pollution is from automobile with Internal Combustion engines.So there will be a major shift from Internal Combustion engines to zero emission vehicle.In near future,because most of the countries including India are now trying to reduce air pollution due to global warming and climate changes.Most of the automobile manufacturers are now producing hybrid electric vehicles(HEVs),because the current battery technology is capable of producing hybrid electric vehicles(HEVs).But they are not a permanent solution as they only reduce the amount of pollutants. Electric vehicles(EVs)are Zero Emission Vehicles(ZEVs).But current battery technology are not capable of producing Electric Vehicles (EVs)which can compete with current gerenation automobiles. In this paper we are discussing about the current scenario and future trends in automobile battery technology in a broad manner.***

Keywords: Electric Vehicles (EVs), Hybrid Electric Vehicle(HEVs), Internal Combustion Engines(ICEs), Battery Electric Vehicles **(**BEVs) , Zero Emission Vehicles(ZEVs)

1. Introduction

A hybrid vehicle is a vehicle that uses two or more distinct power sources to move the vehicle. The term most commonly refers to hybrid electric vehicles (HEVs), which combine an internal combustion engine and one or more electric motors.

An electric vehicle is different from HEVs because it uses only one power sourse, an electric motor. Battery is used to provide energy for the working of EVs. So the battery capacity required for EVs are higher than HEVs

The most common type of hybrid vehicle is the gasoline-electric hybrid vehicles, which use gasoline (petrol) and electric batteries for the energy used to power internal-combustion engines (ICEs) and electric motors. In HEV, the battery alone provides power for low-speed driving conditions where internal combustion engines are least efficient. In accelerating, long highways, or hill climbing the electric motor provides additional power to assist the engine. This allows a smaller, more efficient engine to be used. The presence of the electric motor is used to achieve either better fuel economy than a conventional vehicle or better performance.

But considering the environmental impact produced by conventional engines HEV are intended to provide better economy and eco friendly by using the conventional engine in its economical and less polluting working condition. Thus nowadays these HEVs and EVs are attracting some tax relaxation worldwide. But HEVs are not Zero emission vehicles like EVs. But HEVs are gained more attraction in current market due to less improved battery technology. Thus EVs are not having comprtance with convenssional vehicles and HEVs in terms of speed, range and user friendliness

Both EVs and HEVs are comparatively costilier than convenssional vehicles due to immature battery technology(cost, life, size and heaviness) also lead to less market share contribution. In this paper, we discus about the current battery technology used in EVs and HEVs, its devolopments and future

2. History of EVs & HEVs

In 1898,The Austrian Dr. Ferdinand Porsche, at age 23, built his first car, the Lohner Electric Chaise. It was the world’s first front-wheel-drive. Porsche’s second car was a hybrid, using an internal combustion engine to spin a generator that provided power to electric motors located in the wheel hubs. On battery alone, the car could travel nearly 40 miles.

Shortly after Dr. Porsche introduced the first hybrid, the Electric Vehicle Company, an American automaker, introduced two hybrid models at the 1899 Paris Auto Salon. Next, Belgian automaker Pieper debuted a car with a 3.5-horsepower gasoline engine that was assisted by an electric motor when traveling up an incline. Within years of the Pieper's debut, an American inventor filed a patent for a hybrid propulsion system employing an electric assist motor and a gasoline engine, capable of reaching a top speed of 25 mph.

By 1905, however, Henry Ford had begun mass-producing inexpensive cars with gasoline engines impact the sale of the early hybrid models. Several automakers continued to try and perfect the gas/electric hybrid, for both commercial- and private-vehicle applications, but by 1920 it was clear that the future belonged to the internal-combustion gasoline engine.

By 1965, when the U.S. Congress began introducing bills designed to foster exploration of electric vehicles as a way to reduce air pollution. Auto supplier TRW by 1970 was first to develop a practical hybrid solution, and General Motors had also built a test car that used an electric-assist motor at low speeds and a smaller-displacement gasoline engine at higher speeds.

The oil crisis of 1970s urged further development of modern hybrids. Big companies and individual entrepreneurs successfully developed and introduced gas/electric hybrids throughout the 1970s and 1980s, including Toyota.

Toyota,the company that popularized hybrids, had its first hybrid prototype on the road in 1976. Two decades later, the first Prius was introduced to the Japanese market in 1997, the same year that Audi introduced the Audi Duo, a hybrid based on the A4, to the European market.

Though Audi and Toyota mass-marketed the first modern gas/electric hybrids in Europe and Asia, it was Honda that brought hybrid technology to Americans with the introduction of the 1999 Insight. A year later, the Toyota Prius went on sale in the U.S.

Today, most automakers have a hybrid model for sale, each employing variations of the basic premise of an electric motor assisting a gasoline internal-combustion engine, an idea first developed in the late 19th Century.

3. Classification of HEVs

3.1 Series Hybrid

In a series hybrid system, the combustion engine drives an electric generator (usually a three-phase alternator plus rectifier) instead of directly driving the wheels. The electric motor is the only means of providing power to the wheels. The generator both charges a battery and powers an electric motor that moves the vehicle. When large amounts of power are required, the motor draws electricity from both the batteries and the generator.The main advantages is ICE running mostly at optimal speed and torque .It can be turned off in zero emission zone .Low floor possible.Low fuel consumption.The disadvantages of this hybrid is many energy conversions of energy loss.More suitable for city driving.

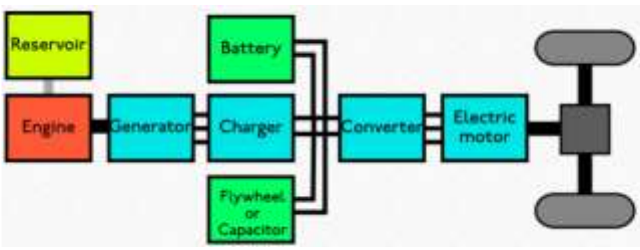

Figure 1: Block diagram of series hybrid system

3.2 Parallel Hyrid

Parallel hybrid systems have both an internal combustion engine (ICE) and an electric motor in parallel connected to a mechanical transmission**.** Most designs combine a large electrical generator and a motor into one unit, often located between the combustion engine and the transmission, replacing both the conventional starter motor and the alternator (see figures above). The battery can be recharged during regenerative breaking, and during cruising (when the ICE power is higher than the required power for propulsion). As there is a fixed mechanical link between the wheels and the motor (no clutch), the battery cannot be charged when the car isn't moving.

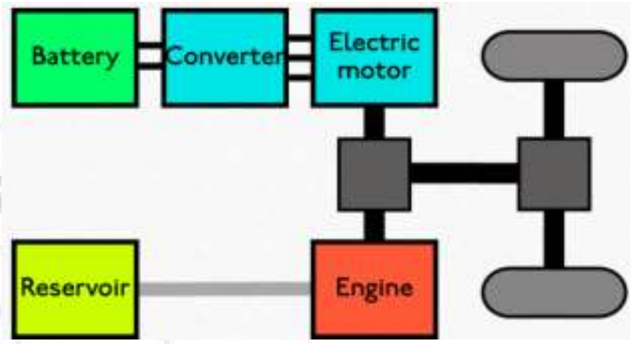

Figure 2: Block diagram of Parallel hybrid system

3.3 Series Parallel Hybrid

Combined hybrid systems have features of both series and parallel hybrids. There is a double connection between the engine and the drive axle: mechanical and electrical. This split power path allows interconnecting mechanical and electrical power, at some cost in complexity.Power-split devices are incorporated in the powertrain. The power to the wheels can be either mechanical or electrical or both. This is also the case in parallel hybrids. But the main principle behind the combined system is the decoupling of the power supplied by the engine from the power demanded by the driver.

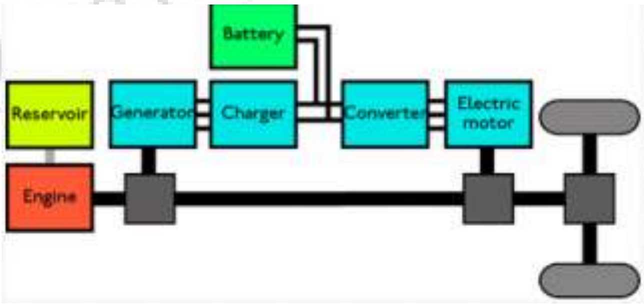

Figure 3: Block diagram of series-Parallel hybrid system

3.4 Plug-in Hybrid

All the previous hybrid architectures could be grouped within a classification of charge sustaining: the energy storage system in these vehicles is designed to remain within a fairly confined region of state of charge (SOC). The hybrid propulsion algorithm is designed so that on average, the SOC of energy storage system will more or less return to its initial condition after a drive cycle.

A plug-in hybrid electric vehicle (PHEV) is a full hybrid, able to run in electric-only mode, with larger batteries and the ability to recharge from the electric power grid. Their main benefit is that they can be gasoline-independent for daily commuting, but also have the extended range of a hybrid for long trips.

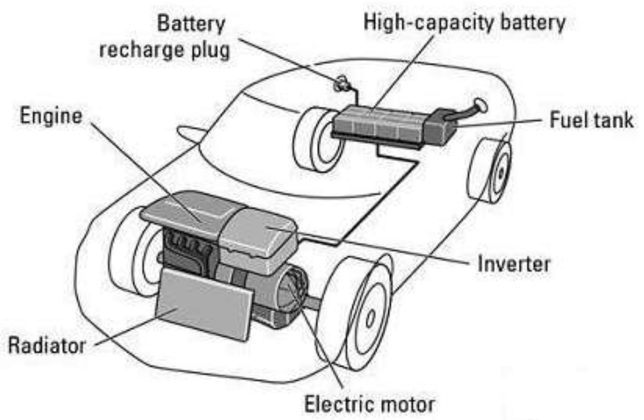

Figure 4: Block diagram of Plug-in hybrid system

Grid connected hybrids can be designed as charge depleting: part of the “fuel” consumed during a drive is delivered by the utility, by preference at night. Fuel efficiency is then calculated based on actual fuel consumed by the ICE and its gasoline equivalent of the kWh of energy delivered by the utility during recharge. The "well-to-wheel" efficiency and emissions of PHEVs compared to gasoline hybrids depends on the energy sources used for the grid utility (coal, oil, natural gas, hydroelectric power, solar power, wind power, nuclear power).

In a serial Plug-In hybrid, the ICE only serves for supplying the electrical power via a coupled generator in case of longer driving distances. Plug in hybrids can be made multi-fuel, with the electric power supplemented by diesel, biodiesel, or hydrogen.

4. Evolution of Battery technology

4.1 Needs of improving battery technology

First electric vehicle produced in 1884 in England using rechargeable batteries. By 1900, only 22 percent of cars were powered by gasoline, while 40 percent were electric and the remaining 38 percent ran on steam. Improvements in internal combustion engines and the invention of the electric starter made gasoline powered cars a better and cheaper option. Eventually, the growth of gasoline-powered cars from companies like Ford and General Motors helped lower the prices of these vehicles to almost half the price of their electric counterparts. By the 1930s, gasoline powered cars had taken over the market, with electric cars disappearing from the marketplace.

In 1950s. Growing concerns about pollution from gasoline powered cars prompted the Air Pollution Control Act in the U.S. This garthered some interest in electric cars and by the 80s and early 90s, there was increasing pressure and demand for fuel-efficient vehicles with the dream of a zero-emission car at some point in the future.

A lot of the limitations that put electric cars out of favor still today; batteries are too heavy, they take too long time to charge, they're too expensive and can't go long distance without stopping to find a place to charge

4.2 Present situation of battery technology

Comparison of Batteries using in Electric and hybrid Electric vehicles

(i)Lead acid battery: It is the most commonly using battery in conventional automobiles .It is also mentioned as Pb-acid battery.Its operating temperature range is-10 to 50^{0}C.Heat capacity and mass density is 0.35Wh/kg-K and 2.1kg/litre.Specific energy and specific power is 30-40Wh/kg and ≈200W/kg.Energy density and Power density is 70-75Wh/litre and ≈400W/litre.Cycle life is 500 to 1000 and Annual life is 5-8 years.Cost of the battery is 30,000 Rs/kWh.

(ii)Nickel Cadmium battery: It is also mentioned as NiCd battery.Its operating temperature range is -20 to 50^{0}C.Heat capacity and mass density is 0.35Wh/kg-K and 1.7kg/litre.Specific energy and specific power is 40-60Wh/kg and 150-200W/kg.Energy density and Power density is 70-100Wh/litre and 220-350W/litre.Cycle life is 1000 to 2000 and Annual life is 10-15 years.Cost of the battery is 90,000 Rs/kWh.

(iii)Nickel Metal Hydride: It is also mentioned as NiMH battery.Its operating temperature range is -10 to 50^{0}C.Heat capacity and mass density is 0.35Wh/kg-K and 2.3kg/litre.Specific energy and specific power is 50-65Wh/kg and ≈150W/kg.Energy density and Power density is 140-200Wh/litre and 450-500W/litre.Cycle life is 1000 to 2000 and Annual life is 8-10 years.Cost of the battery is 150,000 Rs/kWh.

(iv)Lithium Ion: It is also mentioned as Li-ion battery.Its operating temperature range is10 to 45^{0}C.Heat capacity and mass density is 0.38Wh/kg-K and 1.35kg/litre.Specific energy and specific power is 90-120Wh/kg and 200-220W/kg.Energy density and Power density is 200-250Wh/litre and 400-500W/litre.Cycle life is 500 to 1000 and Annual life is 3-5 years.Cost of the battery is 180,000 Rs/kWh.

(v)Lithium polymer: It is also mentioned as Li-poly battery.Its operating temperature range is 50 to 70^{0}C.Heat capacity and mass density is 0.40Wh/kg-K and 1.35kg/litre.Specific energy and specific power is 100-200Wh/kg and >200W/kg.Energy density and Power density is 150-300Wh/litre and >350W/litre.Cycle life is 500 to 1000 and Annual life is 2-4 years.Cost of the battery is >180,000 Rs/kWh.

5. Benchmarks of Hybrid Electric Batteries

Depending on the actual configuration of an EV, part or all of its propulsion power and energy is supplied by the battery inside the vehicle.But incase of HEVs propulsion power and energy is supplied by the battery along with ICEs. Similar to those in regular vehicles, the powertrain in an EV needs to provide power for the vehicle under all kinds of road conditions and driving modes. In addition, an EV also needs to handle regenerative braking so that the kinetic energy of the moving vehicle can be captured and stored in battery for future use.

The acceleration of a vehicle is determined by all the forces applied on it, which is given by Newton's second law as

$$fmM\alpha = F_t - \Sigma Fr \quad (5.1)$$

where M is the overall mass of the vehicle, a is the vehicle acceleration, fm is the mass factor that converts the rotational inertias of rotating components into equivalent translational mass, Ft is the total traction force to the vehicle, and ΣFr is the total resistive force. The resistive forces are normally the rolling resistance between tires and road surface, aerodynamic drag, and uphill grading resistance. The total resistance can be estimated as

$$\Sigma F_r = M_g C_{rr} \cos\theta + 1/2(\rho A C_d (V-V_w)^2) + M_g \sin\theta \quad (5.2)$$

Above figure shows Forces applied on a vehicle.
Where g = acceleration of gravity,
Crr = coefficient of rolling resistance between tires and road surface,

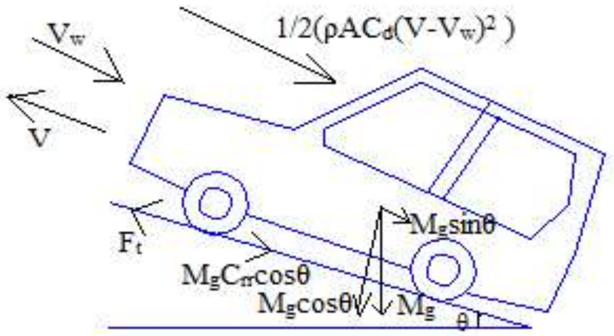

Figure 5: Configuration of Electric Vehicle (EVs)

r = density of the ambient air,
A = vehicle frontal area
Cd = aerodynamic drag coefficient
V = vehicle speed
Vw = wind speed in the vehicle moving direction
y = slope angle
For a downhill slope, y will have a negative valu
F_t= total propulsion force
V=Power to drive the vehicle at speed (P),

During starting of vehicle motion, the propulsion power is mainly used to accelerate the vehicle and to overcome the rolling resistance. When the speed is reached, the power is used to keep the speed by overcoming the rolling resistance and aerodynamic drag force. For an electric vehicle, the battery power capability needs to be sufficient to meet acceleration requirements.

$$P_b = F_t V = f_m M \alpha V + M_g C_{rrV} \cos\theta + 1/2(\rho A C_{dV}(V-V_w)^2) + M_{gV} \sin\theta \quad (5.3)$$

From the above equation we conclude that for a light motor vehicle of mass 1350kg with following approximate values total power required for propulsion Pb is

In case of regenerative braking, the electric propulsion motor in an EV works as a generator to convert the kinetic energy of vehicle motion into electrical energy and charge battery. The braking power can be expressed as (P_b)

$$P_b = F_b V = f_m M \mu V - M_g C_{rr} \cos\theta - 1/2(\rho A C_d (V-V_w)^2) - M_g \sin\theta \quad (5.4)$$

Where P_b =braking power
F_b = braking force
m =deceleration of the vehicle

The current two major battery technologies used in EVs are nickel metal hydride (NiMH) and lithium ion (Li-ion). Nearly all HEVs available in the market today use NiMH batteries because of its mature technology & the potential of obtaining higher specific energy and energy density, the adoption of Li-ion batteries is expected to grow fast in EVs, particularly in PHEVs and BEVs. It should be noted that there are several types of Li-ion batteries base on similar but certainly different chemistry.

Table 1: HEVs available in the market

Manufacturer	Country	Vehicle Model	Battery type
GM	USA	Chevy-Volt Saturn Vue Hybrid	Li-ion NiMH
Ford	USA	Scape Fusion,MKZ Escape PHEV	NiMH Li-ion
Toyota	Japan	Prius,Lexus	NiMH
Honda	Japan	Civic,Insight	NiMH
Hyundai	South Korea	Sonata	Li-poly
Chrysler	USA	Chrysler 200C EV	Li-ion
BYD	China	E6	Li-ion
BMW	Germany	ML450,S400 Smart EV(2010)	NiMH Li-ion
Mitsubishi	Japan	iMiEV(2010)	Li-ion
Tesla	USA	Roadster(2009)	Li-ion
Nissan	Japan	Altima Leaf EV(2010)	NiMH Li-ion
Diamler Benz	Germany	ML450,S400 Smart EV(2010)	NiMH Li-ion
Think	Norway	Think EV	Li-ion,sodium or metal chloride

6. Future Trend of Battery Used in EV

In the current status ,the specific energy Vs specific power is discussed.The specific energy and specific power are obvious in Li-ion over NiMH.The potential of supercapacitor is very high power application.The combined effort the specific energy offered by battery with specific power offered by supercapacitor.

In PHEV, the benchmark of specific energy is around

80Wh/kg and specific power is around 800W/kg. Currently the Li-ion and NiMH achieved the benchmark. Thus most of the manufacturers are now producing HEVs using Li-ion and NiMH power source. So now HEVs are able to compete with convenssional IC engine powered vehicles in terms of power, range, reliability and user friendliness. Only downside is in terms of cost of production and battery life. So future researches are going on to improve the life of battery and reduce the cost

But in BEV, the benchmark of specific energy is around 200Wh/kg and specific power is around 800W/kg. Here the Li-ion and NiMH not achieved the benchmark. Both Li-ion and NiMH are now able to achive the specific power but both are far behind achive the specific energy bunch mark of EVs. Sofurther developments are required to produce BEV to compete the convenssional IC engine powered vehicles and HEVs.

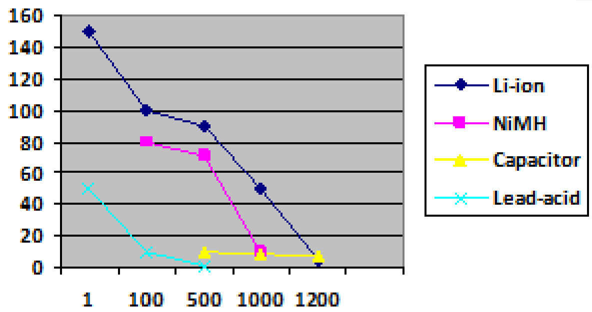

Figure 6(a): Specific Energy-Wh/Kg (Y-axis) Vs Specific Power-W/Kg (X-axis) (Range Vs Acceleration)

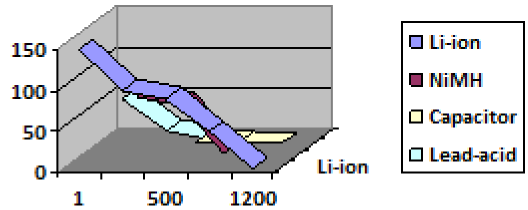

Figure 6(b): Specific Energy-Wh/Kg (Y-axis Vs Specific Power-W/Kg (X-axis) (Range Vs Acceleration)

6.1 Lithium air batteries

These battery can significantly improve range of EV. They are capable of high energy density. Researchers says that it could hold 5-10 times the energy of lithium ion battery. They have an energy density of 2000-3500wh/kg.Here anode is lithium and air cathode made of porous material draws O_2 from surronding lithium combines with O_2 and form lithium oxide and release energy. Toyota and BMW have announced a joint programme in reasearch in lithium air batteries and it will have a range of 500 miles per charge.

6.2 Super capacitor batteries

Capacitors are devices in which two conducting plates are separated by an insulator. A DC voltage is connected across the capacitor, one plate being positive the other negative. The opposite charges on the plates attract and hence store energy. The charge *Q* stored in a capacitor of capacitance ***C***-Farads at a voltage of ***V***-Volts is given by the equation:

$$Q = CV \qquad 6.1$$

Capacitors can provide large energy storage, although they are more normally used in small sizes as components in electronic circuits. The large energy storing capacitors with large plate areas have come to be called super capacitors. The energy stored in a capacitor is given by the equation:

$$E = \frac{1}{2} CV^2 \qquad 6.2$$

where *E* is the energy stored in Joules. The capacitance *C* of a capacitor in Farads will be given by the equation:

$$C = \varepsilon \frac{A}{D} \qquad 6.3$$

where **ε** is the is the permittivity of the material between the plates, **A** is the plate area and **d** is the separation of the plates. The key to modern super capacitors is that the separation of the plates is so small. It has high specific power and low specific energy.it mainly avoids mechanical breakdown.

Super capacitors are capacitor which have the property of capacitor and battery.By this charging will be very fast.A team of researchers have created a supercapacitor film that could replace the need for a battery altogether within the next five years.The supercapacitor consists of two layers of graphene with an electrolyte layer in the middle.The film is strong, exceedingly thin, and is able to release a large amount of energy in a short amount of time, which is essential. Supercapacitors offer a high power output in a short time, meaning a faster acceleration rate of the car and a charging time of just a few minutes, compared to several hours for a standard electric car battery.The table shown below the status of Supercapacitor and Lithium-ion battery.

Table 2: Functions of Supercapacitor and Lithium –ion

Function	*Supercapacitor*	*Li-ion*
Charge Time	1-10sec	10-60min
Cell Voltage	2.3-2.75V	3.6V
Cycle Life	1million/30000hr	500 and high
Service Life	10-15yr	5-10yr
Specific Power(W/kg)	Upto 10000	1000-3000
Specific Energy(Whr/kg)	5	120-240
Cost/kWh	600000	180,000

The Current Indian Scenerio, India is the world's fifth largest electricity generator with total installed capacity of 2,28,722MW.Current intrest in electric vehicles in increasing day by dayDuring the last SIAM annual convention Union minister of Road Transport and Highway Nithin Gadkarispoke of bulldozing all car companies to sell only electric car. He also said that government is taking policy that within 2030 India will have only Electric car. One of the latest news is that Indian government has given a tender to make all government agency vehicles electric car.The tender was taken by TATA motors. First stage they will launch 10000 vehicles.

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