International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 02 Issue: 07 July 2024
Page No: 2006- 2011
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2024.0273

Electric Vehicle Lifecycle: A Review

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Abstract

Today, in order to meet the specifications of net zero carbon emissions we are trying to find out a way to gain sustainable development. While the solution of Electric Vehicles (EV) to reduce carbon emissions has been largely proposed, a review regarding various other aspects concerning the components and sections used in an EV is being presented in this paper. For sustainable development we need to clearly analyze and know the lifecycle of all components and sections of an EV. This review aims to highlight the lifecycle of an EV and its components.

Keywords: *Battery; Electric Vehicle (EV); Lifecycle; Motor; Sustainability.*

1. Introduction

Globally 25% of greenhouse gasses (GHG) are said to be emitted by the transportation sector. The usage of fossil fuels and eventually the GHG emissions can be reduced by introducing electrified powertrain technologies such as hybrid EV, Fuel Cell EV and battery EV. This review explores the complicated landscape of electric vehicles (EVs), examining recent technological strides, addressing persistent challenges, and outlining promising future trajectories. Emphasis is placed on advancements in battery technologies, the evolution of charging infrastructure, and the integration of smart technologies within EV systems. Environmental considerations, policy dynamics, and societal impacts are also scrutinized to provide a holistic perspective. By synthesizing current research and industry trends, this review offers a subtle understanding essential for researchers, and industry leaders steering the course of electric mobility. An electric vehicle has the following features: (i) portable energy source of electrochemical or electromechanical nature and (ii) an electric motor supplies traction effect. [1] Product designing in the market has evolved over the past 2 decades. The automotive industry is going through paradigm shifts while the world wants to move away from fossil fuels and further close to renewable energy sources.

1.1. Sections of EV

Looking at the different subsystems of an EV as given in figure (1) diagram the structure consists of three sections broadly, the power subsystem, energy subsystem, electric propulsion subsystem. All these subsystems work in integration with each other and are made by the combination of different processes. The arrow represents the energy interaction between the components present in the EV. Each part doesn’t necessarily interact with the other but is linked to some or the other part. The below diagram illustrates a vehicle control system that integrates both mechanical and electrical components to enhance vehicle operations. The steering subsystem,

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powered by a power steering unit, uses sensors to adjust steering responses based on driver input for smoother maneuverability. In the propulsion subsystem, an electric motor, powered by a converted energy supply, drives the wheels through a mechanical transmission, adapting torque and speed as necessary. This process is regulated by an electronic controller that takes input from the vehicle's brakes and accelerator to ensure optimal power distribution and vehicle performance, thereby increasing efficiency and driver control.

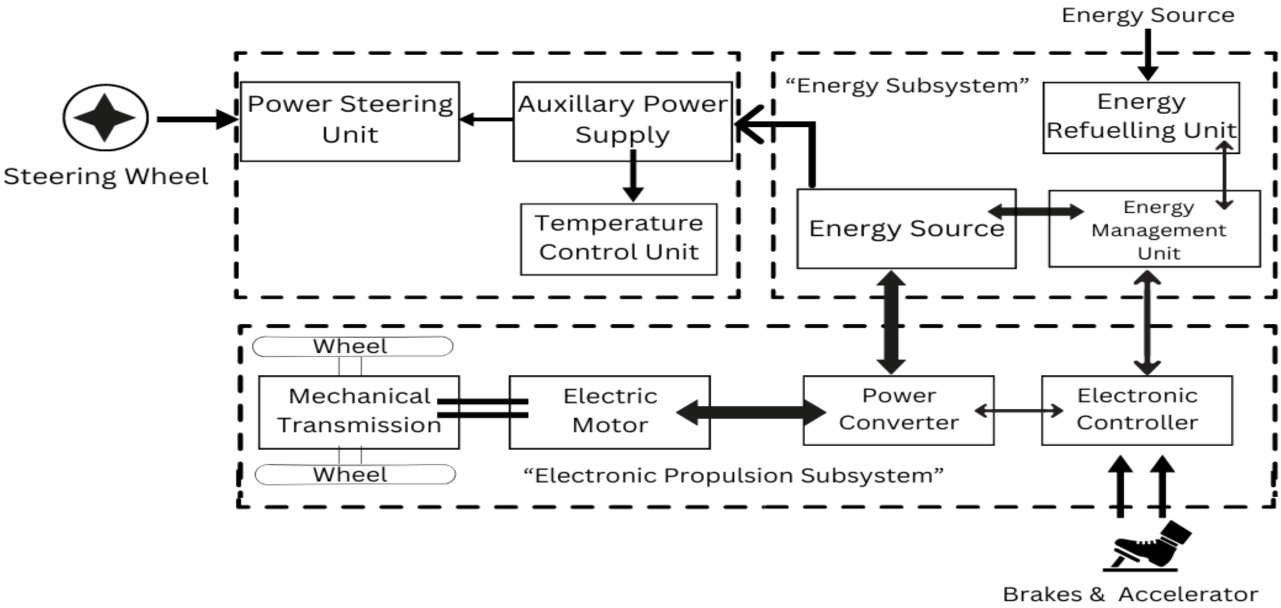

Figure 1 Subsystems Present in the EV

1.2. Component Analysis

In recent years the EVs that were developed have been based either on the induction machines or on the permanent magnet machines. Earlier these were based on the DC machines but their disadvantages led the developers to look for alternatives in the AC devices. [6] The induction machines used in recent years are made up of rare earth materials, which are maintenance free, and cost less but, these machines have a penalty of size as well weight. Design of the electric motor in an EV includes the thermal and structural aspects along with the electromagnetic aspects. Today's electric motor designing is supported by the various computer aided tools and finite element studies forming an efficient designing process. A power electronics based circuit comprising the power semiconductor devices has seen development over the past decades, these power electronics based circuit drives the motor by converting the fixed DC voltage from source into a variable frequency and variable voltage to maintain a suitable operating point of the vehicle. Advances in the power solid-state devices as well as the VLSI (very large scale integration) technology have developed efficient, compact electronic control units. Power electronic motor drives are the high power devices in compact packing, these have enabled the development of lightweight efficient power processing units. [7] Complex control algorithms are enabled in digital signal processing tools and microprocessors. The high speed digital signal processors or microprocessors have enabled complex control algorithms which are implemented with high degree of accuracy, these controllers include algorithms for both the system-level control in the outer loop as well as the motor drive in the inner loop.

2. Analysis

The below diagram outlines a comprehensive lifecycle analysis of vehicle systems, categorized into background and foreground systems, focusing on the production, use, and end-of-life phases. In the production phase, vehicles are manufactured using materials and energy; the diagram specifies options like drive trains for internal combustion engine vehicles (ICEVs) and battery electric vehicles (BEVs), highlighting different electricity sources for battery production such as coal, photovoltaic, and wind. During the use phase, the vehicle's environmental impact is detailed by fuel types (petrol, diesel, CNG) and electricity usage scenarios (e.g., DE 2013, DE 2050), tracking emissions from original estimates to real-world scaled values. Figure 2 Shows The Life Cycle Analysis Maintenance requirements differ between ICEVs and BEVs. [8] Finally, the end-of-life phase considers recycling processes, including material and thermal recycling, and the disposal of waste, thereby encompassing the vehicle's entire lifecycle from creation to disposal, emphasizing energy inputs and emissions outputs at each stage. [9]

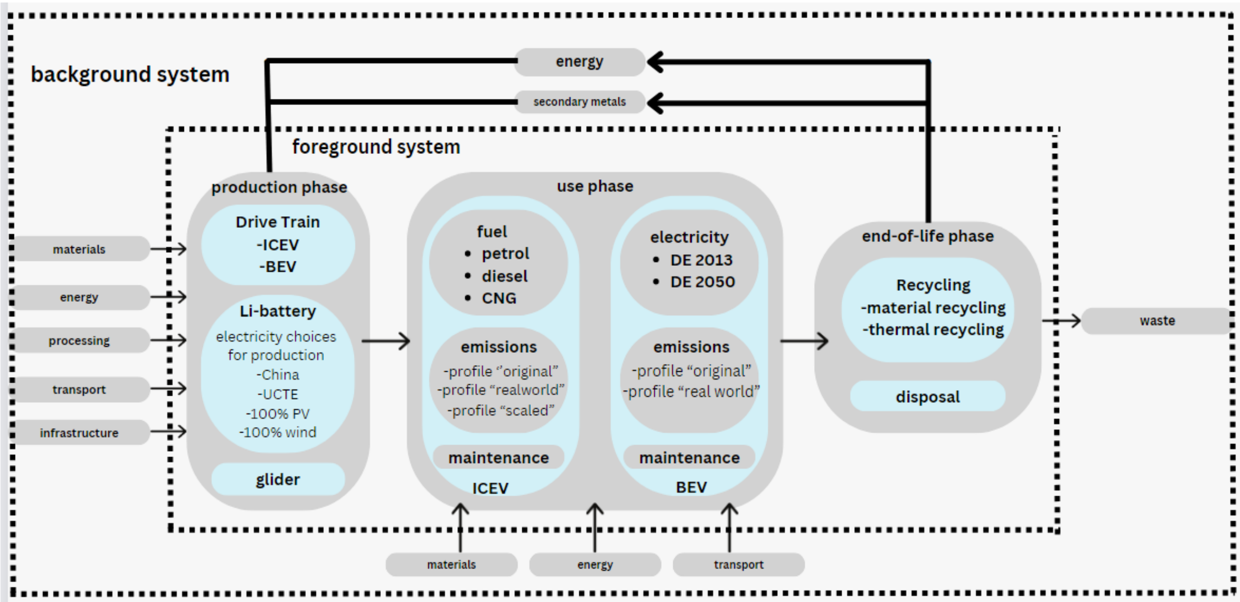

Figure 2 **Life-cycle Analysis**

The energy source or the electrochemical battery is the integral part of an EV system that stands as the driving force behind its every operation. Over time the materials that compose the batteries have changed drastically. In the first commercially available EVs lead/acid batteries were used in the 1990s, since then the technology has developed in the NiMH (Nickel Metal Hydride) and Li-ion (Lithium Ion) rechargeable battery sources. New technologies are being developed to recycle the Li-ion batteries; as today most batteries being used are Li-ion numerous methods using pyro metallurgy and hydrometallurgy to recycle the battery and reobtain the materials are being researched upon by considering the environmental and economic effects of both methods. [5] The value regulated lead-acid (VRLA) battery consists of an electrolyte of two forms which are absorbed electrolyte and gelled electrolyte. This two-formed structure of VRLA battery allows battery for reducing evaporation, leakage and vibration, in comparison of its conventional counterparts. [2] The problem of limited range in battery driven EVs has led to search for alternative energy sources like fuel cells and flywheels. [10] Fuel cells are a type of electrochemical cells that require a continuous source of fuel (usually hydrogen) and oxidizing agent(oxygen) to sustain the electricity production. The flywheel working similar to regenerative braking systems acts like spinning discs working on the basis of the inertia to save energy. Ultra capacitors are also an alternative electrochemical source for charging the Electric Vehicles. In order to mitigate the manual charging infrastructures wireless power transfer (WPT) technique is being studied now. Experiments have been done to

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achieve power transfer of more than 360-W for 120 mm air gap which has an efficiency of 82% with operating frequency around 80 kHz. [4]

3. Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) evaluates the environmental impacts of EVs from production to disposal, covering the manufacture of components like batteries and motors, usage, and recycling. Challenges in LCA include limited data, variability in EV performance, and changing electricity sources. Despite these, LCA is crucial for highlighting environmental impact areas, shaping policy, and driving sustainable EV design. It relies on detailed inventory analysis, current, localized electricity data, and future technology considerations, aiding stakeholders in fostering sustainable EV development. [11]

3.1. Environmental Impacts

Environmental impact analysis of EV as compared to traditional conventional vehicles during the longest duration in lifecycle; its working period is better as it does not have any carbon emissions but, during the initial production stage the emissions are higher. Also, it needs to be noted that while technologies similar to battery recycling are being developed they are not yet in the implementation phase. Table 1 explains CO2 emission of battery electric vehicle, hybrid electric vehicle, and internal combustion engine vehicle.

Table 1 **CO2 Emissions**

		Battery electric vehicle	Hybrid electric vehicle	Internal combustion engine vehicle
Production emissions (tCO2e)	Battery manufacturing	5	1	0
	Vehicle manufacturing	9	9	10
Use phase emissions (tCO2e)	Fuel/electricity production	26	12	13
	Tailpipe emissions	0	24	32
	Maintenance	1	2	2
Post consumer emissions (tCO2e)	End-of-life	-2	-1	-1
	TOTAL	**39 tCO2e**	**47 tCO2e**	**55 tCO2e**

4. Literature Review

C. H. T. Lee, W. Hua, T. Long, C. Jiang and L. V. Iyer, "A Critical Review of Emerging Technologies for Electric and Hybrid Vehicles, “Broadly discusses most aspects related to the evolved & emerging technologies related to EV and HEV. Considers various options with us today for an alternative for the existing technologies the presented technologies are- Induction Machines, Wound Field Synchronous Machines, Reluctance Machines, Stator-PM machines, Field modulation machines, High speed machines. Electrochemical energy sources which can power auxiliary parts including lighting, air conditioning and audiovisual set are studied; the sources include battery, fuel cells and ultra-capacitors. The paper also describes various wireless charging infrastructures. Park and charge, coil designing of wireless EV charging for the same has also been described in the same. Move and charge for dynamic charging by employing an array of transmitters underneath the roads. In conclusion the paper reviews some of the state of the art and most popular EVs, in order to describe various technologies with suitable examples. Choudhury S. Flywheel energy storage systems: A

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critical review on technologies, applications, and future prospects. The paper widely describing and reviewing the flywheel energy storage systems also analyzes them critically with regards to the technologies, applications and future prospects concerning the same. The Flywheel energy storage system (FESS) is said to store energy up to mega joule. Analyzing the components of the FESS like the rotor, motor/ generator, rotor bearings, power electronics, housing, fess characteristics and the uninterruptible power supply. The paper also briefly describes the integration of the renewable energy sources with this technology and the hybrid technologies that can be developed by these technologies collaboratively. The paper concludes with applications and maintenance, future trends, losses and cost models of the FESS technology. ACS Energy Lett. 2022, 7, 2, 712–719 Publication Date: January 19, 2022 https://doi.org/10.1021/acsenergylett.1c02602Lithium-Ion Battery Recycling Overview of Techniques and Trends | ACS Energy Letters The paper studies the evolution of the batteries used while focusing on the Lithium ion batteries (LIB). Special emphasis has been given to the recycling methodologies for LIB while analyzing the energy/environmental impacts of the same. The paper compares various technologies developed to recycle the batteries and economic aspects related to the same while also mentioning the locations where battery recycling facilities are present. Sensitivity Analysis in the Life-Cycle Assessment of Electric vs. Combustion Engine Cars under Approximate Real-World Conditions by Eckard Helmer's *, Johannes Dietz and Martin Weiss The paper compares the conventional vehicles and the electric vehicles through the life cycle assessment (LCA) and Recipe characterization method to capture various categories. It also discusses the production of more sustainable batteries. The paper gives a critical review of the lifecycle of the electric vehicles from production to the disposal. This study is based on the carbon footprint of both vehicles and addresses the shortcomings of EVs by compiling data obtained from life-cycle inventory of the laboratory project for SMART for two and a Volkswagen Caddy. The sensitivity parameters were quantified as, size of the car, emission profile, fossil fuel choice, electricity choices during battery production and use phase, battery size and battery second use, mileage. Un-Noor, F.; Padmanaban, S.; Mihet-Popa, L.; Mollah, M.N.; Hossain, E. A Comprehensive Study of Key Electric Vehicle (EV) Components, Technologies, Challenges, Impacts, and Future Direction of Development. Energies 2017. The paper begins with analyzing the types of EV and the battery configurations present in them. The general setup of EV and its components is indicated and the subsystems present are studied. Today for an EV numerous energy options are available; those energy sources have also been studied; battery, ultra-capacitors, fuel cells, flywheels. Different kinds of motors can be employed to maximize the torque and have a great propulsion system. [14] Various motors are studied in depth for their efficiency and other parameters. Various charging systems including wireless charging mechanisms are also mentioned in the paper. Power conversion techniques employed in the EVs are also highlighted. Control systems and algorithms based on which the vehicle works are also studied. [15] Different studies of control systems for working of the subsystems present in the EV are described. In conclusion, this paper highlights the potential future developments and areas for further research in the development of electric vehicles (EVs). [16]

Conclusion

Electric vehicles (EVs) promise significant reductions in greenhouse gas emissions, but their environmental performance largely depends on the source of electricity used for charging. When the electricity is generated from renewable sources like wind, solar, or hydro, EVs exhibit a markedly lower environmental footprint over their lifecycle. In contrast, if the electricity comes from fossil fuels, such as coal or natural gas, the benefits are considerably reduced. This variation highlights the crucial role of transitioning to renewable energy sources for charging EVs to maximize their sustainability potential. [12] The life cycles environmental performance of EVs, therefore, hinges not only on advancements in vehicle technology and efficiency but also on the greening of the electrical grid. As regions vary widely in their energy mix, the sustainability outcomes of adopting EVs also differ, underscoring the importance of localized energy policies in promoting EV sustainability. [13]

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