
MECHANICAL LOADING ESTIMATION FOR FINDING ELECTRICAL COMPONENTS PERFORMANCE IN EV'S: A REVIEW

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Abstract

The performance of an electric vehicle (EV) is significantly influenced by varying driving conditions, with key components such as the power electronic controller, electric motor, and battery playing a crucial role in ensuring sustainable and efficient operation. The ratings of these components are primarily determined by the load demand on the motor. This paper presents a comprehensive review focused on evaluating the torque, power, and energy requirements of EVs under different driving scenarios. In addition to vehicle modeling, it explores various methods of performance analysis using standardized drive cycles. Furthermore, the paper highlights the correlation between vehicle load demands and the corresponding input power requirements. Recent literature is also discussed, emphasizing how such modeling approaches are used to analyze and optimize EV electrical components.

1. INTRODUCTION

As the global demand for sustainable transportation continues to grow, electric vehicles (EVs) have become a vital alternative to internal combustion engine (ICE) vehicles, offering reduced environmental impact and lower reliance on fossil fuels[1]. However, the design and optimization of EVs require a deep understanding of how they perform under varying real-world conditions. This is where vehicle modeling plays a critical role[2], [3]. Through accurate modeling, engineers can simulate the dynamic behavior of an EV, predict its energy consumption, and optimize components such as the motor, battery, and power electronics to meet performance and efficiency targets. Vehicle modeling also helps in understanding the impact of external factors such as road gradient, tire characteristics, aerodynamic drag, and temperature on vehicle performance and range[4], [5], [6], [7], [8]. By analyzing the forces acting on the vehicle such as rolling resistance, inertia, gradient force, and aerodynamic drag modelling allows for a comprehensive evaluation of tractive force and power demand. This understanding is essential for selecting and designing the appropriate drivetrain components and for developing control strategies that ensure efficiency under diverse driving conditions. In this paper, a systematic approach to EV modeling is presented. It includes the evaluation of torque, power, and energy requirements under different drive cycles and road conditions. A novel mathematical model is proposed that accounts for dynamic parameters like tire pressure, vehicle speed, rolling resistance, and wind effects. The paper also compares the proposed model with existing methods, validates it across various drive cycles, and discusses the role of a Pneumatic-Liquid Thermal Management System (PLTMS) in maintaining optimal performance under temperature variations[6].

In recent years, extensive research like [1], [3], [7], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21] has been conducted to improve the performance, efficiency, and energy management of electric vehicles through advanced modeling techniques and system-level analysis. Various studies [12], [13], [14], have focused on evaluating the dynamic behavior of EVs under different drive conditions, optimizing motor and battery performance, and enhancing the accuracy of range and energy consumption predictions. Researchers have also explored the impact of external factors such as road gradient, aerodynamic drag, and tire characteristics on vehicle performance in [15], [16], [17], Further section presents a comprehensive review of recent literature that highlights the evolution of electric vehicle modeling approaches, methodologies used for estimating tractive power and energy

demands, and advancements in simulation-based performance evaluation[18], [19], [20], [21]. The insights drawn from these studies provide a foundation for the development of improved and more realistic EV models, as discussed in the subsequent sections of this paper.

2. LITERATURE SURVEY

After selecting vehicle parameters and developing representative models, many researchers have evaluated electric vehicle (EV) performance using various drive cycles and modeling approaches. Li et al. [22] estimated the capacity and internal resistance of EV batteries using an ampere-hour-based method, leveraging real-time drive cycle and cloud-based charging data. Huo et al. [23] developed battery models under dynamic current profiles from different drive cycles, focusing on thermal behavior during discharge. Hong et al. [24] combined dynamometer test data to analyze transient battery conditions and evaluated the effectiveness of a Battery Thermal Management System (BTMS) during fast charging and under the US06 drive cycle. Awarke et al. [25] conducted thermal analysis of Li-ion battery modules using ARTEMIS driving cycles under varying load conditions. Guo and Jiang [26] coupled a battery thermal model with an EV power consumption model to estimate heat generation, validating a refrigerant-based BTMS under the NEDC drive cycle. Amini et al. [27] introduced a thermal model integrated with an EV prototype, examining the thermal effects on cylindrical cells under both charging and discharging, including regenerative braking. Their model was tested across the highway-FTP and CITY-I USA cycles. Panchal et al. [28] assessed the thermal and electrical performance of Li-ion battery packs using real-world driving data obtained through vehicle dynamic modeling and onboard data loggers, emphasizing the importance of accurate modeling in predicting battery behavior. Kyjovský et al. [29] simulated mild hybrid vehicles with hydrogen combustion engines using quasi-static drive cycle analysis, highlighting the role of modeling in evaluating alternative propulsion systems. Shelly et al. [30] developed a comprehensive dynamic modeling framework for Battery Electric Vehicles (BEVs), integrating various subsystems to study thermal management across drive cycles. Their study underlined the importance of combining vehicle dynamics with thermal system modeling for optimizing Integrated Thermal Management Systems (ITMS). Miranda et al. [31] focused on four-wheel independent-drive electric vehicles (FWID-EVs), using fuzzy logic control (FLC) for motor power distribution to enhance efficiency and handling via multi-objective optimization. Bhavsar et al. [32] addressed thermal control using machine learning, with probabilistic discharge current forecasting and stochastic model-predictive control, tested on the US06 cycle, effectively reducing temperature fluctuations. Changizian et al. [33] applied computational modeling and control strategies to improve performance in fuel cell-electric hybrid vehicles, evaluating hydrogen consumption and regenerative braking. Zahid et al. [34] proposed advanced machine learning algorithms, including neuro-fuzzy systems, for precise state-of-charge (SoC) estimation using real-time inputs like current and temperature, reinforcing the importance of data-driven battery management. Gao et al. [35] used vehicle dynamic simulations to study fuel economy and emissions in hybrid and conventional vehicles under various combustion modes, linking combustion strategy optimization to drive cycles. Banjac et al. [36] examined different hybrid electric vehicle (HEV) topologies through analytical and simulation-based energy efficiency assessments, determining optimal power ratios under diverse driving conditions. De Robbio et al. [37] compared diesel hybrid vehicle performance with conventional diesel vehicles under WLTC standards, showcasing reduced fuel consumption and emissions through hybridization. Liaw and Dubarry [38] combined real-life driving data with fuzzy logic pattern recognition for drive cycle analysis, aiming to better understand battery behavior across electric and hybrid platforms. Vikram et al. [39] evaluated a liquid-based BTMS under different ambient and cabin conditions, using vehicle dynamic modeling to simulate real-world scenarios and optimize thermal control. These studies collectively highlight the central role of vehicle dynamic modeling in evaluating EV and hybrid vehicle performance, optimizing energy usage, improving battery and thermal management, and informing design decisions.

Final Outcomes from Literature Review

- **Vehicle dynamic modeling** is crucial for estimating key performance metrics such as torque, power demand, energy consumption, and tractive effort under real-world driving conditions.
- **Drive cycle-based analysis** enables realistic simulation of electric vehicle (EV) behavior, capturing transient events, acceleration patterns, and regenerative braking impacts on energy use and battery life.
- **Battery thermal behavior** can be effectively predicted by coupling thermal models with vehicle dynamics, especially under varying ambient conditions and driving loads.
- **Real-time data acquisition** (e.g., through cloud-based systems or onboard loggers) enhances model accuracy, enabling validation against real-world performance and refining control strategies.
- **Machine learning and AI-based models** are emerging as powerful tools for battery SoC estimation, thermal management, and predictive energy efficiency optimization.
- **Integrated modeling approaches** (including electrical, thermal, and mechanical domains) allow for comprehensive evaluation and optimization of EV subsystems.
- **Thermal management systems (BTMS/ITMS)** are more effectively designed when analyzed using dynamic vehicle models, especially under aggressive or fast-charging scenarios.
- **Vehicle dynamic modeling supports technology comparison**—from lithium-ion to hydrogen or hybrid configurations—by simulating performance under standardized and custom drive cycles.
- **Simulation-based control strategies**, such as fuzzy logic and model predictive control, are being increasingly adopted for energy optimization and improved dynamic response.
- **Overall, dynamic modeling** plays a pivotal role in EV development—guiding component selection, control design, and improving overall system efficiency, safety, and range.

From the above discussion, it can be concluded that vehicle modeling serves as the foundational step in the comprehensive analysis of electric vehicles. The following section presents the detailed methodology and framework used for modeling the electric vehicle and evaluating its performance.

3. VEHICLE DYNAMIC MODELLING

In order to eliminate the demerits and evaluate the performance of EV motor, battery, and controllers, Vehicle dynamics are studied. vehicle has its own weight, design, shape, and features which all together are known as vehicle dynamics. Different dynamics produces different drag forces on a running vehicle and accordingly the vehicle require power and torque for its drive. vehicle runs from zero to its maximum velocity as per drivers' choice and road conditions, there are several pauses, halts, cruising at accelerating and decelerating modes, overtaking etc. For the vehicle to drive in all conditions it must overcome these drag forces which are the function of vehicle weight, design, and shape, discussed in [24],[25],[26] [27], [28-32]. figure 1 shows the forces acting on the moving vehicle, The three types of forces are Aerodynamic force, Tyre rolling resistance force, Gradient force, and finally tractive Force.

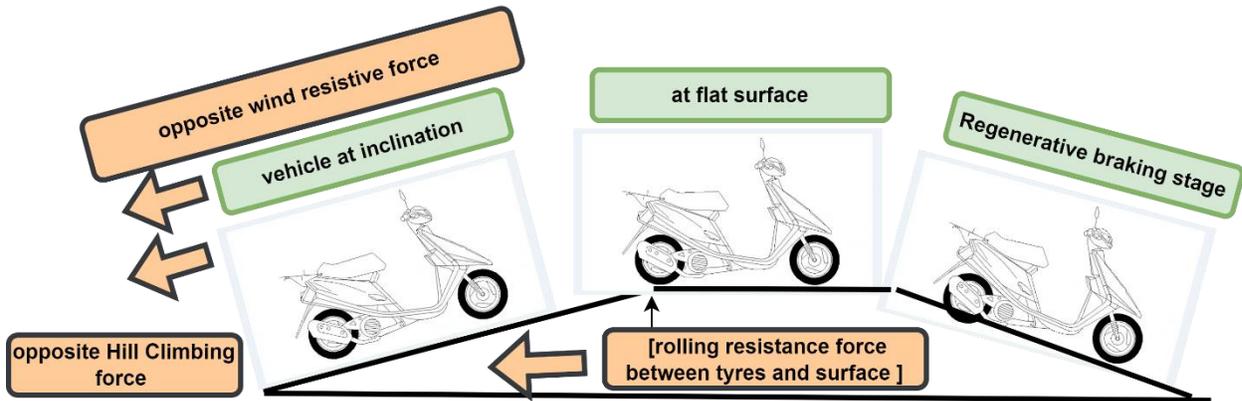


Figure 1: Figure shows the three forces which acts on a moving vehicle and at slopes vehicle can regenerate power

Aerodynamic force

When a vehicle moves than the resistance offered by the wind against the movement of the vehicle is called aerodynamic drag, this drag is directly proportional to the square of the velocity and frontal area of the vehicle. below are the formulae to compute the aerodynamic drag.

$$F_{Ad} = 0.5 \rho A C_d v^2 \dots\dots\dots (1)$$

where F_a = Aerodynamic force (N), A = Frontal area, C_u = Coefficient of drag, ρ =Air density (kg/m^3), and v = Velocity of vehicle (m/s).

Rolling resistance force

The resistive force offered due to friction between tire and road is rolling resistive force, the formulae to calculate it is given in equation below.

$$F_r = \mu mg \cos \theta \dots\dots\dots (2)$$

where F_r = Rolling resistance force (N), μ = Rolling coefficient, M = Gross vehicle weight, g = Gravitational acceleration (m/s^2) and α = Inclination angle (degrees)

Gradient force

During up-hill, down-hill, and normal road a vehicle experience a force opposing and support it, this force is known as gradient force, the force is expressed as

$$F_g = mg \sin \theta \dots\dots\dots (3)$$

where F_g = Gradient force (N)

From 1 to 3, the three forces acting on a moving vehicle are discussed, the constants used in the equations to compute the forces can be taken from the EV manufacturers. Table 3 of this paper earlier provides the values of constants of 6 Indian EV cars taken from manufacturers website. But the velocity with which the vehicle will move depends on drivers' preference and road conditions, for modelling and extracting outputs drive cycles are used as speed and road condition reference which is discussed in the next section.

Traction Force

Traction Force is the total force required on a vehicle to move with acceleration a , it is the sum of Aerodynamic force, rolling resistance force, gradient force, and inertia force. the equation for the traction force is given below were F_a = Acceleration force in (Newton) and a = Acceleration (m/s^2).

$$F_{Acc} = M * A..... (4)$$

$$F_{TF} = F_{Acc} + F_{Ad} + F_r + F_g.....(5)$$

Torque

The required torque T_{req} is the product of total resistive force F and wheel radius r given in equation below, the radius of the wheel can be taken from table 3 of this paper for reference.

$$\tau_L = F_{TF} * T_{rad} (6)$$

Power

To deliver the torque at a given speed power is required which is supplied by the motor, here the mechanical power required is Torque multiplied by angular speed. Speed of the wheels is in Km/ hr which is transformed in rpm to calculate power delivered by the motor. To provide the required output mechanical power the input electrical power is received from the battery, this is why the moving speed of the vehicle with road conditions and driver's preference is a key parameter in evaluating battery discharge per Km. Figure 2 show how all these force can be combine to evaluate power and torque required by a vehicle and figure 3 shows the structure of power flow from battery to wheel from motor to overcome the torque and power needs by the vehicle.

Electrical power (P_e) input to motor = Voltage x Current (7)

Mechanical Power (P_m) as per speed = Torque x Angular speed

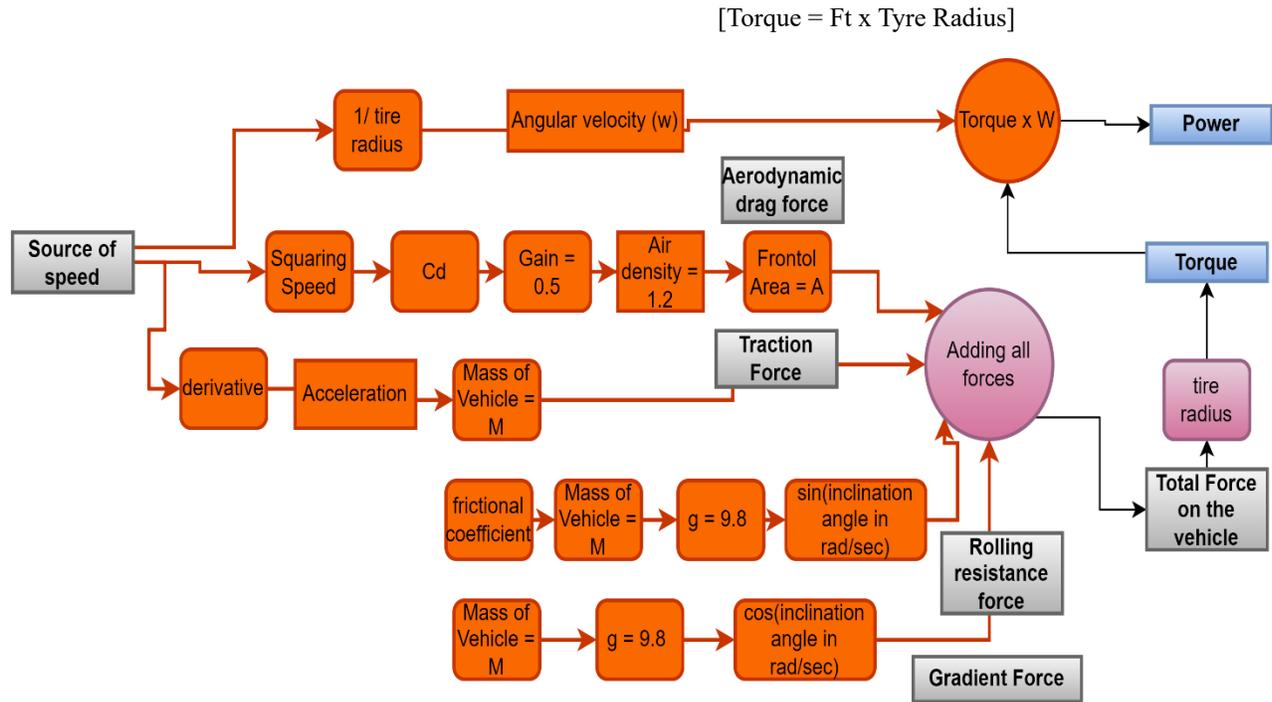


Figure 2: Modelling of forces

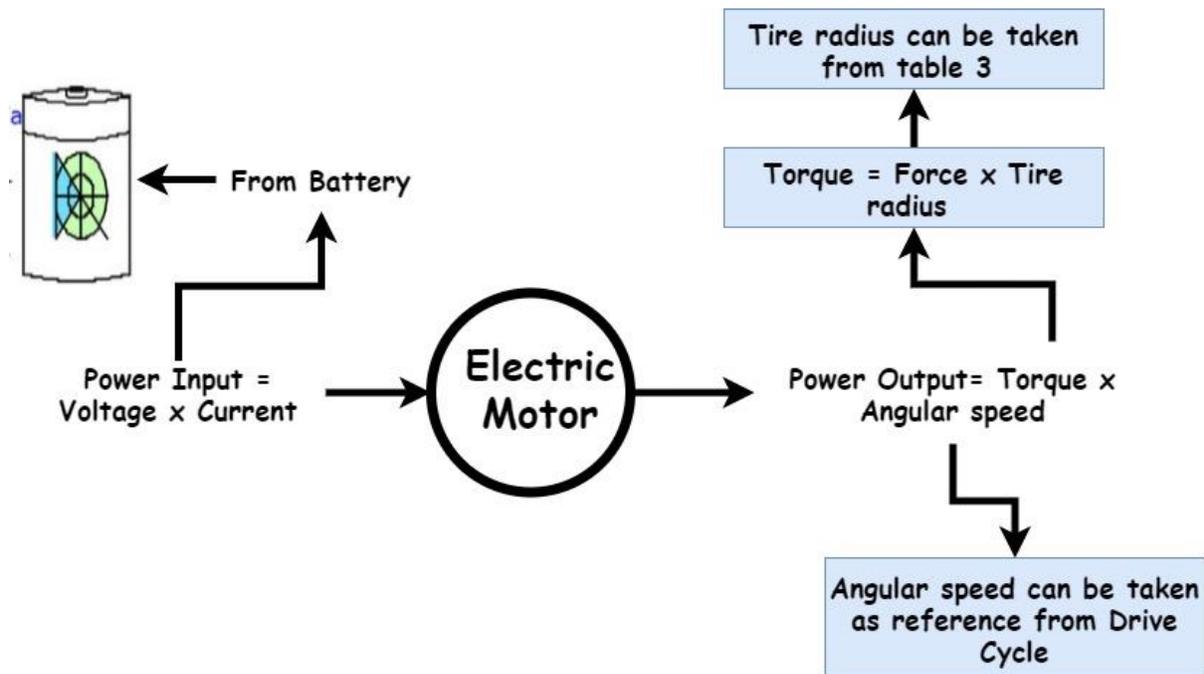


Figure 3: Compilation of Input and outputs across a motor

4. CONCLUSION

The transition towards electric mobility demands accurate and efficient methods for analyzing vehicle performance under diverse operating conditions. This review highlights the critical role of vehicle dynamic modeling as the foundation for evaluating electric vehicle (EV) torque, power, energy consumption, and thermal behavior. By simulating various drive cycles and integrating real-world data, researchers have developed advanced models that improve the accuracy of battery management systems, energy optimization strategies, and component design. The literature emphasizes that drive cycle-based simulations, combined with thermal and electrical modeling, are essential for understanding the dynamic behavior of EVs in realistic scenarios. These models not only guide component selection and system sizing but also enhance energy efficiency, range estimation, and overall vehicle reliability. In summary, vehicle modeling is not just a theoretical exercise—it is a practical and indispensable tool in the design, development, and optimization of electric vehicles. It enables researchers and manufacturers to make informed decisions, evaluate trade-offs, and push the boundaries of EV technology toward more sustainable and high-performance solutions.

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