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Performance Evaluation of Traction Motors Using Simulation Model Considering Different Driving Cycles

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Abstract

The abstract outlines the fundamental principles underlying traction motor operation, elucidating the role of these motors in converting electrical energy into mechanical motion for propelling EVs. Various types of traction motors, including DC motors, permanent magnet synchronous motors (PMSMs), induction motors, and switched reluctance motors (SRMs), are discussed, highlighting their unique features and performance attributes. In this research project we will explore the key performance metrics used to assess traction motor efficiency and effectiveness. Parameters such as torque-speed characteristics, power density, efficiency, and thermal management are analyzed in detail, emphasizing their significance in determining overall vehicle performance and range. Electric Vehicle model is simulated for each type of traction motor for same drive cycles and other vehicle parameters being constant for each simulation model and evaluating traction motor's performance by comparing their results. In this thesis, we develop both a vehicle dynamics model and a vehicle load model, taking into account various road conditions and drive cycles.

Keywords

Electric Vehicle, Traction Motor, Driving Cycle, Matlab Simulink, PMSM, Induction Motor, Switched Reluctance Motor, Urban Drive Cycle, Highway Drive Cycle

1. Introduction

Traction motors are a critical component in electric vehicles (EVs), responsible for converting electrical energy into mechanical energy to propel the vehicle. There are several types of traction motors used in EVs, each with its own advantages and applications. Here are some common types:

1.1. Permanent Magnet Synchronous Motor (PMSM)

Permanent Magnet Synchronous Motors (PMSMs) generate torque by using permanent magnets in the rotor, which interact with the magnetic field produced by the stator. They are known for their high efficiency and power density.

1.2. Induction Motor (IM)

IMs work by inducing a current in the rotor through electromagnetic induction. They do not require permanent magnets in the rotor, making them simpler and potentially cheaper to manufacture.

1.3. Switched Reluctance Motor (SRM)

SRMs operate by creating reluctance torque, which is generated when the rotor aligns itself with the stator's magnetic field due to the reluctance of the magnetic circuit. SRMs are known for their simplicity and robustness. They have fewer parts compared to other types of motors, making them potentially more reliable and easier to manufacture.

1.4. Brushless DC Motor (BLDC)

BLDC motors operate similarly to PMSMs but without the use of brushes for commutation. They rely on electronic controllers to switch the current in the stator windings. BLDC motors are known for their high efficiency and reliability. The importance of traction motors in EVs lies in their role as the primary source of propulsion. The choice of motor type can significantly impact the vehicle's performance, efficiency, and cost. Factors such as torque output, power density, efficiency, reliability, and manufacturing cost influence the selection of traction motors for different EV applications. Additionally, advancements in motor technology continue to drive improvements in EV performance, range, and overall driving experience. The rest of the paper is organized as follows. In section 2, authors have given a review of existing literature. Section 3 explains the methodology used in the work. Section 4 gives the Matlab simulation model. Section 5 explains the results identified and section 6 gives the conclusion.

2. Literature Review

Commonly, the evaluation of electric motors encompasses a blend of standard routine tests following industry benchmarks such as those set by IEEE and SAE, alongside tailored performance assessments specific to particular applications. Routine tests for industrial electric motors typically involve measuring power, current input under no-load and rated voltage conditions, and current input when the rotor is locked at rated voltage. These tests are crucial for acquiring the data needed to evaluate efficiency, power factor, starting torque, pull-up torque, breakdown torque, and rated-load temperature rise.

Industrial electric motors typically boast higher efficiencies compared to motors utilized in electric vehicles (EVs), primarily because the efficiency of these motors is gauged solely when they power their rated load. This efficiency rating disregards other operational aspects, such as the time spent by the motor in accelerating to a specific speed or coasting to a halt. For numerous industrial motor applications, the duration of acceleration and coasting is minimal, rendering these factors less crucial. However, in the context of EVs, the motor dedicates a substantial portion of its operational time to acceleration and deceleration. Consequently, when assessing the performance of traction motors, their behavior during these phases cannot be overlooked. Thus, traction motors for EVs and hybrid electric drivetrains operate within dynamic environments vastly distinct from those of industrial motors. To evaluate the performance of electric motors as propulsion systems in electric vehicles, three primary methods are currently prevalent: software-based system simulation, hardware-in-the-loop (HIL) simulation utilizing a test platform, and on-road vehicle testing. While the software-based approach is cost-effective, practical, and flexible, it lacks the realism and real-time performance offered by hardware-in-the-loop simulation and on-road vehicle testing [1-3].

Recent trends in motor research and development emphasize the exploration of more cost-effective materials for laminations and cores, aiming to circumvent the reliance on costly rare earth magnets. Efforts are underway to address this challenge through the advancement and optimization of less expensive magnet options such as Alnico and Ferrite for PM-motors. Nevertheless, enhancing the operational efficiency of PM-motors equipped with smaller and more economical magnets like Alnico and Ferrite presents another design and development hurdle. Research into materials holds the promise of substantially reducing motor losses and enhancing overall efficiency [4-7].

3. Methodology

Our methodology specifically considers longitudinal vehicle dynamics and is limited to straight-line motion, operating under the assumption that vehicle stability remains consistent across all conditions [8]. Vehicle dynamics explore how a vehicle maneuvers on a road surface, taking into account various influencing factors such as tire-road forces, aerodynamics, and gravity. Understanding these dynamics is essential for assessing the impact of the powertrain on vehicle performance, typically evaluated through simulations considering mainly 2 types of driving cycles [9-10].

3.1. Urban Driving Cycle (UDDS)

Purpose: Simulates stop-and-go urban traffic with frequent starts, stops, and idling periods.

Features: Characterized by low average speeds and frequent acceleration and deceleration.

Example: New European Driving Cycle (NEDC) Urban segment. A commonly employed driving pattern is the New European Driving Cycle (NEDC). This cycle encompasses urban driving scenarios with frequent starts and stops, as well as highway driving, providing a realistic depiction of typical driving conditions. The NEDC is characterized by a maximum speed of 120 km/h, an average speed of 33.2 km/h, a duration lasting 1184 seconds, and spanning a distance of 10.9 kms. The graphical representation of the NEDC profile is depicted in the figure below:

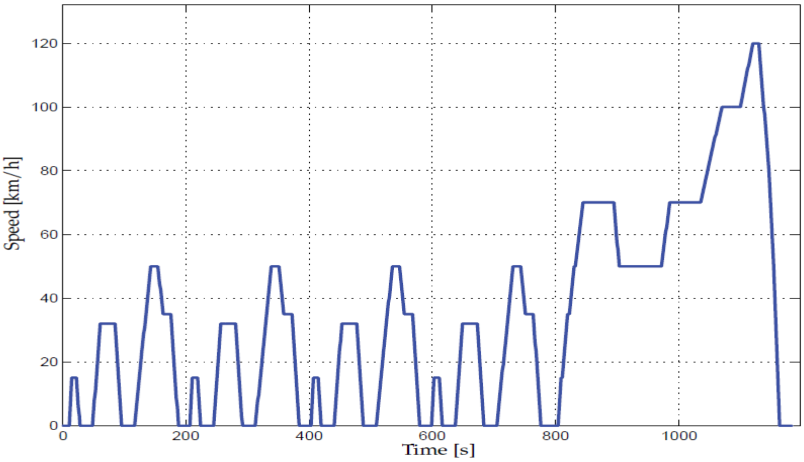


Figure 1. Speed-Time characteristics of urban driving cycle

3.2. Highway Driving Cycle (HWFET)

Purpose: Represents steady-speed driving conditions typical on highways or freeways.
Features: Higher average speeds with fewer stops and more stable driving.
Example: Highway Fuel Economy Test (HWFET).

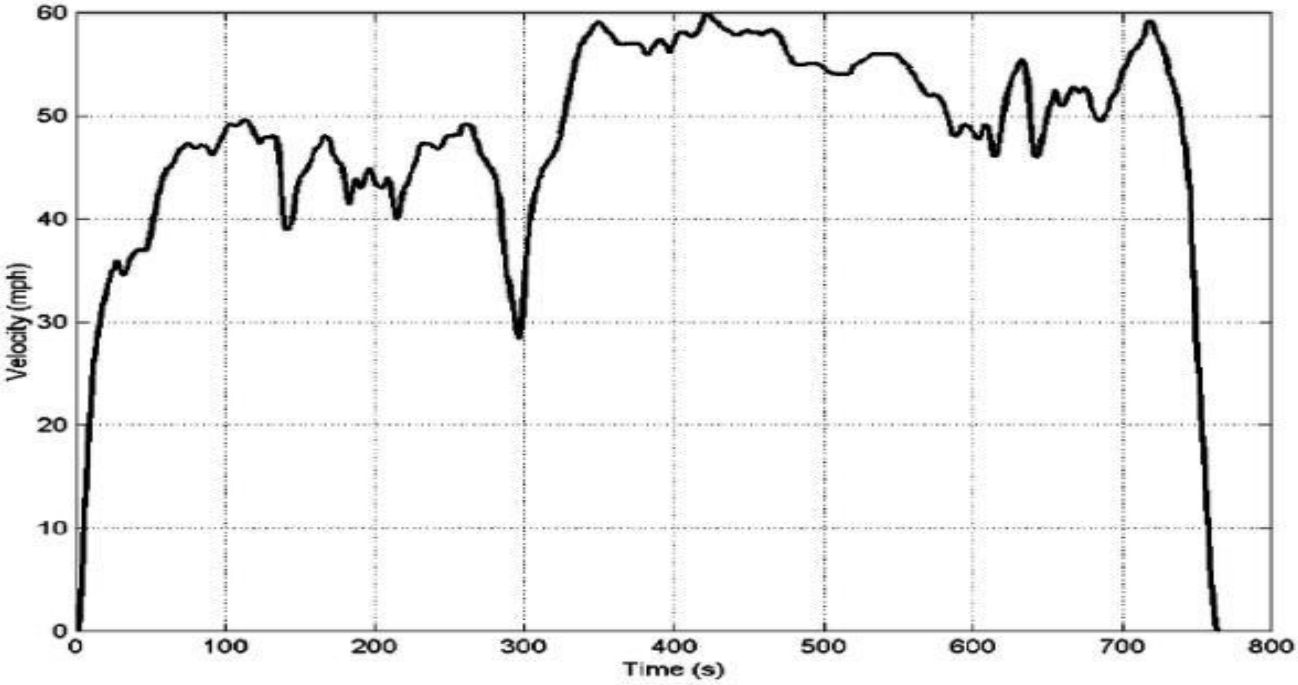


Figure 2. Speed-Time characteristics of Highway driving cycle

4. Matlab Simulation Model of EV

This paper details the steps involved in modelling and simulating high-performance Electric Vehicles (EVs) utilizing different kinds of traction motors. It starts with defining essential vehicle specifications and proceeds to create an equation-based model using MATLAB/Simulink software. The primary aim of the modelling is to assess the efficiency and performance of the traction motors. The model outcomes are then confirmed through practical tests conducted on the designated EV platform.

4.1. EV model specification and external conditions

MATLAB/Simulink software to fit specific specifications, followed by initial testing on the intended vehicle platform. This paper delves into the process and comprehensive outcomes of the simulation-based performance test results carried out on the modelled vehicle. Table 1 represents the EV model technical specifications and Table 2 represents atmospheric and surrounding conditions in which electric vehicle to be tested.

Table 1. EV model technical specifications

Description (Parameter)	Value
Curb weight	2756 kg
Motor Peak Power	250 KW
Motor Continuous Power	132 KW
Motor Peak Torque	2150 N-m
Motor Continuous Torque	685 N-m
Motor Speed (RPM)	3500
No. Of Phase	6
Inverter Max. Output Power	170 KW
Inverter Max. Output Current	350 A
Inverter Max. Electrical Frequency	750 Hz
Inverter Max. Performance Voltage	500-750 VDC
Battery Energy at 100% SOC Level	400 KWH
Rear Axle ratio	41/9
Wheel Size	295/80 R22.5, 16PR

Table 2. Atmospheric and surrounding conditions in which electric vehicle to be tested

Description (Parameter)	Value
Air density	1.23 kg/m3
Drag coefficient	0.38
Road Angle	0
Vehicle Frontal Area	4.3 m2
Air Temp.	305 K

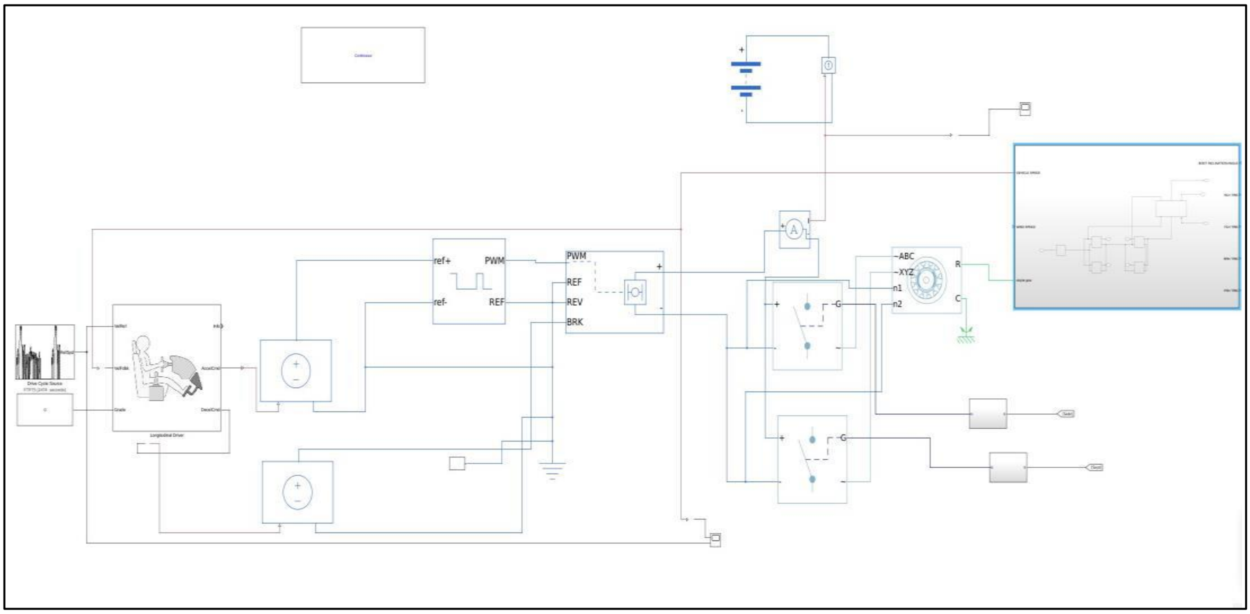


Figure 3. EV Simulation model employing PMSM motor as traction motor

4.2. EV Simulation Model with PMSM Traction Motor

The objective of the Simulink model is to emulate the behaviors of a real-world Battery Electric Vehicle (BEV) and to analyse the performance differences between lithium-ion and lead-acid batteries using data extracted from battery datasheets. For comparison the parameters included are State of Charge (SOC), vehicle range, motor torque, axle torque, and the characteristics of speed-battery discharge. Constructing the Simulink model requires a comprehensive grasp of vehicle dynamics. The model comprises several smaller functions, each contributing uniquely to the vehicle's overall operation. Here 6-phase PMSM motor with compatible power and voltage controllers are being taken to create electric vehicle simulation model.

4.3. EV Simulation Model with 3- phase Induction Motor

The objective of the Simulink model is to emulate the behaviors of a real-world Battery Electric Vehicle (BEV) and to analyse the performance differences between lithium-ion and lead-acid batteries using data extracted from battery datasheets. Key factors for comparison include State of Charge (SOC), vehicle range, motor torque, axle torque, and speed-battery discharge characteristics. Constructing the Simulink model requires a comprehensive grasp of vehicle dynamics. The model comprises several smaller functions, each contributing uniquely to the vehicle's overall operation. Here 3-phase AC Induction motor with compatible power and voltage controllers are being taken to create electric vehicle simulation model.

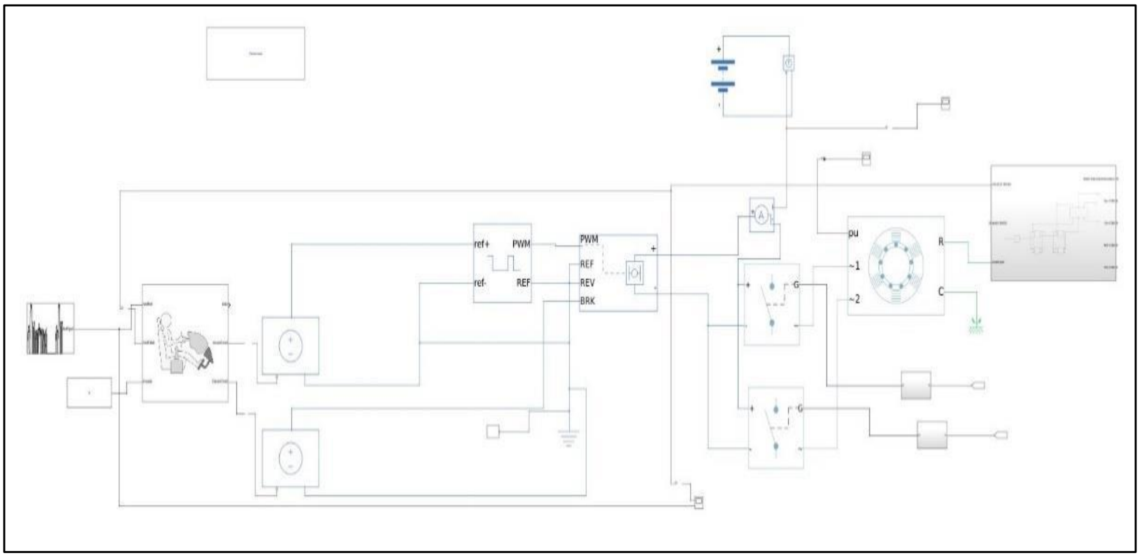


Figure 4. EV Simulation model employing 3-phase induction motor as traction motor

4.4. EV Simulation Model with Switched Reluctance Motor

The objective of the Simulink model is to emulate the behaviors of a real-world Battery Electric Vehicle (BEV) and to analyse the performance differences between lithium-ion and lead-acid batteries using data extracted from battery datasheets. Key factors for comparison include State of Charge (SOC), vehicle range, motor torque, axle torque, and speed-battery discharge characteristics. Constructing the Simulink model requires a comprehensive grasp of vehicle dynamics. The model comprises several smaller functions, each contributing uniquely to the vehicle's overall operation. Here DC input voltage based SRM motor with compatible power and voltage controllers are being taken to create electric vehicle simulation model.

4.5. EV Simulation Model with Brushless DC Motor

The objective of the Simulink model is to emulate the behaviors of a real-world Battery Electric Vehicle (BEV) and to analyse the performance differences between lithium-ion and lead-acid batteries using data extracted from battery datasheets. Key factors for comparison include State of Charge (SOC), vehicle range, motor torque, axle torque, and speed-battery discharge characteristics. Constructing the Simulink model requires a comprehensive grasp of vehicle dynamics. The model comprises several smaller functions, each contributing uniquely to the vehicle's overall operation. Here BLDC motors with compatible power and voltage controllers are being taken to create electric vehicle simulation model.

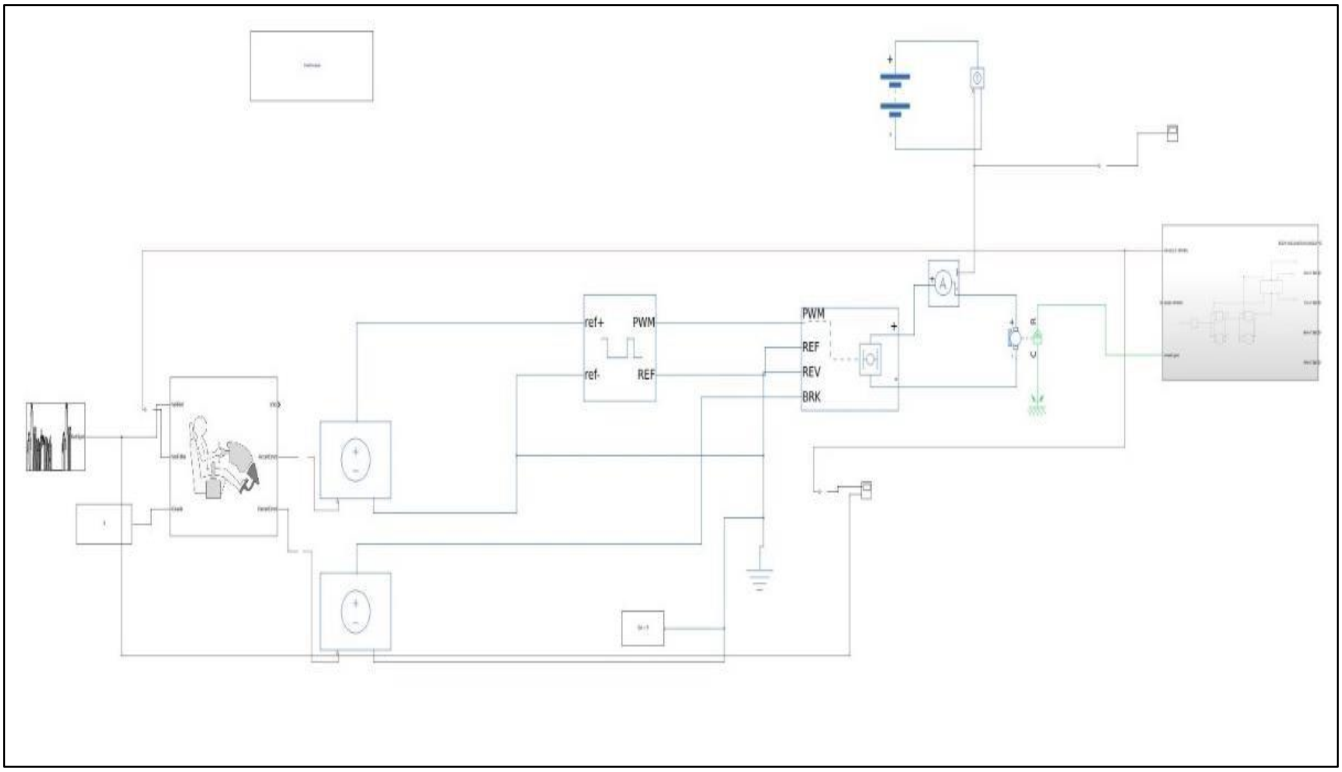
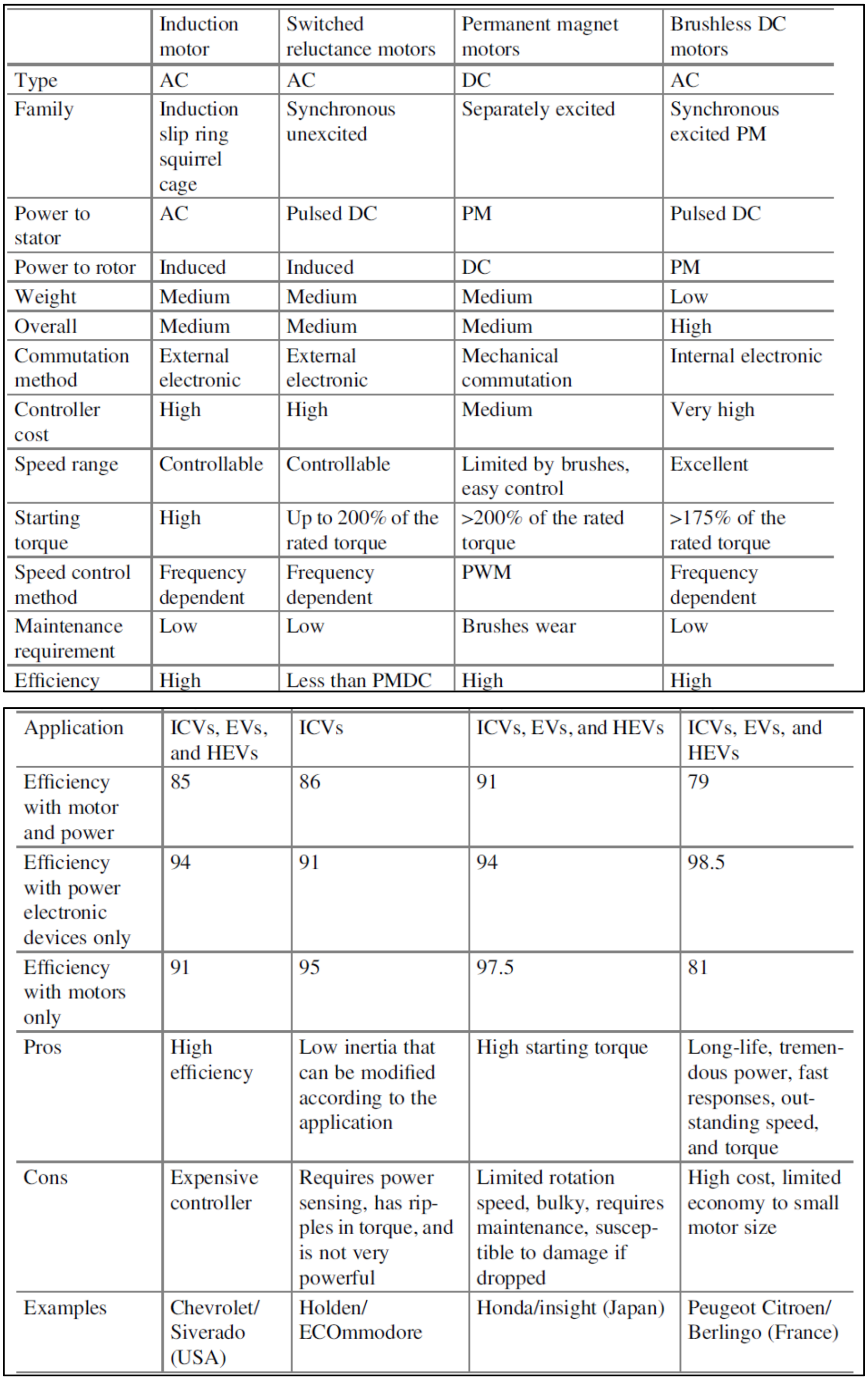


Figure 5. EV Simulation model employing brushless DC motor as traction motor

5. Results

Traction motors, essential for powering electric vehicles (EVs), come in various types, each with distinct advantages and limitations. The most common types are DC motors, induction motors, and permanent magnet synchronous motors (PMSMs). DC motors, known for their simplicity and ease of control, are less efficient and require more maintenance due to brushes and commutators. Induction motors, widely used in industrial applications, are robust and require less maintenance, offering good performance at a relatively lower cost. However, they are generally less efficient than PMSMs. PMSMs are highly efficient and provide superior torque density and performance, making them ideal for EVs, but they are more expensive due to the use of rare earth materials in the magnets. Each motor type must be carefully evaluated based on specific application requirements such as cost, efficiency, size, and control complexity to determine the best fit for a given EV design. Table 3 compares the electric motors utilized in electric vehicles, assessing their power, efficiency, and other pertinent characteristics to ascertain the most suitable electric motor for the vehicle.

Table 3. Electric motors utilized in electric vehicles, assessing their power, efficiency, and other pertinent characteristics



	Induction motor	Switched reluctance motors	Permanent magnet motors	Brushless DC motors
Type	AC	AC	DC	AC
Family	Induction slip ring squirrel cage	Synchronous unexcited	Separately excited	Synchronous excited PM
Power to stator	AC	Pulsed DC	PM	Pulsed DC
Power to rotor	Induced	Induced	DC	PM
Weight	Medium	Medium	Medium	Low
Overall	Medium	Medium	Medium	High
Commutation method	External electronic	External electronic	Mechanical commutation	Internal electronic
Controller cost	High	High	Medium	Very high
Speed range	Controllable	Controllable	Limited by brushes, easy control	Excellent
Starting torque	High	Up to 200% of the rated torque	>200% of the rated torque	>175% of the rated torque
Speed control method	Frequency dependent	Frequency dependent	PWM	Frequency dependent
Maintenance requirement	Low	Low	Brushes wear	Low
Efficiency	High	Less than PMDC	High	High
Application	ICVs, EVs, and HEVs	ICVs	ICVs, EVs, and HEVs	ICVs, EVs, and HEVs
Efficiency with motor and power	85	86	91	79
Efficiency with power electronic devices only	94	91	94	98.5
Efficiency with motors only	91	95	97.5	81
Pros	High efficiency	Low inertia that can be modified according to the application	High starting torque	Long-life, tremendous power, fast responses, outstanding speed, and torque
Cons	Expensive controller	Requires power sensing, has ripples in torque, and is not very powerful	Limited rotation speed, bulky, requires maintenance, susceptible to damage if dropped	High cost, limited economy to small motor size
Examples	Chevrolet/ Siverado (USA)	Holden/ ECOmmodore	Honda/insight (Japan)	Peugeot Citroen/ Berlingo (France)

6. Conclusion

This paper aims to analyse the various types of electric motors utilized in electric vehicles. Based on the observations made, the following conclusions are drawn regarding the different motors examined:

DC motors are challenging to control but capable of producing high torque at low speeds. However, they exhibit low efficiency, have a bulky structure, and entail significant maintenance costs. BLDC (Brushless DC) motors are compact in size, offer high efficiency, and boast advanced power density. However, they require costly control systems. Induction motors can achieve efficiencies exceeding 90%. They have a larger footprint, lower power density, and average acceleration characteristics. At lower acceleration rates, synchronous machines demonstrate greater efficiency, enhancing battery utilization and providing extended range. For applications requiring steady torque, synchronous motors are preferred. SRMs (Switched Reluctance Motors) are particularly suitable when cost is a primary consideration, as they are economical, adaptable to internal failures, and exhibit high efficiency and reliability. The choice of motor depends on the type of electric vehicle and its specific characteristics, with any of the four motors surveyed capable of delivering optimal results based on the vehicle's requirements. In conclusion we can simulate electric vehicle model employing any kind of traction motor as per our application using MATLAB Simulink software and we can analyze and compare performance results specific to our application requirements and choose wisely which traction motor will be suitable for our application.

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