

A Review Paper on Scheduling of Electric Vehicle using Different Types of Electric Motor

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Abstract

The rapid growth of electric vehicles has created a strong need for efficient scheduling strategies to enhance overall system performance and energy utilization. This paper presents a comprehensive review of scheduling approaches for electric vehicles by considering different types of electric motors, including direct current motors, brushless direct current motors, permanent magnet synchronous motors, switched reluctance motors, and induction motors. Each motor type exhibits unique operational characteristics that influence efficiency, control complexity, cost, and reliability.

The proposed review integrates motor selection with scheduling strategies based on varying load conditions, battery constraints, and real-time driving scenarios. A comparative analysis is carried out to evaluate the suitability of each motor type for electric vehicle applications. The results indicate that permanent magnet synchronous motors and brushless direct current motors provide higher efficiency and better performance, whereas switched reluctance motors and induction motors offer cost-effective and robust alternatives. Furthermore, effective scheduling plays a crucial role in improving battery lifespan, optimizing energy consumption, and ensuring reliable system operation. The study highlights that an appropriate combination of motor selection and intelligent scheduling can significantly contribute to the advancement of sustainable and energy-efficient transportation systems.

Keywords: Permanent Magnet Synchronous Motor, Brushless Direct Current Motor, Switched Reluctance Motor, Induction Motor, Electric Vehicle, Scheduling, Energy Optimization

INTRODUCTION

Electric vehicles (EVs) have developed quickly due to the growing need for environmentally friendly and sustainable transportation [1-10], [7]. EVs are thought to be a practical way to lessen pollution, reliance on fossil fuels, and greenhouse gas emissions [11-22]. The electric motor, which has a direct impact on efficiency, power delivery, and overall vehicle operation, is a crucial part of EV performance [7]. Depending on needs, EVs employ a variety of electric motor types, including DC motors, brushless

DC (BLDC) motors, permanent magnet synchronous motors (PMSM), switching reluctance motors (SRM), and induction motors [5],[7]. Regarding torque-speed profile, cost, economy, and control method, each type of motor has distinctive features [5]. Thus, choosing and planning the right motor operation becomes crucial to maximizing EV performance [22]. In this context, scheduling refers to the effective control of motor utilisation, energy consumption, and operational timing according to load demand, battery condition, and driving circumstances.

A solar-assisted induction motor-based EV drive was investigated to improve propulsion efficiency

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through soft phase conversion [1]. A solar PV-powered switched reluctance motor drive was developed and analyzed for efficient water-pumping applications [2].

EV scheduling can be enhanced by dynamically adjusting motor performance to current conditions thanks to the development of intelligent control systems and optimisation methodologies. This increases battery life and dependability in addition to improving energy efficiency (Figure 1). The development of sophisticated EV systems and environmentally friendly transportation options depends heavily on the integration of motor characteristics with intelligent scheduling techniques [22]. A comprehensive survey and comparative analysis of the characteristics of different motor drives used in electric vehicles were presented [7].

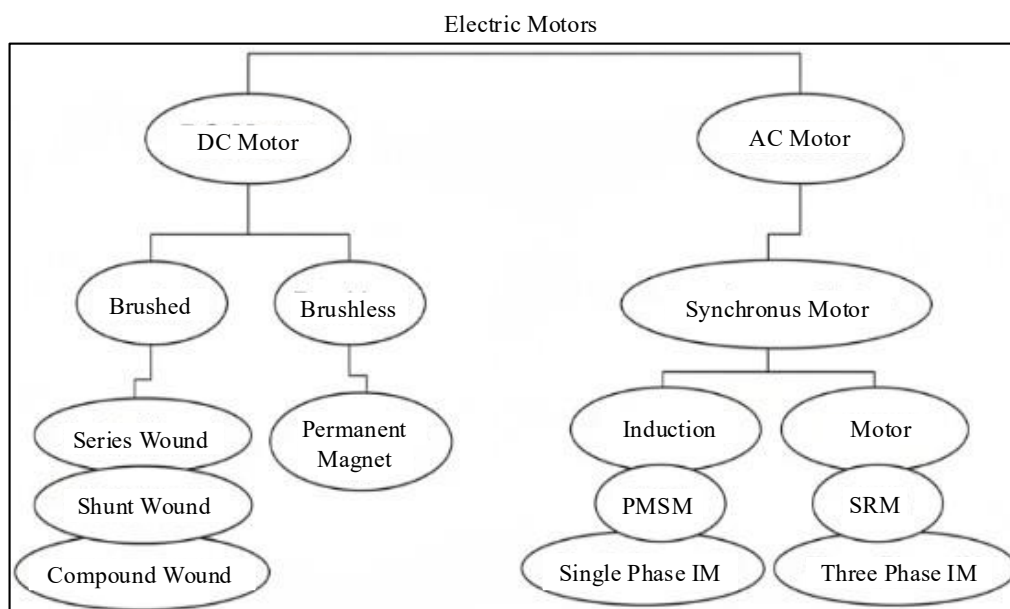


Figure 1. Different Types of Electric Motors.

CLASSIFICATION OF ELECTRIC MOTORS

DC Motor

DC motors are renowned for their high starting torque and accurate speed control. A microcontroller-based power-electronic controller was investigated for speed control of a DC motor supplied by a solar PV system [12]. They run on a direct current (DC) source. They operate on the premise that a current-carrying conductor in a magnetic field is subject to force. Cranes, lifts and electric cars are just a few of the many uses for DC motors. They are divided into two categories: brushless and brushed [22]. Voltage fluctuation makes speed control easy. But because of their brushes and commutators, conventional DC motors need greater upkeep. They are nevertheless frequently utilised in situations where variable speed control is crucial. They are appropriate for control systems because of their design, which enables seamless operation and rapid reaction. A microcontroller-based controller was employed to regulate the speed of a DC motor supplied by a solar PV system [18].

Brushed DC Motor

The stability and wheel-force characteristics of an electric vehicle equipped with a BLDC motor drive were analyzed [3]. Carbon brushes and a commutator are used in brushed DC motors to supply current to the revolving armature [11]. They are easy to control and have a straightforward design. These motors are utilised in power tools, automotive systems, and toys because of their strong starting torque [12]. But with time, brushes deteriorate and need to be maintained. They also emit sparks and electrical noise. Despite these disadvantages, their affordability and ease of use make them popular. Voltage adjustment makes it simple to manage their speed. The application and control of a BLDC motor drive for electric

vehicle propulsion were investigated [8]. A solar PV-fed Cuk converter with a VSI-controlled BLDC motor drive was proposed for improving the performance of solar-powered water-pumping systems [9]. The effectiveness of a BLDC motor-driven electric vehicle was analyzed in terms of vehicle stability and wheel-force characteristics [10]. A controller for a BLDC motor used in electric vehicle applications was developed to achieve effective motor control and propulsion performance [11].

Series Wound Motor

The field winding and armature of a series-wound DC motor are connected in series. Because of its extremely high beginning torque, it can be used in traction systems and cranes [12]. Nevertheless, speed fluctuates with load and can reach dangerously high levels when there is no load. Applications requiring consistent speed are not appropriate for these motors. Despite their strength, they must be handled carefully.

Shunt Wound Motor

The field winding and armature of a shunt wound DC motor are linked in parallel. This ensures a constant speed regardless of changes in the load [12]. Applications for these motors include conveyors and lathes. Although they have less beginning torque than series motors, they provide superb speed regulation. For consistent operation, they are dependable and stable.

Compound Wound Motor

Shunt and series windings are combined in compound wound motors [12]. High starting torque and effective speed control are balanced as a result. They are utilised in heavy machinery, presses, and elevators. These motors are appropriate for applications that need both torque and stability because of their flexible performance [23].

Brushless DC Motor

The performance of a solar-powered PMBLDC motor drive was investigated through simulation for evaluating its suitability for electric-drive applications [6]. Brushless DC (BLDC) motors use electronic controllers in place of brushes and commutators [8]. Longer lifespans, reduced maintenance, and increased efficiency are the outcomes of this. They are extensively utilised in computer fans, drones, and electric cars [3], [8]. Better speed-torque characteristics and less noise are offered by BLDC motors. Electronic control systems make them more complicated and costly. But in contemporary applications, they are greatly favoured due to their performance and dependability. The design and performance of a solar-powered BLDC motor-driven electric vehicle were investigated for renewable-energy-based transportation [17].

Permanent Magnet Motor

Field windings are replaced by permanent magnets in permanent magnet motors. A closed-loop PMSM drive supplied by photovoltaic cells was investigated for controlled-speed operation in solar water-pumping applications [13]. As a result, efficiency rises, and energy losses are decreased. They are commonly utilized in electric vehicles and small electronics due to their modest size. Due to the materials used in the magnets, these motors are more costly despite their excellent efficiency and dependability.

AC Motor

The most often used motors in both home and industrial settings are AC motors, which run on alternating current. Compared to DC motors, they are straightforward, durable, and require less upkeep [5]. Synchronous and induction motors are the two types of AC motors [5]. Fans, compressors, conveyors, and pumps all make extensive use of them. They are perfect for continuous operation because of their longevity and efficiency. Variable frequency drives (VFDs) can be used to achieve speed control, however it is more complicated than with DC motors. AC motors are prevalent in contemporary electrical systems due to their affordability and dependability [24-29].

Motor Synchronization

Synchronous motors run at a steady speed that is in sync with the frequency of the supply [5]. Unlike induction motors, they don't slip. These motors are utilised in devices like industrial drives and clocks that need accurate speed. They have great efficiency and power factor correction, but they need extra starting mechanisms.

Permanent Magnet Synchronous Motor, or PMSM

PMSM motors run synchronously and employ permanent magnets [13]. They are extensively utilised in robotics and electric cars due to their excellent efficiency [22]. They work exceptionally well, but they need sophisticated control systems. The speed-control performance of a PMSM drive supplied by photovoltaic cells was investigated for solar-powered applications [19]. The performance of photovoltaic- and battery-powered electric vehicles equipped with PMSM drives was comparatively analyzed [22].

Switched Reluctance Motor, or SRM

Magnetic reluctance is the basis for SRM motor operation [15]. They are affordable, robust, and easy to use [15]. A closed-loop PI control strategy was developed for a solar-fed switched reluctance motor drive used in water-pumping applications [14]. The suitability and characteristics of switched reluctance motor drives for electric vehicle propulsion were investigated and discussed [15]. A solar PV-fed water-pumping system employing a switched reluctance motor drive was developed and analyzed for improved pumping performance [16]. However, they need intricate control and make noise. Both EVs and industrial applications employ them. A solar PV-fed DC-load system integrating maximum power point tracking and energy storage through a bidirectional DC/DC converter was investigated [20]. A closed-loop PI control technique was investigated for a solar-fed switched reluctance motor drive intended for water-pumping applications [21].

Induction Motor (Asynchronous)

Without a direct electrical connection to the rotor, induction motors function by electromagnetic induction [1], [5]. They are strong, inexpensive, and extensively utilised in several industries [1]. Their rotor speed is somewhat slower than synchronous speed due to slip. They are very dependable and require very little upkeep. A solar-assisted induction motor drive for electric vehicles was presented with emphasis on enhanced efficiency and soft phase conversion [4].

Single Phase Induction Motor

Fans and refrigerators are examples of home appliances that employ single-phase induction motors. They are inexpensive and easy to use, but they need starting mechanisms and are less efficient.

Three Phase Induction Motor

Because of their great power and efficiency, three-phase induction motors are frequently utilised in industries. They are dependable, self-starting, and appropriate for large loads. Industrial applications are dominated by these motors.

EV ELECTRIC MOTOR TECHNOLOGIES.

The construction, control complexity, and performance characteristics of the electric motors used in EVs vary. PMSM motors, which may reach efficiency levels of up to 97%, are frequently utilized because of their great efficiency and small size [22]. Different electric motor drive technologies for HEV propulsion were comparatively evaluated in terms of their suitability for hybrid-electric vehicle applications [5]. Lightweight EV applications can benefit from the high dependability and 85–92% [3],[8] efficiency of BLDC motors. With an efficiency of 85–90%, [1] induction motors are renowned for their durability and affordability. They lessen reliance on rare-earth materials because they don't need permanent magnets. SRM motors have a straightforward design and a high fault tolerance [15], although they have torque ripple and a marginally lower efficiency (80–88%). Despite being

straightforward and affordable, brushed DC motors are less effective and require regular maintenance [11], which restricts their use in contemporary EVs.

SCHEDULING FRAMEWORK FOR EV OPERATION

The suggested scheduling system combines real-time vehicle information including speed, torque demand, and battery state of charge with motor characteristics [22]. Motors with high torque density and efficiency are chosen to reduce energy losses under high-load scenarios [13],[22], such as climbing or accelerating. In these situations, PMSM motors function better. Induction motors operate steadily and effectively during steady-state cruising when load demand is moderate. BLDC motors are more responsive and efficient when driving in urban environments with frequent start-stop cycles [3]. A switched-stator BLDC motor drive was proposed for electric vehicles to improve propulsion-system energy efficiency [24].

Because of their durable design, SRM motors are useful in challenging working conditions that demand high dependability [15]. To ensure optimal energy utilization and performance, the scheduling system continuously assesses these factors and modifies motor operation accordingly. The application of switched reluctance motor drives in electric vehicles was investigated, highlighting their potential for electric propulsion systems [25]. A solar PV-powered water-pumping system using an SRM drive was investigated for efficient utilization of photovoltaic energy in motor-drive applications [26].

ENERGY OPTIMIZATION & CONTROL STRATEGY.

Effective scheduling in EVs requires sophisticated control mechanisms. Adaptive control methods use sensor data to make real-time adjustments [22] to motor characteristics like voltage and current. To keep operations close to maximum efficiency, these systems keep an eye on load circumstances, motor temperature, and battery status. By lowering switching losses and preserving effective operating points, model predictive control and AI-based algorithms have been demonstrated to enhance scheduling performance. According to studies, these methods can save energy use by as much as 18% when compared to traditional control systems [22].

The **Table 1**, summarizes common electric vehicles and their propulsion systems. Most models, such as Tesla, Nissan, Ford, Hyundai, BMW, Audi, Porsche, and Rivian, are battery electric vehicles (BEVs) powered by lithium-ion batteries and typically use permanent magnet motors, though some use induction or other advanced motor types [27]. The Toyota Prius Prime is a hybrid that combines an electric motor with a gasoline engine, while the Toyota Mirai uses a hydrogen fuel cell to produce electricity. Overall, it shows the main types of EV systems and the technologies used to power them [28].

Table 2 compares different traction motor types used in electric vehicles—DC, induction (IM), permanent magnet synchronous (PMSM), and switched reluctance (SRM)—based on factors like power density, efficiency, controllability, reliability, maturity, and cost. PMSMs perform best in efficiency and power density but are more expensive, while induction motors offer a strong balance of performance, reliability, and low cost. SRMs are simple and reliable but less efficient and harder to control, and DC motors, though mature and easy to control, are less efficient for modern EV needs. Overall, PMSMs and induction motors are the most suitable and widely used in current electric vehicles [29].

RESULT & DISCUSSION

A comparison of various motor types under typical driving cycles reveals notable performance variations. The best efficiency and power density [13],[22] are regularly attained by PMSM-based systems, especially under high-speed circumstances. While induction motors offer a reasonably priced option with a reasonable level of efficiency, BLDC motors operate effectively in low-power applications [3]. A solar PV-powered integrated synchronous power-conversion system with multiple outputs was investigated for efficient power-management applications [23]. SRM systems are

appropriate for applications needing high endurance and exhibit exceptional reliability. Data analysis demonstrates that combining motor selection with scheduling improves overall system efficiency and lowers energy losses, increasing battery life [22] and driving range. The quantitative comparison presented in Table II provides a systematic evaluation of the major electric motor technologies used in electric vehicles. Based on the considered performance criteria, the PMSM achieves the highest scores in power density (5) and efficiency (5), indicating its suitability for applications requiring high efficiency and compact propulsion systems. The induction motor achieves high scores in power density (4.5), reliability (5), technological maturity (5), and cost/simplicity (5), demonstrating a balanced performance with advantages in robustness and economic feasibility. The DC motor obtains the highest controllability score (5) and technological maturity score (5); however, its lower power density (2.5) and efficiency (2.5) limit its suitability for modern EV propulsion. The SRM provides high reliability (5) and moderate power density (3.5), but its lower controllability score (3) and efficiency score (3.5) indicate limitations in achieving smooth and highly efficient EV operation. Overall, the comparative analysis indicates that PMSM is advantageous where efficiency and power density are the primary requirements, whereas induction motors provide a suitable compromise among performance, reliability, maturity, and cost. These findings demonstrate that motor selection should be integrated with EV scheduling according to the operating condition, load demand, and required energy efficiency.

Table 1. Common EVs & Their Propulsion Systems [27]

Vehicle Make & Model	Propulsion System Type	Electric Motor Technology	Primary Power Source
Tesla Model 3 / Model Y	BEV (Battery Electric Vehicle)	Permanent Magnet Synchronous Reluctance (Rear) & AC Induction (Front, AWD models)	Lithium-ion Battery Pack
Nissan LEAF	BEV	Permanent Magnet Synchronous Motor (PMSM)	Lithium-ion Battery Pack
Toyota Prius (Prime)	HEV / PHEV (Hybrid / Plug-in Hybrid)	Permanent Magnet Synchronous Motor (PMSM)	Lithium-ion / NiMH Battery + Gasoline Engine
Ford Mustang Mach-E	BEV	Permanent Magnet Synchronous Motor (PMSM)	Lithium-ion Battery Pack
Hyundai IONIQ 5 / Kia EV6	BEV	Permanent Magnet Synchronous Motor (PMSM)	Lithium-ion Battery Pack
BMW i4 / iX	BEV	Externally Excited Synchronous Motor (EESM)	Lithium-ion Battery Pack
Audi Q8 e-tron	BEV	Asynchronous Motor (AC Induction Motor)	Lithium-ion Battery Pack
Porsche Taycan	BEV	Permanent Magnet Synchronous Motor (PMSM)	Lithium-ion Battery Pack
Toyota Mirai	FCEV (Fuel Cell Electric Vehicle)	Permanent Magnet Synchronous Motor (PMSM)	Hydrogen Fuel Cell
Rivian R1T / R1S	BEV	Dual or Quad Permanent Magnet Motors	Lithium-ion Battery Pack

Table 2. Analysis of Traction Power Systems in Modern Electric Vehicles [29]

Characteristic	DC Motor	Induction Motor (IM)	PM Motor (PMSM)	Switched Reluctance (SRM)
Power Density	2.5	4.5	5	3.5
Efficiency	2.5	3.5	5	3.5
Controllability	5	4	4	3
Reliability	3	5	4	5
Tech Maturity	5	5	4	4
Cost/Simplicity	4	5	3	4

CONCLUSION

An extensive analysis of electric vehicle scheduling utilising various electric motor types is presented in this work. The findings show that EV performance is greatly enhanced by adaptive scheduling depending on motor parameters and operating conditions. SRM motors offer cost advantages and ruggedness, whereas PMSM motors offer the maximum efficiency. Incorporating intelligent scheduling techniques can result in increased vehicle range, decreased losses, and enhanced energy economy. Future research may concentrate on using machine learning methods for intelligent energy management and predictive scheduling. Because they are reliable, affordable, technologically advanced, and require minimal maintenance, induction motors have been recognised as the ideal option for EV applications. However, it is shown in this study that permanent magnet and brushless DC motors have higher priorities in terms of pollution and fuel consumption, such as lower pollution, lower fuel consumption, and a higher power to volume ratio, which makes them appealing in EV applications.

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