Holistic Approach to Electric Vehicle Design: Vehicle Dynamics, Motor Configuration, and Active Battery Cell Balancing

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Abstract *– Electric Vehicles are becoming a revelatory trend in the automotive industry, due to increased environmental consciousness, better efficiency, and low-cost operations. The awareness of sustainable development and transportation has started the rapid development of electric vehicles. This paper covers the three major domains of EV: dynamics of EV, motor configuration, and active cell balancing. The number of iterations and simulations of components that determine the operations and functioning of the electric vehicle (EV) have been presented here. All the sections wisely covered the specifications of vehicle dynamics, motors, and battery systems which leads to the proper design and development of electric vehicles. This paper also investigates the functions of MATLAB, the study of different driving cycles, and the environmental aspects of the performance matrix of electric vehicles. The findings of this research readily contribute to current efforts in the proper advancement of technology involved in electric vehicles as well as the proper design and development of them.*

Keywords – Battery Management System, Electric Vehicle Dynamics, Electric Vehicle Motor Configuration, State of Charge, State of Health.

1. INTRODUCTION

As the population is rising globally, directly correlated with the growing mobility of individuals. Consequently, transportation experiences a significant surge. Currently, governments across the world have implemented countless rules and regulations in the automobile industry to label issues related to fuel consumption and air pollution. Contrarily, users are demanding increased safety, performance, luxury, and comfort features in their vehicles. To maintain an equilibrium between reducing air pollution and fulfilling user demands, the automobile industry is transitioning towards electric vehicles. An electric vehicle draws power from a battery and utilizes an electric motor for propulsion. EV plays a vital role in attenuating climate change and depleting carbon emissions in comparison to gasoline-powered vehicles. Throughout their lifetime, EVs have contributed positively to the climate. They offer numerous advantages over conventional vehicles, incorporating simpler controls, lesser maintenance requirements, and lower costs. In addition, they are ecologically sound due to the absence of conventional fuel consumption by which they provide opportunities to utilize renewable energy sources. Furthermore, EVs boast appreciable energy efficiency as throughout their operation they involve less energy consumption [1], [2].

This paper hunts through the designing of the electric vehicles. The vehicle design procedure incorporates the following steps as shown in Figure 1.

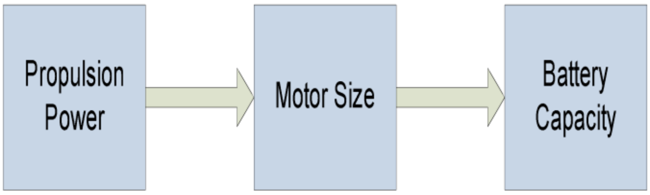

Fig. 1. Vehicle design procedure.

The EV design begins with the calculation of propulsion power which is required to move the vehicle. To design an electric vehicle, the initial step involves collecting the vehicle specifications and gaining a fundamental understanding of vehicle basics. When a vehicle is parked on a flat surface, various forces come into play, ensuring the vehicle remains stationary. In order to move the vehicle, two primary forces act on the vehicle, the push force which is exerted by the vehicle's motors to propel the vehicle forward, and the friction force. For the vehicle to move, the push force must be higher than the friction force. On an inclined road, the vehicle may move in a reverse direction due to the influence of gravity. The friction force encompasses both aerodynamic drag force and gravitational force. The power required to propel the EV can be calculated by using this formula,

$$\text{Power} = \text{Total Tractive Forces} \times \text{Velocity of Vehichle} \quad (1)$$

Here tractive forces include all the opposing forces exhibiting against the vehicle's movement. The subsequent stage additionally encompasses the selection of motor size. Motors are the powerhouses of EVs that propel the electric vehicle. These are the devices that govern all the factors that drive the system. The paper presents the design of EVs along with the different motors that are used in EVs. Due to worries about

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energy security and environmental pollution, electric vehicles (EVs) have drawn a lot of attention as sustainable alternatives to internal combustion engine automobiles [3]. This paper gets under the hood of EV motor technology, examining various motor designs and the control systems that keep them running smoothly and are the brains behind an electric vehicle. This study provides an in-depth analysis of the electric motor technology found in electric vehicles, covering different motor kinds and the controllers that are used with them. Some specifications are to be remembered for choosing a motor for an EV. These include high efficiency, fast torque response, high acceleration, high power density, and robustness. The motor constitutes the controller which manages and assures some features such as power delivery and regulation protection and safety. The Controller acts as the brain of the motor [4].

The third stage involves the management of a battery system. Electric vehicles are assembled with an enormous number of battery cells that need a systematic BMS while supplying the power they need. The battery fitted in an electric vehicle provides long-lasting power as well as high power. The prominent traction batteries are lithium-ion, metal hydride, and lead–acid. The lithium-ion battery is used frequently because the memory effect is low. Batteries are generally grouped into two categories, primary and secondary. EV batteries are classified into four types -Lead, nickel cadmium, Nickel Metal Hydride, and Lithium. Battery parameters are classified into seven types, which are classified as – Battery state of charge (SoC) is determined by dividing the total energy used by the battery by its capacity, which performs the overall available energy, depth of charge is termed as the percentage of battery capacity (discharged) to the ideal capacity, state of health is defined as the measurement of the ability of a battery for storing and delivering the electrical energy, C-rate is characterized as time duration in which charging and discharging takes place, Battery management system is the key element in guarantying the safety of electric vehicle [5]. Its primary function is to achieve, increased battery life, and battery protection, to ensure the battery parameters. The BMS manages this by monitoring the state of health of the battery (SoH), balancing the voltage across all cells, and collecting data. BMS depends upon charging and discharging rates and makes decisions on that. Additionally, it is employed to maximize the vehicle’s range by proficiently, utilizing the stored energy.

2. VEHICLE DYNAMICS

The initial stage in the design procedure of an electric vehicle involves determining the propulsion power, which can be calculated by examining the dynamics of the vehicle. The study of different forces exerted on the vehicle while moving is carried out in the vehicle dynamics. When an EV is running on a flat surface with constant speed, two forces come into play that is the rolling resistance force and the aerodynamic drag force. Additionally, two more forces act on the vehicle while running on a rough surface, uphill or downhill which is the acceleration force and the hill climbing force. The total tractive forces are the sum of all these four forces depending upon the condition of the road [4].

2.1 Rolling Resistance Force

This force acts opposite to the motion of the vehicle. The vehicle's weight, the force of gravity and inertia, and the level of friction between the road and tires, all play a part in constituting the rolling resistance force. The rolling resistance coefficient is a function of the road roughness, tire material, temperature, pressure, tread geometry, and presence/absence of liquids on the surface. It is given by the formula,

$$F_{rr} = \mu_{rr} \times m \times g \tag{2}$$

Where μ_{rr} denotes the rolling resistance coefficient, F_{rr} represents the rolling resistance force, m is the mass, and g is the coefficient of gravitational acceleration. The value of this force varies with speed inversely. The value of the rolling resistance coefficient ranges from 0.001 to 0.3 depending upon the road conditions [5].

2.2 Aerodynamic Drag Force

The force inserted on an object which opposes the motion via air is called drag. It acts either in parallel or in the same direction as the same direction of airflow. It increases proportionally to the square of the speed. It is given by the equation,

$$F_{ad} = \frac{1}{2} \times \rho \times C_d \times A \times v^2 \tag{3}$$

Where, ρ denotes the air density in kg/m3, v is the velocity of the vehicle in m/s, C_d is the drag coefficient, and A represents the frontal area in m^2.

The frontal area of the vehicle should be minimized to reduce the pressure of air and improve aerodynamics, which allows for better management of air resistance and improved vehicle dynamics. The drag coefficient for EV lies between 0.3- 0.7 [6] while for buses and modified buses, it is 0.6-0.7 and 0.3-0.4 respectively.

For prototype designing, firstly consider the vehicle moving on a flat surface with a constant speed. So, the aerodynamic drag force and rolling resistance come into play. During this design, the following EV specifications have been taken into account, as shown in Table 1.

To calculate the different tractive forces, the different specifications should be taken into account. Then the propulsion power is calculated. The calculated data is shown in the given Table 2.

By using the given data, the propulsion power is calculated as 3720.29 watts. When the road conditions are not smooth, and the vehicle is moving uphill or downhill then hill climbing force and acceleration force are also calculated [7]. The understanding of vehicle dynamics gained in this section, allows us to further delve into electric motor configuration.

Table 1. EV specifications.

Parameters	Notations	Value	Units
Weight	m	1000	Kg
Width	w	1.00	m
Height	H	1.50	m
Rolling Resistance	μ_{rr}	0.02	–
Air Density	ρ	1.25	Kg/m^2
Drag Coefficient	Cd	1.2	–
Gravitational force	g	9.80	N
Speed in Km	s	40.00	Km
Frontal Area	A	1.50	m2
Velocity	v	11.11	m/sec

Table 2. Force calculations.

Force acting on vehicle	Value
Rolling Resistance	196 N
Aerodynamic Drag Force	138.86 N
Total tractive forces	334.86 N

3. ELECTRIC MOTOR CONFIGURATIONS FOR EV

Motors are the powerhouses of EVs that propel the electric vehicle. Figure 2 shows the most commonly used motors in EVs. These are the devices that govern all the factors that drive the system. The paper presents the design of EVs along with the different motors that are used in EVs [8]-[10].

This paper gets under the hood of EV motor technology, examining various motor designs and the control systems that keep them running smoothly and are the brains behind electric vehicles. This study provides an in-depth analysis of the electric motor technology found in electric vehicles, covering different motor kinds and the controllers that are used with them.

Some specifications are to be remembered for choosing a motor for an EV. These include high efficiency, fast torque response, high acceleration, robustness, and high-power density.

The motor constitutes the controller which manages and assures some features such as power delivery, regulation, protection, and safety. The Controller acts as the brain of the motor [11]-[13]. Table 3 depicts the design considerations for electric vehicle motors. Table 4 emphasizes the characteristics of different motors used in EVs.

Table 3. Factors for EV motor.

Factors	Features
Vehicle Characteristics	Size, Weight, Aerodynamics
Driving Cycles	Frequent acceleration and Regeneration
Vehicle Configuration	Driven System of the motor
Maximal Speed	Higher speeds need high power capabilities
Maximal Power	High power leads to faster acceleration
Maximal Torque	High torque for heavy vehicles
Battery Capacity	High capacity leads to better performance

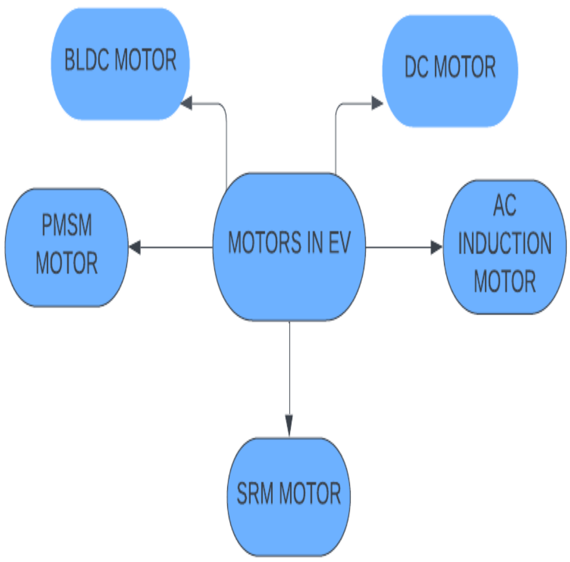

Fig. 2. Types of motors in EV.

Table 4. Motor characteristics.

Motors	Characteristics
DC Motor	Low efficiency, High torque
AC Motor	Robust, Rugged construction
Brushless DC (BLDC) Motor	Electrical commutation
Switched Reluctance Motor (SRM)	High thermal toughness
Permanent Magnet Synchronous Motor (PMSM)	No sparks, Low noise

The use of different motors in electric vehicles is dependent on the diverse requirements and design of the vehicle as shown in Table 5.

Table 5. Motor according to their uses.

Motors	Uses
DC Motor	Good performance over wide speed range
AC Motor	Balanced cost efficiency and better performance
Brushless DC (BLDC) Motor	Provides longer range and better energy savings
Switched Reluctance Motor (SRM)	Less susceptible
Permanent Magnet Synchronous Motor (PMSM)	Provides high torque at low speeds

The EV's performance is dependent upon the specifications of the electrical motor. Scientists compared all the parameters for different motors which include torque, iron loss, efficiency, etc. It is observable that induction motors have all the appropriate characteristics for electric vehicles [14]-[16]. The rotor speeds, electromagnetic torques, and stator currents for PMSM and Induction motors have been shown in Figure 3 and Figure 4 respectively. For BLDC and SRM, the relevant waveforms have been depicted in Figure 5 and Figure 6 respectively. The performance, dependability, and sustainability of electric vehicles (EVs) are being improved by developments in materials, control systems, and thermal management as electric motor technology advances.

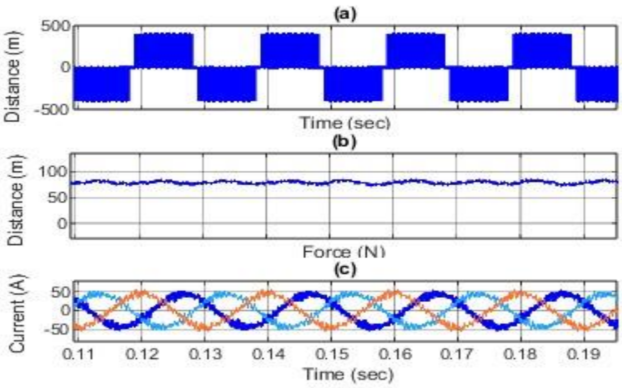

Fig. 3. (a) Rotor speed curve (b) Electromagnetic torque curve (c) Stator current curve – PMSM.

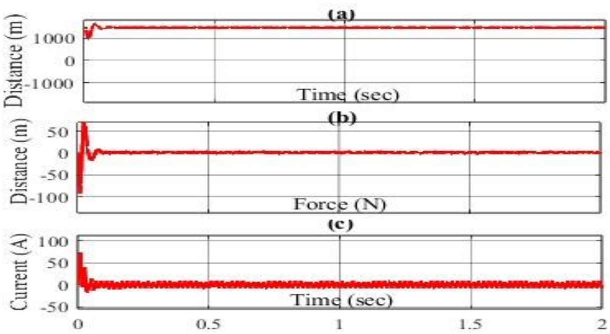

Fig. 4. (a) Rotor speed curve (b) Electromagnetic torque curve (c) Stator current curve – Induction motor.

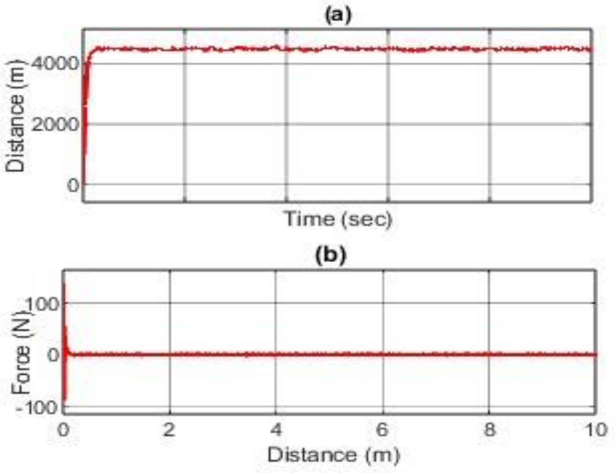

Fig. 5. (a) Rotor speed curve (b) Electromagnetic torque curve – BLDC Motor.

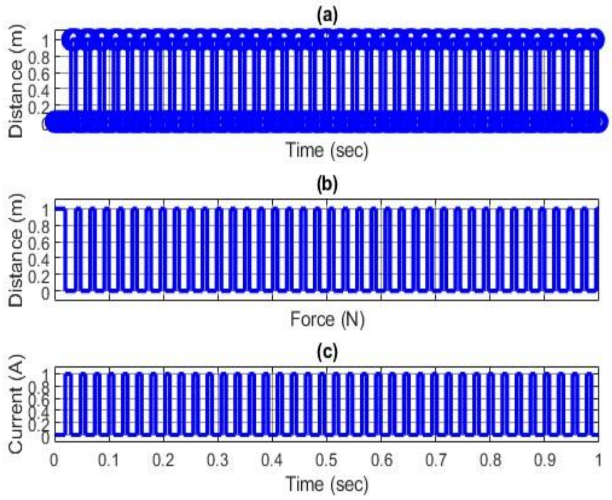

Fig. 6. (a) Rotor speed curve (b) Electromagnetic torque curve (c) Stator current curve – SRM.

4. BATTERY MANAGEMENT SYSTEM (ACTIVE CELL BALANCING)

The BMS plays an essential role in electric vehicles as it certifies that the batteries are not subjugated to overcharging or overcharging. Any appearance of such can lead in damage, a shortened battery life cycle, increased temperature, and even risks to the consumers. A typical block diagram for the same is depicted in Figure 7. There are additional features of the battery management system as described below.

State of charge estimation – It is the total available energy divided by the battery capacity that has been used. It plays a key role in the battery management system. As it helps and ensures that it operates within a safe range. Figure 8 depicts the waveforms of charging and discharging in the active mode [17]-[19].

State of Health Estimation – State of health access to the condition of a battery as compared to the battery's original state, when it was newly produced. It provides information regarding the level of discharging capacity that can be used throughout its lifetime. SOH is used to indicate its ability to cover a specific distance [20], [21].

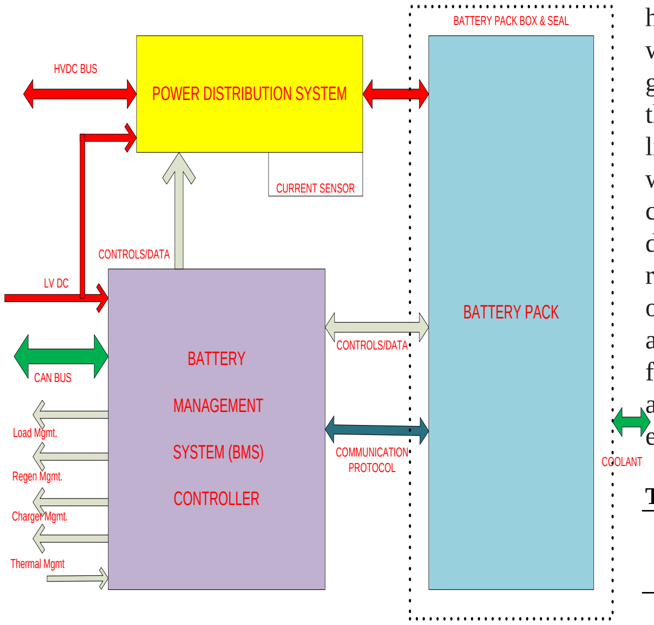

Fig. 7. Block diagram of the battery management system.

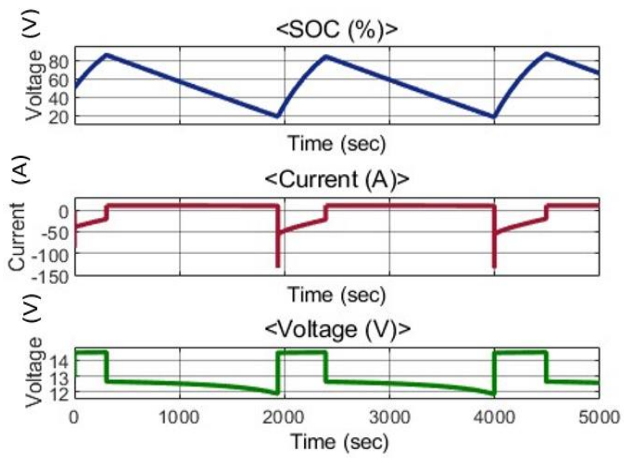

Fig. 8. Charging and discharging of a battery.

Estimation of maximum capacity- The maximum capacity of the battery depicts the consummation and life span of the battery. The maximum capacity of a battery is calculated by:

$$Capacity = \int Idt \tag{4}$$

Where, I = current flowing through the battery.

Electric vehicles use several types of batteries as described in Table 6.

5. CONCLUSION

Ultimately, this discussion underscores the importance of the design and development of electric vehicles which withstands a proper way for sustainable development of vehicles. Starting from the calculations of forces, electing components for vehicles, and propulsion of vehicle systems to manage battery management systems, every component plays an important role in enhancing efficiency and performance. Advancements in motor technology, battery chemistry, and lightweight materials have revolutionized electric vehicle design, paving the way for increased range, faster charging times, and greater safety standards. However, the journey towards this development is full of challenges. It is full of issues like synchronization in weight and capacity of battery, well-balanced efficiency, simple infrastructure, and cost-efficient vehicle. For the proper sustainable development through EV, all the issues should be remembered. Nonetheless, these obstacles present opportunities for further innovation and collaboration across industries. By addressing technological barriers, fostering supportive policies, and engaging stakeholders, a transition to a cleaner, more sustainable transportation ecosystem can be accelerated.

Table 6. Types of EV batteries.

Types of batteries	Characteristics	Applications	Advantages
Lead Acid	Lifespan of holding a charge up to 3 years	As a backup power source at a time of emergency	Reasonably priced
Nickel-Cadmium	Fast, even energy release	Most popular battery for audio and video appliances	Comparatively inexpensive
Nickel Metal Hydride	Relatively flat discharge, Recycling option available	Cellular phones, Portable computers	Capacity which is unused remains unstable
Lithium Ion	Stable and safe, Power capacity is higher	Portable computers, cellular phones	Charge capacity is twice of Ni-Cd

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