

Design Challenges of Electric Vehicle and Energy Storage System

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Abstract - The rapid growth of electric vehicles (EVs) and energy storage systems (ESS) plays a crucial role in reducing greenhouse gas emissions and dependence on fossil fuels. However, the widespread adoption of these technologies faces several design challenges related to performance, safety, cost, and reliability. One of the prime dares in electric vehicles is battery technology, which includes limits in energy density, high cost, long charging time, thermal management issues, and battery degradation over time. This paper highlights the types of electrical vehicles, key design challenges associated with electric vehicles and energy storage systems and underlines the need for advanced battery technologies, improved thermal management, intelligent control systems, and sustainable recycling solutions.

Key Words: Electric Vehicle (EV), Energy Storage System (ESS), Battery Technology, Battery Management System (BMS), Charging Technology.

1.INTRODUCTION

The growing global demand for bearable and environmentally friendly transport has speeded the enlargement and acceptance of electric vehicles (EVs) and energy storage systems (ESS). Increasing anxieties over climate change, reduction of fossil fuel resources, and stringent emission regulations have encouraged governments and industries to shift toward electrified transportation and renewable energy-based power systems. In this context, EVs and ESS have emerged as key technologies for achieving energy efficiency, reducing carbon emissions, and improving overall system sustainability. Electric vehicles rely heavily on advanced energy storage technologies, primarily lithium-ion batteries, to deliver reliable performance and acceptable driving range. However, the design and implementation of EVs present several technical challenges, including limitations in battery energy density, long charging times, thermal management issues, high system cost, and

safety concerns. Additionally, efficient power electronic converters, electric motor control, and integration of charging infrastructure with existing power grids are critical design considerations that influence vehicle performance and user acceptance. Similarly, energy storage systems show a dynamic role in supporting renewable energy integration, grid stability, and peak load management. Despite their advantages, ESS faces challenges related to battery aging, thermal safety, accurate state estimation, system scalability, and environmental impact. The intermittent nature of renewable energy sources further complicates the design and control of large-scale storage systems.

2. Overview of electric vehicle

The body of the paper consists of numbered sections that present the main findings. These sections should be organized to best present the material.

It is often important to refer back (or forward) to specific sections. Such references are made by indicating the section number, for example, "In Sec. 2 we showed..." or "Section 2.1 contained a description..." If the word Section, Reference, Equation, or Figure starts a sentence, it is spelled out. When occurring in the middle of a sentence, these words are abbreviated Sec., Ref., Eq., and Fig.

At the first occurrence of an acronym, spell it out followed by the acronym in parentheses, e.g., charge-coupled diode (CCD).

The grail behind the electric vehicle is to substitute an internal combustion engine with an electric motor which is powered by the energy stored in the batteries through a power electronic traction inverter. The Electric motor uses 90–95% of input energy to power the vehicle, which makes it a very efficient one. The main constituents of an Electric car are battery, charging port, charger, DC/DC converter, power electronics controller, regenerative braking, and drive system.

The purpose of the electric motor is that it consumes the electrical energy stored in batteries for powering the Electric vehicle. The EVs become environment-friendly

as they are recharged with lower emission power sources. The cells are charged from the electric grid. The primary function of the battery is to provide power to the Electric car for creating it in running condition. Generally, EVs use lithium-ion batteries because they are more efficient than other cells due to their lightweight and negligible maintenance. The manufacturing of these Li-ion batteries is bit costly as compared to the nickel-metal hydride and lead-acid batteries. Depending upon the climatic location and maintenance schedule, the Li-ion batteries last up to 8 to 12 years. The charging port is the point that permits the vehicle to connect with an external power supply system through a charger to charge the battery. The function of the charger is to take AC supply from the power source using a charge port and convert it into DC power for charging the battery. It also monitors the voltage, current, temperature and state-of-charge of the battery while charging it. The DC/DC converter converts high voltage DC from the battery to low voltage DC power to run the vehicle accessories. The power electronics controller controls the speed of the traction motor and torque by handling the flow of electrical energy from the traction battery.

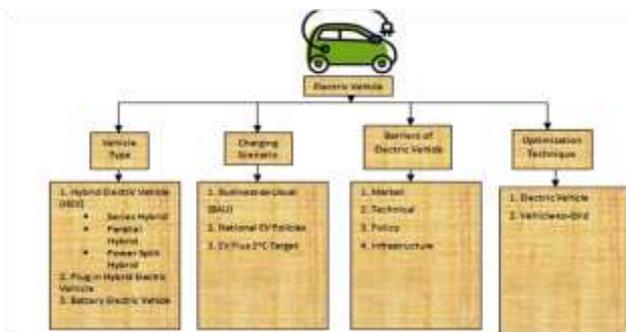


Fig 1. Overview of the Electric Vehicle

3. Types of electric vehicles

1. Battery electric vehicles (BEVs)

BEVs are also known as plug-in or pure EVs. They use an electric motor and run only on battery power, meaning they produce zero emissions from driving. BEVs can use a standard power outlet in your home to recharge or a public charging station. Fast charging outlets are also existing from vehicle manufacturers and can also be installed by a capable electrician in your home to charge your car faster. BEVs can also draw some charge with a regenerative braking system. That means the kinetic energy created from braking is converted into electrical power that can charge the car.

2. Hybrid electric vehicles (HEVs)

HEVs run on a grouping of petrol or diesel and battery power. It combines a conventional internal combustion engine (ICE) with an electric motor. These cars do not plug in to recharge. Like BEVs, HEVs use a regenerative braking system to recharge the battery. While you still need to fill up with petrol, each tank will get you further than a comparable petrol car.

3. Plug-in hybrid electric vehicles (PHEVs)

Similar to HEVs, PHEVs are powered by a combination of petrol or diesel fuel and battery power. The key variance is that you can also recharge the battery using a standard power outlet in your home or public charging station. PHEVs can drive greater distances using just battery power. When the battery power drops, the petrol or diesel engine will be used.

4. Hydrogen or fuel cell electric vehicles (FCEVs)

FCEVs convert fuel into energy through an electrochemical reaction with hydrogen and oxygen. This produces electricity which powers an electric motor.

1. Charging Technology

Although EV load may be relatively minor compared to total system load, the ability to shift charging has important inspirations on emissions. Scarcity of charging infrastructure and lack of standard charging infrastructure pointers to the charging point anxiety, with EV owners wonder whether they can find a charging station for top up or not even if there is one, and whether the connector type at charging station matches their vehicle type or not. In fact, there is indeed a lack of interoperability as the EV and EV Service Equipment (EVSE) market is primarily controlled by three technologies with different connectors and communication protocols. Charging technology or EV power supply equipment connects EVs and power grid. Fig.2 shows the three dominating sorting of EV charging technologies, including conductive charging, inductive charging, and battery swapping.

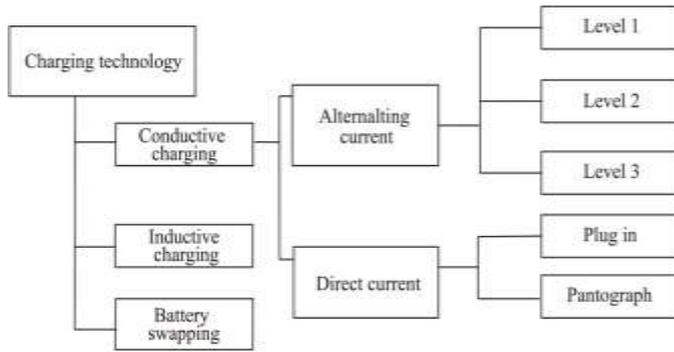


Fig 2. Classification of EV Charging Technology

1. Conductive charging

In conductive charging, the EVs are charged by alternating current (AC) or direct current (DC). An EV battery can be recharged by conductive AC charging if the EV possesses an on-board charger that can convert supplied AC to DC.

2. Inductive charging

Inductive charging is wireless transmission of electricity by static or dynamic induction. The area required for inductive charging is minimal thereby decreasing the cost of land required in the case of inductive charging. However, inductive charging requires many auxiliary devices such as high-frequency transformer, supervisory control and data acquisition (SCADA), and vehicle alignment monitoring system.

3. Battery swapping

An alternative battery recharging method that is receiving global attention is battery swapping, in which a depleted EV battery is removed from the vehicle and replaced with a fully charged one. The technology is being tried out for various EV segments, including e-2Ws, e-3Ws, e-cars and even e-buses.

2. Energy storage system

The automotive industry is undergoing a amazing transformation with electric vehicles (EVs) emerging as a top competitor for the future transportation. One of the critical reasons determining the success of EVs is the performance, efficiency and reliability of their energy storage system. This paper illustrates the latest expansions in the energy storage technologies for EVs, concentrating on the growth of the revolution solution to improve performance, range, and overall performance. Energy storage system can be categorized into

1. Mechanical Storage System:

Certainly, let's examine into the theory behind mechanical energy storage systems (MESS) and explore how they function, principally in the context of electric vehicles. Mechanical energy storage systems store energy in the form of kinetic or potential energy, which can be released and attached when needed. One of the most prominent examples of MESS is the flywheel, which will be the primary focus in this discussion.

2. Fly Wheel Energy System:

It is a power-driven device which stores the energy in the form of rotational kinetic energy. The main parts of FES are important. A typical FES system contains of a flywheel supported by bearings and connected to a motor-generator. The usage of magnetic bearings in its place of regular mechanical bearings helps reduce friction and energy loss, improving how well the system works. Also, the evolution of FES technology has led to the making of advanced systems that use strong but light materials for the flywheel, making it even better at storing energy while keeping its weight low. The superior structures of FES systems make them different from other energy storage methods. To sum up, flywheel energy storage is a really interesting and useful technology that looks really promising for energy storage and management.

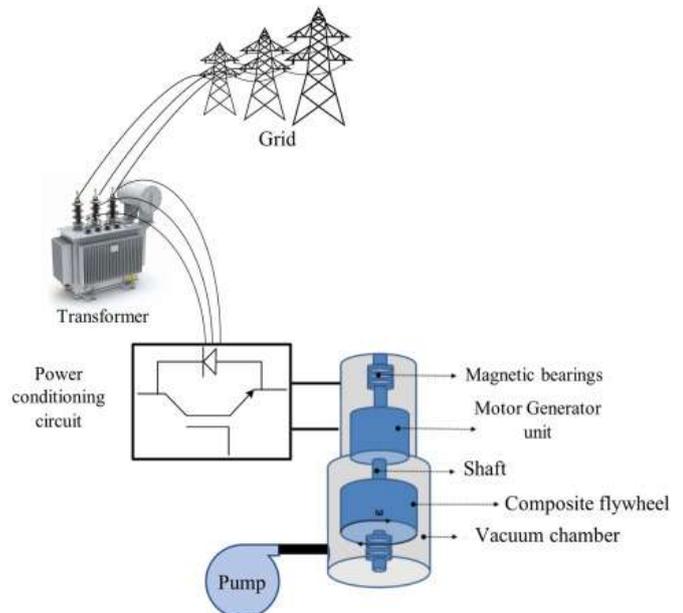


Fig 3. Fly Wheel Energy System

3. Lead -Acid Battery

Usually lead acid battery comprises of a negative electrode made of porous lead and spongy in nature. The lead is porous to accommodate the formation and dissolution of lead. The positive electrode consists of

lead oxide. Two electrodes are immersed in an electrolytic solution of sulfuric acid (H₂SO₄) and water. The reversible chemical reaction which takes place is given below.

The charging and discharging reactions are
 $Pb + SO_4^{2-} \rightarrow PbSO_4 + 2e^-$

3. Challenges

1. **High initial cost:** the upfront cost of purchasing an electric vehicle is relatively higher compared to conventional vehicles. The high initial cost makes it less affordable for many potential buyers, limiting the demand for ev.

This cost difference is primarily due to the expensive battery technology used in ev.

2. **Limited charging infrastructure:** in India, the charging infrastructure is still in the early stages of development and is concentrated in major cities.

The lack of a robust and widespread charging network makes it inconvenient for ev owners,

Especially for those living in apartments or without dedicated parking spaces.

3. **Range anxiety:** range anxiety refers to the fear or concern of running out of battery charge while driving. Limited driving range is a significant challenge for ev adoption.

Although ev ranges have been improving, there is still a perception that evs may not offer

Sufficient range for long-distance travel, particularly in a country with vast distances like india.

The batteries in evs degrade over time, which can lead to a decrease in range.

4. **Battery technology and supply chain:** the production of lithium-ion batteries, which are a key component of evs, requires specific minerals and rare earth elements.

India currently relies heavily on imports for battery manufacturing, leading to supply chain

Challenges. The charging time of evs is longer than the refuelling time of conventional vehicles, which

Affects their convenience and usability.

5. **Limited model options:** currently, the availability of electric vehicle models in India is relatively limited compared to conventional vehicles. The market needs more options in various segments, including affordable evs, to cater to diverse consumer preferences and requirements.

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