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# Traction Motor Trends for Indian Passenger EV

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**Abstract- The rapid electrification of India's four-wheeler (4W) passenger vehicle market presents unique powertrain engineering challenges, characterized by stringent cost constraints, dense urban driving conditions, and a strategic imperative to minimize reliance on imported rare-earth materials. This paper presents a comprehensive analysis of traction motor trends within the Indian electric vehicle (EV) sector, focusing on the strategic selection rationale and the resulting drivability dynamics. A critical comparative study is conducted between the currently dominant Interior Permanent Magnet Synchronous Motors (IPMSM) and the highly relevant alternative, AC Induction Motors (ACIM). Furthermore, the paper highlights how advanced dynamic control strategies specifically Field-Oriented Control (FOC) are implemented in high-power simulation environments to mitigate the inherent drivability limitations of each architecture. The findings conclude that while IPMSMs offer unmatched volumetric efficiency and low-end torque for urban commuting, ACIMs provide a vital, supply-chain-secure alternative with superior high-speed coasting dynamics. Ultimately, optimizing Indian EV powertrains requires balancing localized manufacturing capabilities with sophisticated, closed-loop motor control algorithms.**

**Keywords: Electric Vehicle Traction Motors.Interior Permanent Magnet Synchronous Motor (IPMSM), AC Induction Motor (ACIM), Synchronous Reluctance Motor (SynRM), EV trends.**

## I. INTRODUCTION

The global transition toward electric mobility is fundamentally reshaping automotive powertrain engineering. In India, this transition is uniquely acceleratedd by a combination of severe urban pollution challenges, the macroeconomic necessity to reduce crude oil dependency, and aggressive government frameworks such as the Production Linked Incentive (PLI)[1] scheme and the Electric Mobility Promotion Scheme (EMPS)[2]. For the four-wheeler (4W) passenger vehicle segment, these policies mandate high levels of localized manufacturing. Consequently, Original Equipment Manufacturers (OEMs) are compelled to design electric powertrains that not only meet global efficiency standards but are also economically viable for a highly cost-sensitive demographic. At the core of this electromechanical transformation is the traction motor, a component that directly governs the vehicle's dynamic performance, driving range, and overall manufacturing cost.

Designing traction motors for the Indian market requires navigating a distinct set of operational and environmental constraints. Unlike the standardized WLTP (Worldwide Harmonized Light Vehicles Test Procedure)[3] or EPA drive cycles, Indian real-world driving conditions often modeled alongside the Modified Indian Drive Cycle (MIDC) are characterized by dense, bumper-to-bumper urban traffic, frequent start-stop events, and relatively low average speeds. These conditions demand traction motors with exceptional low-end torque for immediate acceleration and robust thermal management systems capable of withstanding high ambient temperatures during prolonged periods of low-speed, high-load operation.[4] Furthermore, the necessity to utilize smaller, cost-effective battery packs (typically ranging from 30 kWh to 45 kWh) strictly dictates that the selected motor must operate at peak efficiency across a broad spectrum of the urban drive cycle to prevent range anxiety.

Currently, the Indian passenger EV market is dominated by Interior Permanent Magnet Synchronous Motors (IPMSM) due to their unmatched power density and high volumetric efficiency. However, the reliance on IPMSMs presents a critical strategic vulnerability: the dependence on imported rare-earth materials, specifically Neodymium (Nd) and Dysprosium (Dy).[5] The price volatility and supply chain concentration of these heavy rare-earth elements conflict directly with India's imperative for localized, cost-predictable manufacturing.[5] This economic reality has catalyzed significant research into alternative topologies, most notably AC Induction Motors (ACIM) and Synchronous Reluctance architectures, which offer absolute supply chain security at the expense of inherent electromagnetic trade-offs.

Beyond strategic and economic rationales, the selection of motor topology profoundly impacts the vehicle's "drivability" the subjective and objective measure of throttle responsiveness, torque ripple (NVH), regenerative braking predictability, and high-speed coasting dynamics. As the Indian consumer transitions from Internal Combustion Engine (ICE) vehicles to EVs, matching or exceeding traditional drivability expectations is paramount for market acceptance. Bridging the performance gaps between different motor architectures heavily relies on the implementation of advanced, closed-loop control algorithms, which manipulate stator flux linkages in real-time to optimize transient responses.

Therefore, this paper aims to critically evaluate the current trends in 4W traction motors within the Indian context. By isolating the electromechanical machine from the broader powertrain, this study conducts a rigorous comparative analysis of IPMSM and ACIM topologies. Section 2 establishes the strategic and economic rationale driving motor selection in India. Section 3 presents a detailed drivability comparative matrix, evaluating the inherent dynamic advantages and limitations of each motor. Section 4 explores how advanced dynamic control strategies, specifically Field-Oriented Control (FOC), are utilized in high-power environments to mitigate these limitations and optimize the Indian EV driving experience.

## II. EVOLUTION OF THE INDIAN EV PASSENGER MARKET AND STRATEGIC RATIONALE FOR MOTOR SELECTION

The early Indian passenger EV market was pioneered by Mahindra Electric (formerly Reva). Vehicles like the Mahindra e2o and the subsequent eVerito utilized low-voltage (48V–72V) 3-phase AC Induction Motors (ACIM) rated between 15 kW and 30 kW. The selection of ACIMs during this period was primarily driven by their robust, low-cost architecture, absence of expensive rare-earth magnets, and ease of manufacturing. However, these early ACIMs suffered from lower efficiencies at higher speeds and required bulky packaging, limiting vehicle range and top-end drivability.

The paradigm shifted dramatically with the introduction of high-voltage (300V+) architectures, led predominantly by Tata Motors' "Ziptron" technology (powering the Nexon EV, Tiago EV, and Punch EV), alongside offerings from MG Motor (ZS EV) and Mahindra (XUV400). [7],[8],[9].To deliver a consumer-acceptable range of over 250 km from relatively small battery packs (30 kWh to 40 kWh), OEMs required motors with peak efficiencies exceeding 93%. Consequently, the industry pivoted almost entirely to IPMSMs. Rated typically between 55 kW and 110 kW, these IPMSMs provided instantaneous torque response (enhancing urban drivability) and exceptional power-to-weight ratios, allowing them to be packaged seamlessly into vehicle architectures originally designed for ICE powertrains. While IPMSMs are widely utilized in the Indian 4W segment, their broad adoption presents certain supply chain considerations.

Given the high ambient temperatures during Indian summers, traction motors can experience internal operating temperatures nearing 150°C. To mitigate the risk of thermal demagnetization in Neodymium-Iron-Boron (NdFeB) magnets under these conditions, it is generally necessary to add heavy rare-earth elements such as Dysprosium (Dy) or Terbium (Tb).As domestic processing capabilities for these specific heavy rare-earth metals are still developing, the industry relies largely on global supply chains. With federal policies increasingly encouraging localized manufacturing, fluctuating costs for materials like Dysprosium can impact the overall production economics of passenger EVs.These supply-chain and economic factors have prompted the industry to explore alternative motor topologies.

Although IPMSM remains a standard choice for optimizing range within given battery capacities, automotive manufacturers and suppliers are assessing the viability of advanced AC Induction Motors (ACIM) and Synchronous Reluctance Motors (SynRM) for future platforms. These alternatives offer reduced reliance on rare-earth materials and potentially favorable high-speed coasting dynamics. However, achieving drivability and efficiency levels comparable to IPMSMs generally requires the implementation of advanced closed-loop control algorithms

TABLE 1. EV Trend in India from Major OEMs.

| Make | Model | SOS | Battery (kWh) | Range (km) | Motor Type | Motor Rating |
|---|---|---|---|---|---|---|
| Tata Motors | Tiago.ev | Sep-22 | 19.2 / 24 | 223 / 293 | Single PMSM | 45 / 55 kW |
| Tata Motors | Tigor.ev | Aug-21 | 26 | 315 | Single PMSM | 55 kW |
| Tata Motors | Nexon.ev (Prime/Max) | Jan-20 | 30.2 / 40.5 | 312 / 437 | Single PMSM | 95 / 105 kW |
| Tata Motors | Nexon.ev (Facelift) | Sep-23 | 30 / 45 | 275 / 489 | Single PMSM | 95 / 110 kW |
| Tata Motors | Punch.ev | Jan-24 | 25 / 35 | 315 / 421 | Single PMSM | 60 / 90 kW |
| Tata Motors | Curvv.ev | Aug-24 | 45 / 55 | 502 / 585 | Single PMSM | 110 kW |
| Tata Motors | Harrier.ev (RWD) | Jun-25 | 65 / 75 | Up to 627 | Single PMSM | 175 kW |
| Tata Motors | Harrier.ev (QWD/AWD) | Jun-25 | 75 | 622 | Dual PMSM (Front + Rear) | 116 kW (Front) + 175 kW (Rear)Combined: 291 kW |
| Mahindra REVA | REVAi (G-Wiz) | 2001 | 7.2 (Lead-acid) | 80 | DC Series Motor | 13 kW |
| Mahindra REVA | NXR / e2o | Mar-13 | 10.8 | 120 | 3-Phase AC Induction Motor | 19 kW |
| Mahindra Electric | e2o Plus | Oct-16 | 15 | 140 | 3-Phase AC Induction Motor | 19 kW |
| Mahindra Electric | eVerito | Jun-16 | 21.2 | 18 | 3-Phase AC Induction Motor | 31 kW |
| Mahindra | XUV400 EV | Jan-23 | 34.5 / 39.4 | 375 / 456 | Permanent Magnet Synchronous Motor (PMSM) | 110 kW |
| Mahindra | BE 6 | Nov-24 | 59 / 79 | 557 / 682 | Permanent Magnet Synchronous Motor (PMSM) | 169 / 210 kW |
| Mahindra | XEV 9e | Nov-24 | 59 / 79 | 542 / 656 | Permanent Magnet Synchronous Motor (PMSM) | 169 /210 kW |
| Hyundai | Kona Electric | Jul-19 | 39.2 | 452 | Permanent Magnet Synchronous Motor (PMSM) | 100 kW |
| Hyundai | Ioniq 5 | Jan-23 | 72.6 | 631 | Permanent Magnet Synchronous Motor (PMSM) | 100 kW |
| Hyundai | Creta Electric | Jan-25 | 42 / 51.4 | 390 / 473 | Permanent Magnet Synchronous Motor (PMSM) | 98 kW / 126 kW |

| | | | | | | |
|---|---|---|---|---|---|---|
| MG | ZS EV | Jan-20 | 50.3 | 46 | Permanent Magnet Synchronous Motor (PMSM) | 130 kW |
| MG | Comet EV | Apr-23 | 17.3 | 230 | Permanent Magnet Synchronous Motor (PMSM) | 31 kW |
| MG | Windsor EV | Sep-24 | 38 | 332 | Permanent Magnet Synchronous Motor (PMSM) | 99 kW |
| MG | Windsor EV Pro | May-25 | 52.9 | 449 | Permanent Magnet Synchronous Motor (PMSM) | 100 kW |
| Maruti Suzuki | e Vitara FWD | Feb-26 | 49 / 61 | 500 | Permanent Magnet Synchronous Motor (PMSM) | 105 kW / 128 kW |
| Maruti Suzuki | e Vitara AWD (AllGrip-e) | Feb-26 | 61 | 500 | Dual PMSM | 134 kW + 135 kW |

Table 2 : Motor trend evolution in Indian EV markets

| Period | Dominant Motor Technology | Representative Vehicles |
|---|---|---|
| 2001–2012 | DC Series Motor | REVA |
| 2013–2019 | AC Induction Motor | Mahindra e2o, eVerito |
| 2019–Present | PMSM | Tata, Hyundai, MG, Kia, Maruti |
| 2024–Present | Dual PMSM / Mixed Motor AWD | Harrier.ev AWD, EV6 AWD, BYD Seal AWD |

# III. EXPECTATIONS AND OPERATIONAL REQUIREMENTS OF EV TRACTION MOTORS

The engineering requirements for automotive traction motors differ fundamentally from those of standard industrial electric motors. Stationary industrial motors generally operate at steady, continuous speeds under predictable load conditions, drawing power from a virtually infinite electrical grid in relatively controlled environments. In contrast, traction motors for four-wheeler (4W) passenger vehicles are subjected to highly dynamic drive cycles, frequent start-stop events, and significant load transients. According to the analysis of advanced automobile traction technologies, EV motors are constrained not only by standard current and voltage limitations but also by the specific discharge capabilities of the finite onboard energy source. Consequently, these motors must be designed to meet a stringent and multi-objective set of operational criteria.[10]

### 1. Dynamic Torque-Speed Envelope

The dynamic performance of a passenger electric vehicle is primarily evaluated by its starting acceleration, passing ability, gradeability, and maximum attainable speed. Unlike traditional internal combustion engines, traction motors dictate this performance entirely through their specific torque and power characteristics across the speed spectrum. An optimal EV traction motor must deliver a high instantaneous torque at low speeds to overcome static inertia for rapid starting and steep climbing. As the vehicle accelerates, the motor must transition into a wide constant power region to sustain high speeds for highway cruising.

Ideally, extending this constant power region as much as possible is desirable, but doing so introduces significant system level conflicts. Expanding the constant power ratio effectively reduces the peak power rating required for initial acceleration. However, this extension conversely demands a much higher rated shaft torque at the base speed. To support this elevated flux and torque, the motor requires greater amounts of active materials like copper and iron, which inherently increases the physical size, volume, and cost of the machine. Furthermore, an overly extended constant power region can noticeably degrade the passing performance of the vehicle at higher speeds.

To resolve these conflicting requirements and downsize the motor, engineers focus on increasing the maximum rotational speed of the machine. A higher maximum speed allows the use of steeper reduction gear ratios, which multiplies the shaft torque at the wheels while keeping the motor physically compact. This approach lowers the motor's moment of inertia and improves the transient torque response. However, the maximum motor speed cannot be increased indefinitely, as it is strictly bounded by transmission mechanical limits, bearing friction, and overall drivetrain costs. Consequently, designing the torque-speed envelope requires a precise optimization of the base speed, the field-weakening range, and the gear ratio to meet the demanding acceleration and efficiency targets of the Indian urban drive cycle.

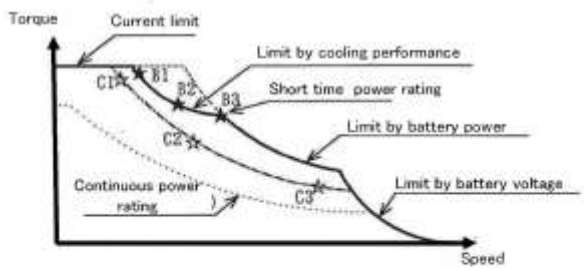


Figure 1 Characteristics of torque-speed envelop [11]

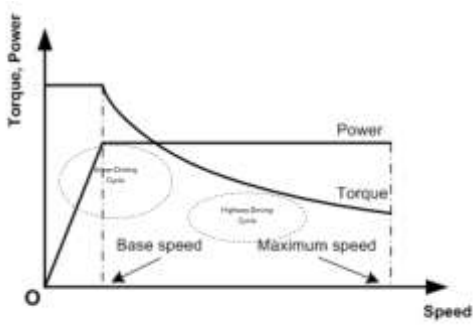


Figure 2 Ideal Torque-Power / Speed characteristics of EV traction Motor [12].

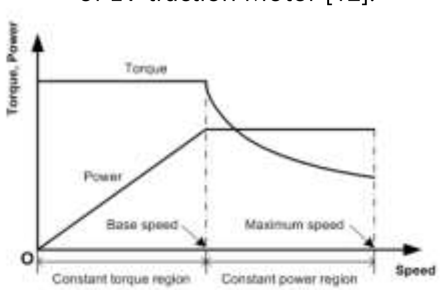


Figure 3 Typical industrial Electrical Motor Drive characteristics [12].

## 2. Volumetric and Gravimetric Power Density

Packaging constraints within a passenger car chassis are very tight. Traction motors must be miniaturized and lightweight to integrate effectively into the vehicle architecture. High gravimetric (kW/kg) and volumetric (kW/L) power densities are critical expectations, directly contributing to overall vehicle weight reduction and improved energy efficiency. Compared to traditional motors, selecting architectures with inherently high power density is essential to offset the weight penalty of the onboard battery pack.[13]

## 3. Broad-Map Efficiency

While industrial motors are typically optimized for peak efficiency at a single rated operating point, EV traction motors must maintain high efficiency across a broad operating map. Urban driving involves continuously shifting operating points (low-speed/high-torque during acceleration, high-speed/low-torque during cruising). Minimizing both copper losses at low speeds and iron losses at high speeds is essential to maximize the driving range extracted from the battery pack. Furthermore, achieving peak efficiencies exceeding 95% across a wide operational spectrum is now a foundational requirement for modern electric powertrains.

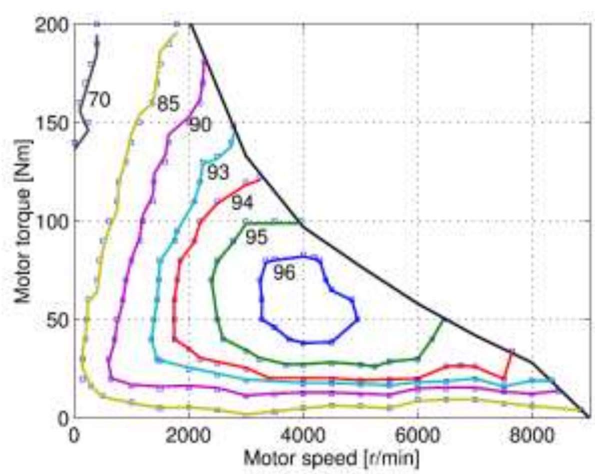


Figure 4 Typical efficiency contour curve of EV traction motor.[14]

## 4. Noise, Vibration, and Harshness (NVH) Performance

Without the masking effect of a traditional internal combustion engine, the acoustic profile of an electric motor becomes highly prominent in the passenger cabin. Traction motors are expected to operate with minimal torque ripple, low core vibration, and reduced electromagnetic noise radiation. High-frequency whining generated by airgap harmonics or inverter switching must be actively suppressed. This is increasingly achieved through careful electromagnetic design modifications, such as implementing continuous or step-skewed rotors, optimizing flux barriers, and employing advanced structural damping.[15]

## IV. TOPOLOGIES, PERFORMANCE CHARACTERISTICS, AND CONTROL STRATEGIES OF EV Traction Motors.

### 1. AC Induction Motors (ACIM)

The Induction Motor (IM) remains a highly relevant candidate for electric propulsion in four-wheeler passenger vehicles due to its structural robustness, reliability, and cost-effectiveness. According to Electric Motor Drive Selection Issues for HEV Propulsion Systems: A Comparative Study, the cage induction motor is considered a mature technology capable of operating in the demanding environments inherent to automotive traction. The operating principle relies on electromagnetic induction, where stator windings generate a rotating magnetic field that induces currents in the squirrel-cage rotor. The interaction between this rotor current and the stator field creates the necessary electromagnetic torque. Unlike permanent magnet topologies, induction motors do not require rare-earth magnets, which simplifies the supply chain and enhances thermal stability in high-ambient-temperature operating environments.

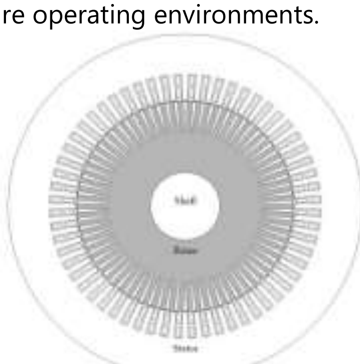

Figure 5 Cross section view of Tesla Model S Induction Motor [16]

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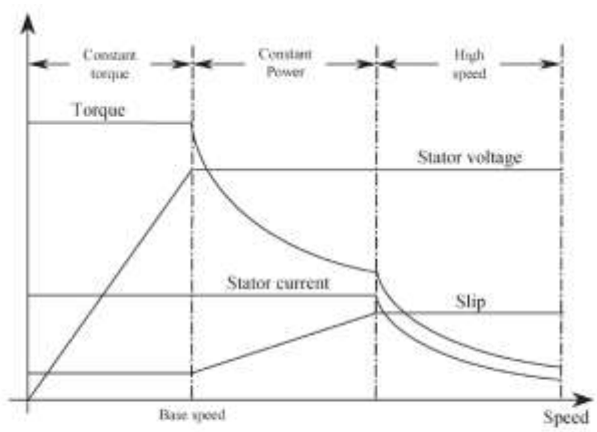


Figure 6 Typical ACIM Characteristics [19]

From a drivability perspective, the induction motor provides a smooth, linear torque delivery characteristic. The inherent slip between the rotor speed and the rotating magnetic field acts as a mechanical damper, smoothing the transmission of torque and reducing sensitivity to sudden pedal inputs. However, this topology experiences a transient delay in torque production because the rotor flux cannot be altered instantaneously. To achieve the dynamic response required for modern passenger EVs, manufacturers utilize Field-Oriented Control (FOC). By applying mathematical coordinate transformations, FOC decouples the stator current into torque-producing and flux-producing components. This allows the induction motor to mimic the dynamic precision of a separately excited

DC motor. Recent technological advancements, such as the implementation of multi-phase pole-changing drives and dual-inverter architectures, are increasingly used to extend the constant-power speed range and mitigate the breakdown torque limitations, thereby ensuring competitive performance for 4W highway cruising and urban acceleration.[17],[18]. Induction motor as traction motor is not in trend nowadays however Renault/Kangoo (France) , Chevrolet/Silverado (USA), DaimlerChrysler/Durango (Germany/USA), BMW/X5 (Germany) runs on Induction motor. [19]. In India an EV version of Tata Nano also onboarded Induction motor. [23]

## 2. Interior Permanent Magnet Synchronous Motors IPMSM

The Interior Permanent Magnet Synchronous Motor (IPMSM) currently represents the industry standard for modern four-wheeler passenger electric vehicles. Unlike surface-mounted topologies, the IPMSM features permanent magnets embedded deep within the steel laminations of the rotor. This buried configuration serves a crucial dual purpose in automotive applications. First, it physically shields and secures the magnets against extreme centrifugal forces during high-speed rotation. Second, it creates magnetic anisotropy within the rotor, meaning the magnetic inductances along the direct and quadrature axes are unequal. As a result, the IPMSM generates its total electromagnetic torque through a combination of traditional magnetic alignment torque and reluctance torque, which significantly maximizes the overall volumetric and gravimetric power density of the machine.[19]

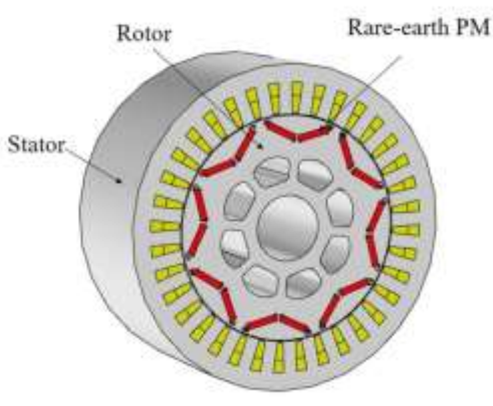


Figure7 Typical construction of IPMSM [20]

Permanent magnet motors inherently possess a limited constant power operational range. To overcome this limitation and extend the operating speed, engineers utilize conduction angle control within the power converter. By precisely adjusting the switching duration at speeds exceeding the base speed, the operational range can be extended to three or four times the base speed. Despite the advantages of this control strategy, the topology faces a significant technical limitation regarding magnetic stability. Exposure to excessive thermal loads or intense armature reaction currents creates a risk of irreversible demagnetization, which can permanently impair motor performance.

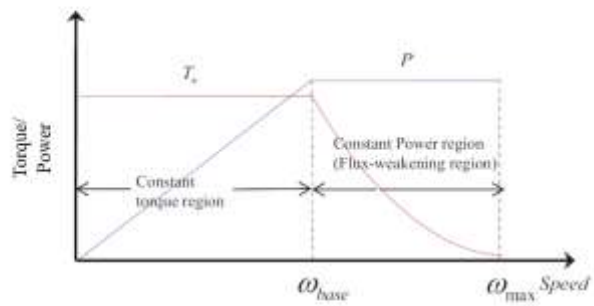


Figure 8 Typical IPMSM characteristics [21]

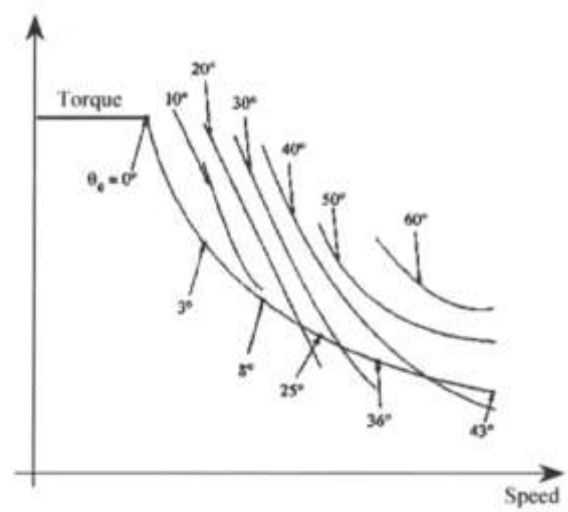


Figure 9 IPMSM characteristics with conduction angle control

The IPMSM is currently the leading choice for passenger electric vehicles in India. It offers the right balance of efficiency and power for typical Indian driving conditions. Although its dependence on rare-earth magnets makes it costly and sensitive to global supply chain changes, it remains the standard for performance. Engineers are currently using better design methods and smarter control software to make these motors more reliable. While the industry investigates cheaper alternatives, the IPMSM continues to be the most practical solution for meeting the current demands of the Indian electric vehicle market.

### 3. Synchronous Reluctance Motors (SynRM)

The Synchronous Reluctance Motor (SynRM) is gaining attention in the electric vehicle market as a promising bridge between the high efficiency of permanent magnet motors and the low cost of induction motors. The stator of a synchronous reluctance motor (SynRM) is structurally similar to that of a conventional induction motor. However, unlike an induction motor, the SynRM rotor consists solely of laminated silicon steel sheets and does not contain any winding or permanent magnets. These laminations are specially shaped with air cavities that act as magnetic flux barriers. The axis along which these flux barriers are oriented is known as the quadrature (q) axis, whereas the direction containing a continuous magnetic path through the silicon steel laminations is referred to as the direct (d) axis.

The stator windings of the SynRM are supplied with a three-phase AC source, generating a rotating magnetic field. As the magnetic field rotates, the rotor continuously aligns itself with the position of minimum magnetic reluctance. For example, when the first phase reaches its peak voltage, the rotor aligns with the corresponding direct axis because it provides the lowest reluctance path (Position A), while the reluctance along the other phase axes remains significantly higher. As the second phase reaches its maximum voltage and the first phase weakens, the rotor shifts to align with the second phase, which now offers the minimum reluctance path. This process repeats sequentially for the third phase and subsequent cycles, enabling the rotor to follow the rotating magnetic field at synchronous speed.[24]

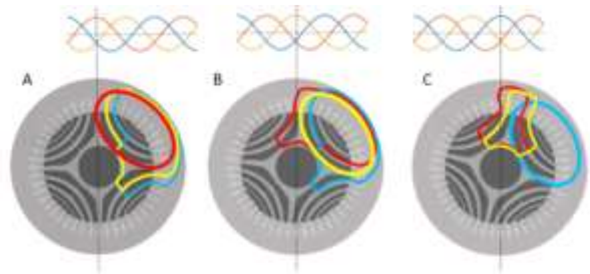

Figure 10 SynRM Flow of Flux [24]

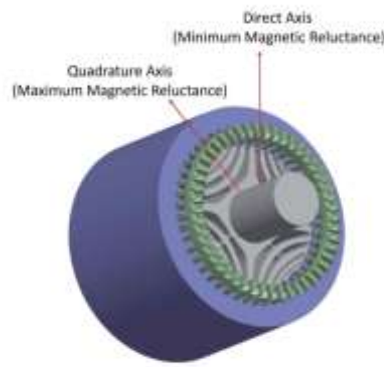

Figure 11 Syn RM construction

The SynRM offers a torque-speed profile similar to the IPMSM, providing robust constant torque at low speeds for vehicle acceleration. Its major advantage lies in its high-speed performance. Since the rotor contains no magnets, it generates zero back-EMF at high rotational speeds. This feature allows the motor to enter a very deep constant power region and enables drag-free coasting at high speeds, which can improve highway efficiency. However, a pure SynRM inherently possesses a lower power factor compared to permanent magnet machines. This usually requires an oversized inverter to handle the higher reactive power, which can be a drawback in cost-sensitive Indian vehicle platforms.

Achieving the smooth, responsive drivability required for passenger EVs is a challenge for SynRM due to its non-linear electromagnetic characteristics. Manufacturers typically implement Field-Oriented Control (FOC) to manage the motor. Unlike the IPMSM, where the control logic is relatively stable, the SynRM control algorithm must account for the highly non-linear relationship between current and inductance as the rotor position changes.To mitigate the power factor limitations, current trends in the

Indian EV market are leaning toward the Permanent Magnet Assisted Synchronous Reluctance Motor (PMa-SynRM). By inserting small, cost-effective ferrite magnets into the rotor flux barriers, engineers can significantly boost the power factor and torque density without the volatility of heavy rare-earth supply chains. This hybrid topology requires more complex FOC algorithms, as the controller must dynamically balance the reluctance torque with the added magnetic torque across all operating points. As manufacturers refine these control strategies, the SynRM and its hybrid variants are becoming a primary focus for next-generation, rare-earth-independent EV powertrains.

## V. COMPARATIVE ANALYSIS ACROSS KEY DIMENSIONS

### 1. Efficiency and Power Density

The IPMSM represents the benchmark for power density and efficiency. By embedding high-energy permanent magnets directly within the rotor core, the IPMSM minimizes rotor losses and provides exceptional torque-to-weight ratios. The SynRM achieves intermediate performance, utilizing pure reluctance torque to deliver respectable efficiency without the burden of rotor winding losses, though its overall power factor is lower. Conversely, the IM scores lower because it relies on electromagnetic induction, which generates continuous resistive losses within the rotor cage, thereby lowering overall drive-cycle efficiency.

### 2. Thermal Stability and Reliability

The IM and SynRM share the highest ratings for both thermal stability and structural reliability. Lacking permanent magnets, both rotors are immune to irreversible thermal demagnetization. This allows them to safely withstand high operating temperatures and temporary overload conditions. The IPMSM remains highly susceptible to magnet degradation at elevated temperatures, requiring complex liquid or oil cooling architectures to protect the rotor assembly.

### 3. Ease of Control

The induction motor (IM) benefits from decades of research and industrial implementation, resulting in highly mature field-oriented control (FOC) techniques. However, high-performance IM drives require accurate rotor flux and slip estimation, particularly in sensorless operation. Interior permanent magnet synchronous motors (IPMSMs) employ well-established FOC algorithms but additionally require Maximum Torque Per Ampere (MTPA), flux-weakening, and, in some applications, Maximum Torque Per Voltage (MTPV) control to achieve optimal efficiency over a wide speed range. Synchronous reluctance motors (SynRMs) generally present the greatest control challenge because their torque production depends strongly on nonlinear, current-dependent d-axis and q-axis inductances, magnetic saturation, and cross-saturation effects. Consequently, high-performance SynRM drives often incorporate parameter estimation, compensation algorithms, and lookup tables to achieve optimal torque, efficiency, and dynamic response.

### 4. Noise, Vibration, and Harshness (NVH)

The induction motor (IM) generally exhibits excellent NVH characteristics owing to its smooth squirrel-cage rotor and the inherent electromagnetic damping associated with rotor slip, which helps attenuate torque transients. Interior permanent magnet synchronous motors (IPMSMs) inherently produce cogging torque due to the interaction between rotor magnets and stator slots; however, this effect is substantially mitigated in modern traction motors through rotor skewing, optimized magnet geometry, and advanced control algorithms. Synchronous reluctance motors (SynRMs) are comparatively more susceptible to torque ripple and acoustic noise because their salient rotor geometry and flux barriers generate stronger radial magnetic force harmonics. Nevertheless, recent advances in rotor optimization and control techniques have significantly improved the NVH performance of SynRMs, making them increasingly suitable for electric vehicle traction applications.

### 5. Manufacturing Cost (Economic Viability)

From a motor manufacturing perspective, the synchronous reluctance motor (SynRM) offers the lowest material cost because its rotor consists solely of laminated electrical steel and contains neither permanent magnets nor rotor windings. The induction motor (IM) is also highly economical due to its mature manufacturing processes and the use of conventional materials such as electrical steel and copper (or aluminum). In contrast, the interior permanent magnet synchronous motor (IPMSM) generally has the highest manufacturing cost owing to its reliance on rare-earth permanent magnets, whose prices are subject to significant supply-chain and market volatility. However, when evaluating the complete electric powertrain, the higher efficiency and power density of IPMSMs can partially offset their higher motor manufacturing cost by enabling reductions in battery capacity, cooling requirements, and drivetrain size.

TABLE 3: SCORE CARD

| Criterion | ACIM | IPMSM | SynRM |
|---|---|---|---|
| Efficiency | 3 | 5 | 4 |
| Power Density | 3 | 5 | 4 |
| Thermal Stability | 5 | 3 | 4 |
| Reliability | 4 | 3 | 4 |
| Ease of Control | 3 | 4 | 2 |
| NVH | 4 | 4 | 3 |
| Manufacturing Cost | 3 | 1 | 5 |

Figure 5 Comparison of various EV traction motor topologies.

## VI. CONCLUSION AND FUTURE TRENDS

The selection of the optimal electric traction motor topology for passenger electric vehicles remains a multi-dimensional optimization problem. There is no single machine design that completely excels across all operational, financial, and mechanical requirements. In the context of the Indian passenger electric vehicle market, traction motor selection is heavily driven by a balance of operating efficiency and driving range with optimal cost.

The highly efficient and power-dense Interior Permanent Magnet Synchronous Motor (IPMSM) has largely phased out the traditional Induction Motor (IM) as the dominant trend for mainstream Indian passenger EVs. Meanwhile, the Synchronous Reluctance Motor (SynRM) remains restricted to high-end premium vehicles rather than the mass market. Although the SynRM scores a highly favorable 5 in manufacturing cost due to its magnet-free rotor design, its low ease of control and moderate NVH require highly sophisticated and expensive inverter controllers. For the highly cost-savvy Indian consumer base, the added system-level expense of these advanced electronics completely cancels out the motor's raw material savings, keeping pure SynRM technology out of the budget-friendly mass market segments for the foreseeable future.

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