An Overview of E-Mobility, Battery Technologies and Future Challenges

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Abstract:
With the depletion of the earth’s ozone layer and the shortage of our oil supply becoming an issue, we have to look at alternative fueled vehicles that will not harm the environment, but will still provide us with a reliable source of transportation. Compared to IC engine vehicles, electric vehicles are considered to be 97 percent cleaner, producing absolutely no tailpipe emissions that can place particulate matter into the air. Exceptionally quiet, Electric Vehicles produce no noise pollution. In fact they are so quiet that manufacturers are thinking that Electric Vehicles may one day require some kind of noise device on them to alert pedestrians that they are within the area. This paper describes the state of art of electric vehicles, Batteries for storage of power and future challenges.

I. INTRODUCTION
Automotive industry globally is at the cusp of a major transformation. Growing concerns for environment and energy security clubbed with rapid advancements in technologies for power train electrification, increasing digitalization, evolution of future technologies and innovative newer business models and ever-increasing consumer expectations are transforming the automotive business. One of the key facets of such a change is the rapid development in the field of electric mobility which might transform the automotive industry like never before. E-mobility by far is the greatest opportunity for the Indian industry to participate and emerge amongst the top in the globalized automotive world.

I. Electric Vehicles
Electric vehicle is an automobile propelled by one or more electric motors which derives power from battery. Figure 1 describes the block diagram of electric vehicle.

Figure.1. Block diagram of Electric Vehicle
There are three main types of electric vehicles (EVs), classed by the degree that electricity is used as their energy source. BEVs or battery electric vehicles, PHEVs of plug-in hybrid electric vehicles, and HEVs or hybrid electric vehicles.

a) Battery Electric Vehicles (BEV)
Battery Electric Vehicles, also called BEVs, and more frequently called EVs, are fully-electric vehicles with rechargeable batteries and no gasoline engine. Battery electric vehicles store electricity onboard with high-capacity battery packs. Their battery power is used to run the electric motor and all on-board electronics. BEVs do not emit any harmful emissions and hazards caused by traditional gasoline-powered vehicles. BEVs are charged by electricity from an external source. Mercedes-Benz B-Class Electric and Chevy Spark are examples of Electric vehicles.

b) Plug-in Hybrid Electric Vehicle (PHEV)
Plug-in Hybrid Electric Vehicles or PHEVs can recharge the battery through both regenerative braking and “plugging in” to an external source of electrical power. While “standard” hybrids can (at low speed) go about 1-2 miles before the gasoline engine turns on, PHEV models can go anywhere from 10-40 miles before their gas engines provide assistance.

c) Hybrid Electric Vehicles (HEV)
The second type is the Hybrid Electric Vehicle (HEV) that uses mechanically a combination of Electric Motor (EM) in low speeds dedicated for in-city traffic and a conventional Internal Combustion Engine (ICE) to be used outside urban areas. When ICE mode is activated, the EM stops and batteries start charging using an alternator driven by the same equipped ICE. HEVs are powered by both gasoline and electricity. The electric energy is generated by the car’s own braking system to recharge the battery. This is called ‘regenerative braking’, a process where the electric motor helps to slow the vehicle and uses some of the energy normally converted to heat by the brakes. HEVs start off using the electric motor, then the gasoline engine cuts in as load or speed rises. The two motors are controlled by an internal computer, which ensures the best economy for the driving conditions. HEV Examples are Toyota Prius Hybrid, Honda Civic Hybrid

2. Fuel Cell Electric Vehicle (FCEV)
FCEV In addition to these three main types, Fuel Cell Electric Vehicle (FCEV) has been introduced to perform long distances. It uses a fuel cell system to power its on-board electric motor. Proton Exchange Membrane fuel cells generally called Polymer Electrolyte Membrane (PEM) fuel cells used in FCEVs use hydrogen fuel stored onboard and oxygen from the air to produce electricity. As long as a fuel is supplied FCS continues to generate electricity, similar to conventional IC engines. However, fuel cells are much cleaner; they convert fuels directly into electricity via an electrochemical process that does not need combustion. The generated power from a fuel cell stack depends on the number and size of the
individual fuel cells that comprise the stack and the surface area of the Polymer Electrolyte Membrane. A fuel cell vehicle that is fuelled with hydrogen emits only water and heat. By providing clean, high-efficiency, reliable green transportation facilities, FCVs have become important technology in development of electric vehicles. In addition, fuel cells are being developed for buses, boats, motorcycles, and many other kinds of vehicles. The latest FCVs to be introduced to the market later next year are the all-new Mercedes-Benz B-Class F-CELL, Honda FCEV-Concept and Hyundai Tucson-ix35 FCEV.

3. SEV Solar electric vehicle (SEV)

It is an electric vehicle powered importantly or completely by direct solar energy. Through solar arrays installed on top of the vehicle, often photovoltaic (PV) cells, solar energy is converted directly into electric energy. Since converted solar energy is the only source, it powers all or part of SEV’s propulsion, electronics, communication, navigation, security and other auxiliary features. Sensors provide assistance to the driver similar to conventional vehicles. Here, gathered information allows monitoring the car's energy consumption, solar energy capture and other parameters. SEVs can be equipped with a battery pack assistance to ensure continuous driving during shaded days or night using sun as a power source. SEVs have been exploited in Solar Buses. Both all-solar bus such as the TINDO project that is operated using an effective battery management system. The German Power Core Suncruiser, Japanese Kaitu II and the Australian eVe are most remarkable solar race cars. Commercially, Photovoltaic modules are used as auxiliary power units for different EVs especially PHEV application. Depending on the power train structure, solar panels usually feed batteries or energy management system (EMS) with electric power through a charge controller. SEVs structure has been exploited in Solar Buses. Both all-solar bus such as the TINDO project that is operating as free public transport service in Australia and Hybrid Solar Bus that uses solar energy to power electronics, video monitoring system, air conditioning and auxiliary functions, meanwhile, traction is ensured by a HEV structure. Main disadvantage of pure solar electric vehicles is sun dependency on solar arrays installed on top can’t provide sufficient amount of electric power within a short time. Today’s solar cells technology limits the possibilities we can explore in a SEV. Despite its improvement compared to first generation PV panels, new Concentrating Photovoltaic panels (CPV) have only slightly lower energy density. Nevertheless, certain precautions should be made during charging and discharging. The Sony Corporation was the first company to commercialize the lithium-ion battery in 1991, which has since become popular and remains the best choice for rechargeable batteries. The lithium-ion battery requires almost no maintenance during its lifecycle, which is an advantage that other batteries do not have. No scheduled cycling is required, and there is no memory effect in the battery. Furthermore, the lithium-ion battery is well suited for electric vehicles because its self-discharge rate is less than half of the discharge rate of lead-acid and NiMH batteries. Despite the advantages of lithium-ion batteries, they also have certain drawbacks. Lithium ions are brittle. To maintain the safe operation of these batteries, they require a protective device to be built into each pack. This device, also referred to as the battery management system (BMS), limits the peak voltage of each cell during charging and prevents the cell voltage from dropping below a threshold during discharging. The BMS also controls the maximum charging and discharging currents and monitors the cell temperature.

II. POWER SOURCE

Currently, three types of traction batteries are available: the lead-acid, nickel-metal hydride and lithium-ion batteries. Lithium-ion batteries have a number of advantages over the other two types of batteries, and they perform well if they are operated using an effective battery management system.

a) Lithium-Ion-Battery Lithium is the lightest metal with the greatest electrochemical potential and the largest energy density per weight of all metals found in nature. Using lithium as the anode, rechargeable batteries could provide high voltage, excellent capacity and a remarkably high-energy density. However, lithium is inherently unstable, especially during charging. Therefore, lithium ions have replaced lithium metals in many applications because they are safer than lithium metals with only slightly lower energy density. Nevertheless, certain precautions should be made during charging and discharging. The operating temperature of lithium-ion cells should be carefully controlled because excessively high or low temperatures could damage the cell. Temperature-related
damages could be grouped into three types: low-temperature operational impact, high temperature operational impact and thermal runaway.

b) (NiMH) battery
The nickel-metal hydride (NiMH) battery was the next rechargeable battery widely produced for commercial applications in hybrid electric vehicles (HEV). Toyota released its Prius HEV in 1997 to the Japanese market and to the rest of the world in 2000. The Prius used both an electric motor and a small ICE for propulsion. At low speeds, the electric motor drove the vehicle exclusively, and when more power or speed was needed, a small ICE turned on automatically to provide additional power for propulsion. NiMH batteries were used to supply energy to the electric motor because they offered a higher specific energy than lead-acid batteries, at 60 Wh/kg—1 and had a much better energy density (watt-hours per liter) of 140 Wh/l compared to a lead-acid batteries 70 Wh/l. NiMH batteries are also highly reliable, and safe similar to lead-acid batteries. In contrast to lead acid batteries, NiMH batteries are composed of noncorrosive substances resulting in safer handling and recycling. Therefore, NiMH batteries were well suited for the development of hybrid vehicle technology.

Although the Prius only provided modest propulsion, it was still able to increase the miles per gallon (mpg) metric, to 42 mpg. By employing a hybrid drive system, Toyota was able to reduce the Prius carbon dioxide (CO₂) emissions by up to 37.4% The NiMH battery is still being deployed today in HEVs and plug-in hybrid electric vehicles (PHEVs). PHEVs operate in the same manner as HEVs, however, they have the additional ability to plug into the electric grid to charge the battery. The NiMH battery’s limited specific energy does constrain the electric-only range of HEVs and PHEVs.

Figure 4. A comparison of electricity storage in Lead acid, Nickel Metal hydride and Lithium Ion Batteries

c). Super Capacitors
To obtain a power boost, super capacitor is used. It has the characteristics between a capacitor and a battery. It can release a large charge in a short period. A super capacitor bank is hence adopted to supply instantaneous charge to assist the main battery in heavy consumption. The super capacitor, under management, can be charged by the main batteries. In order to recover kinetic energy lost in vehicle breaking electric vehicles can also save energy in stop and go driving through regenerative breaking. In this technique, the Electric motor is used as a generator converting the kinetic of the vehicle’s motion back to electric energy, rather than dissipating it as heat in the breaks. The regenerative breaking can recover 50% to 80% of the kinetic energy for later use. This is especially valuable for vehicles that stops and start frequently like buses and in-city BEVs.

III. CHARGING TECHNIQUES AND STANDARDS:
There are four key standards related to safety, installation and connection of the Electric Vehicle Supply Equipment (EVSE) to the EV; UL 2594, UL 2231, SAE J1772, and NEC Article 6252. EVs typically charge from conventional power outlets or dedicated charging stations, a process that typically takes hours, but can be done overnight and often gives a charge that is sufficient for normal everyday usage. To date, mainly three charging techniques are available. Conductive charging, this is a direct electrical connection (typically through an insulated wire/cord set) between the source and the charging circuitry. The circuitry and its controls may be housed within the vehicle or external to it. All new EVs are compatible with this approved standard. There are three modes of EV charging; In Standard mode, AC Level 1 supplies 120V single phase power at up to 12 Amps. For example, a Nissan Leaf with its battery charge totally depleted would take about twenty hours to completely recharge. Meanwhile, Semi-Quick mode provides up to 3 phases 32A current. It takes much shorter time to charge electric vehicles compared to standard charging. And finally, Quick mode uses a specialized fast charger connected to a high powered electrical source; the high power greatly reduces charging time. Nevertheless, it requires infrastructure investment, spaces and extra costs. It is suitable for emergency charging purpose. The actual charge time will vary based on the charge level and condition of the batteries. Inductive charging: No wiring is required; instead the energy is transferred between the charger and the “Paddle” inside the vehicle’s inlet via a magnetic field generated by a high AC current. Inductive charging is still expensive and complicated to set up for end user. Batteries swapping: Instead of recharging EVs from electrical socket, batteries could be mechanically replaced in a couple of minutes in some special stations. Here battery size and geometry should be standardized in order to relay on Battery swapping technique.

IV. REQUIREMENTS OF EVS ON ELECTRIC MOTOR DRIVES
Selection of electric motor drives for EVs is a very important step that requires special attention. In fact, the automotive industry is still seeking for the most appropriate motor drive for EVs or HEVs. Previous literatures discussed the major requirements of EVs on electric motor drives. Therefore, selecting the most appropriate motor drives for an EV is a challenging issue. In this paper, the basic requests are summarized as follows: 1) a high instant power and a high power density; 2) a high torque at low speed for starting and climbing, as well as a high power at high speed for cruising; 3) a very wide speed range with constant-power region; 4) a fast torque response; 5) a high efficiency over the wide speed range with constant torque and constant power regions; 6) a high efficiency for regenerative breaking; 7) downsizing, weight reduction, and lower moment of inertia; 8) a high reliability and robustness for various vehicle operating conditions; 9) a reasonable cost; 10) a fault tolerance; and 11) suppression of electromagnetic interface (EMI) of motor controllers.

V. EVALUATION OF MOTOR DRIVES FOR EVS
As so far, four types of motor drives have been applied to EVs. They are brushed DC motor drives, induction motor (IM) drives, permanent magnet (PM) brushless DC (BLDC) motor drives, and switched reluctance motor (SRM) drives.

A. Brushed DC Motor Drives
Brushed DC motors are well known for their ability to achieve high torque at low speed and their torque--speed characteristics suitable for the traction requirement. The motor speed is
adjusted through varying voltage. Being suitable to propel a vehicle and easy to be controlled, they have been used on EVs. Brushed DC motors can have two, four or six poles depending on power output and voltage, and may have series or shunt field windings. On the other hand, shunt motors have the better controllability than series motors. Separately excited DC motors are inherently suited for field weakened operation, due to its decoupled torque and flux control characteristics. On the other hand, a range of extended constant power operation is obtained by separate field weakening. However, brushed DC motor drives have a bulky construction, low efficiency, low reliability, and higher need of maintenance, mainly due to the presence of the mechanical commutator and brushes. It is difficult to downsize brushed DC motors. This makes brushed DC motors more heavy and expensive. Furthermore, friction between brushes and commutator restricts the maximum motor speed.

B. Induction Motor Drives
Induction motors are of simple construction, reliability, ruggedness, low maintenance, low cost, and ability to operate in hostile environments. The absence of brush friction permits the motors to raise the limit for maximum speed, and the higher rating of speed enable these motors to develop high output. Speed variations of induction motors are achieved by changing the frequency of voltage. Field orientation control (FOC) of induction motor can decouple its torque control from field control. This allows the motor to behave in the same manner as a separately excited dc motor. This motor, however, does not suffer from the same speed limitations as in the dc motor. Extended speed range operation beyond base speed is accomplished by flux weakening, once the motor has reached its rated power capability. A properly designed induction motor, e.g., spindle motor, with field oriented control can achieve field weakened range of 3-5 times the base speed. However, the controllers of induction motors are at higher cost than the ones of DC motors. Furthermore, the presence of a breakdown torque limits its extended constant-power operation. At the critical speed, the breakdown torque is reached. Generally, for a conventional IM, the critical speed is around two times the synchronous one. Any attempt to operate the motor at the maximum power current beyond this speed will stall the motor. Although FOC may extend constant power operation, it results in an increased breakdown torque thereby resulting in an over-sizing of the motor. In addition, efficiency at a high speed range may suffer in addition to the fact that IMs efficiency is inherently lower than that of permanent magnetic (PM) motors and switched reluctance motors (SRMs) due to the absence of rotor winding and rotor copper losses.

C. Permanent Magnet Brushless DC Motor Drives
PM BLDC motor drives are specifically known for their high efficiency and high power density. Using permanent magnet, the motors can eliminate the need for energy to produce magnetic poles. So they are capable of achieve higher efficiency than DC motors, induction motors and SRMs. Furthermore, heat is efficiently dissipated to the surroundings. The speed range may be extended three to four times over the base speed if for a PM BLDC motor a conduction-angle control is used. PM BLDC motor drives have the other drawbacks in that the magnet is expensive and that the mechanical strength of the magnet makes it difficult to build a large torque into the motor. PM BLDC motors have no brush to limit speed, but questions persist over the fixing intensity of the magnet because it restricts the maximum speed if the motors are of an inner-rotor type. Furthermore, this motor suffers from a rather limited field weakening capability. This is due to the presence of the PM field which can only be weakened through production of a stator field component which opposes the rotor magnetic field. Nevertheless, extended constant power operation is possible through the advancing of the commutation angle.

D. Switched Reluctance Motor Drives
SRM drives are gaining much interest and are recognized to have a potential for EV applications. These motor drives have definite advantages such as simple and rugged construction, fault-tolerant operation, simple control, and outstanding torque–speed characteristics. SRM drives can inherently operate with an extremely long constant-power range. The torque-speed characteristics of SRM drives match very well with the EV load characteristics. The SRM drive has high speed operation capability with a wide constant power region. The motor has high starting torque and high torque-inertia ratio. The rotor structure is extremely simple without any windings, magnets, commutators or brushes. The fault tolerance of the motor is also extremely good. Because of its simple construction and low rotor inertia, SRM has very rapid acceleration and extremely high speed operation. Because of its wide speed range operation, SRM is particularly suitable for gearless operation in EV propulsion. In addition, the absence of magnetic sources (i.e., windings or permanent magnets) on the rotor makes SRM relatively easy to cool and insensitive to high temperatures. The latter is of prime interest in automotive applications, which demand operation under harsh ambient conditions. An extended range of 2-3 times the base speed is usually possible using an appropriate control. The disadvantages of SRM drives are that they have to suffer from torque ripple and acoustic noise. However, these are not potential problems that prohibit its use for EVs application.

E. Comparisons
The comparative investigation in the efficiency, weight, cost, cooling, maximum speed, and fault-tolerance, safety, and reliability has been accomplished for SRM, IM, PM BLDC, and brushed DC motor drives. To be specific, a) In the aspect of efficiency, PM BLDC motor drives are better than SRM drives, IM drives and brushed DC motor drives; b) The weight of SRM drives is lower than PM BLDC motor, IM, and brushed DC motor drives; c) Brushed DC motor drives have the lowest cost for these four types of motor drives; d) Taking into account the aforementioned three criteria, SRM drives are superior to other three types of motor drives. Furthermore, SRM drives also have the ascendancy in the aspects of cooling, maximum speed, fault tolerance, safety, and reliability. Therefore, SRM drives are ideally suitable for nowadays EV applications.

VI. CONCLUSION
Electric Vehicles have great potential of becoming the future of transport while saving this planet from imminent calamities caused by global warming. They are a viable alternative to conventional vehicles that depend directly on the diminishing fossil fuel reserves. The EV types, configurations, energy sources, motors and charging technologies for EVs have been discussed in detail in this paper. The challenges in implementing electric vehicles as a major source of transport is also analysed.

VII. REFERENCES
