



# A Review Paper on Electric Vehicle Power Electronics

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**Abstract-** The automotive industry is undergoing a pivotal transformation as electric vehicles (EVs) shift from traditional 400V Silicon-based systems toward high-efficiency 800V architectures. While Silicon IGBTs have long been the industry standard due to their cost-effectiveness and maturity, they face physical limits regarding switching speeds and heat. This paper explores the transition to Wide-Bandgap (WBG) materials like Silicon Carbide (SiC) and Gallium Nitride (GaN). These materials enable faster charging, increased driving range, and more compact designs. Despite challenges like high material costs and manufacturing complexities, WBG semiconductors are essential for the next generation of high-performance, zero-emission transportation.

**Keywords:** Electric Vehicles (EVs), Power Electronics, DC-DC Converters, Inverters, Wide-Bandgap Semiconductors.

## I. INTRODUCTION

The global shift toward vehicle electrification is fundamentally reshaping the automotive industry, fueled by ambitious international policies aiming for zero-emission sales by 2040 and a surge in market penetration that saw over 14 million EVs sold in 2023 alone.

As major manufacturers like Tesla and BYD engage in aggressive price competition to secure market share, the industry is under immense pressure to innovate within the powertrain and battery sectors to deliver high performance at a lower consumer cost.

A critical technological leap currently underway is the transition from standard 400-V architectures to 800-V systems. This shift is designed to eliminate "range anxiety" by allowing for ultra-fast charging—reaching 250 kW or more to charge a vehicle in under 30 minutes—while simultaneously improving efficiency through the use of thinner wiring and more compact electronic components.

To support these high-voltage requirements, the industry is moving away from traditional Silicon

## II. RELATED WORK

A Comprehensive Review of Power Semiconductor Technologies in Modern Electric Vehicles  
Since its invention in 1979, the Silicon Insulated-Gate Bipolar Transistor (Si IGBT) has evolved into the most essential power switch for electric vehicle powertrains, prized for its ability to handle high current ratings through bipolar conduction. The device operates by flooding drift layer with charge carriers, allowing it to maintain efficiency even with the thick layers required to block voltages up to 1,200V.

Recent architectural advancements, such as the transition from planar to trench gate structures and the implementation of micro-pattern trench technology, have successfully reduced the collector-emitter saturation voltage by approximately 20%, significantly lowering power dissipation during operation. Furthermore, the development of specialized layers—such as Punch-Through (PT), Field-Stop (FS), and Non-Punch-Through (NPT) structures—has allowed engineers to thin the drift layer without compromising voltage-blocking capabilities.

These innovations help reduce "tail current" during the turn-off phase, which minimizes switching losses and enhances overall system efficiency. Notably, the NPT structure positive temperature coefficient makes it ideal for parallelization in high-power traction inverters. Together, these refinements enable modern EV components to achieve impressive power densities, with traction inverters now reaching over 40 kW/L and handling power outputs up to 400 kW, ensuring that Si IGBTs remain a competitive and reliable cornerstone of EV power electronics.

### III. FUNDAMENTALS OF EV POWER

\*Core Fundamentals of EV Power Electronics.

#### Power Conversion (The Four Types):

At its heart, power electronics is about changing electricity from one form to another. In an EV, this includes DC-AC (for the motor), DC-DC (for the 12V battery), and AC-DC (for charging from the grid).

#### Switching Frequency and Efficiency:

Unlike a simple light switch, power electronic switches (like MOSFETs and IGBTs) turn on and off thousands of times per second. Higher frequencies allow for smaller components (capacitors and inductors) but can generate more heat, requiring a balance between size and cooling.

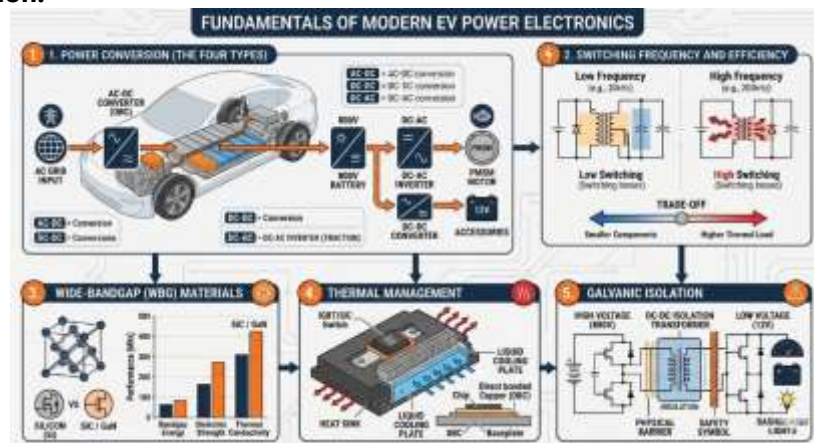
#### Wide-Bandgap (WBG) Materials:

The fundamental shift in modern EVs is moving from Silicon (Si) to Silicon Carbide (SiC) and Gallium Nitride (GaN). These materials allow devices to operate at higher voltages, higher temperatures, and faster speeds with less energy loss.

#### Thermal Management:

Since no converter is 100% efficient, lost energy turns into heat. Fundamentals include using "Heat Sinks" or liquid cooling to ensure the semiconductor chips do not melt or degrade, which is critical for the vehicle's long-term reliability.

#### Galvanic Isolation:



This is a safety fundamental. It ensures that the high-voltage side (800V battery) is physically separated from the low-voltage side (car dashboard/lights) so that a short circuit doesn't electrocute the passengers or fry sensitive electronics.

(credit .Gemini) Core Fundamentals of EV Power Electronics.

#### IV. POWER ELECTRONIC ARCHITECTURE OF EVS

- **High-Voltage Transition (800V Systems)**
- The industry is rapidly transitioning from 400V to 800V architectures. This shift reduces the current required for the same power output, minimizing resistive  $I^2R$  losses and enabling
- **Higher Efficiency:**
- 5–10% improvement in traction inverter efficiency, which translates to roughly 7% additional driving range without increasing battery size (MDPI, 2026)
- **Thermal Resilience:**
- SiC devices can operate at theoretical junction temperatures up to 600°C, though commercial limits are currently 200–300°C, significantly reducing cooling requirements (MDPI, 2023).

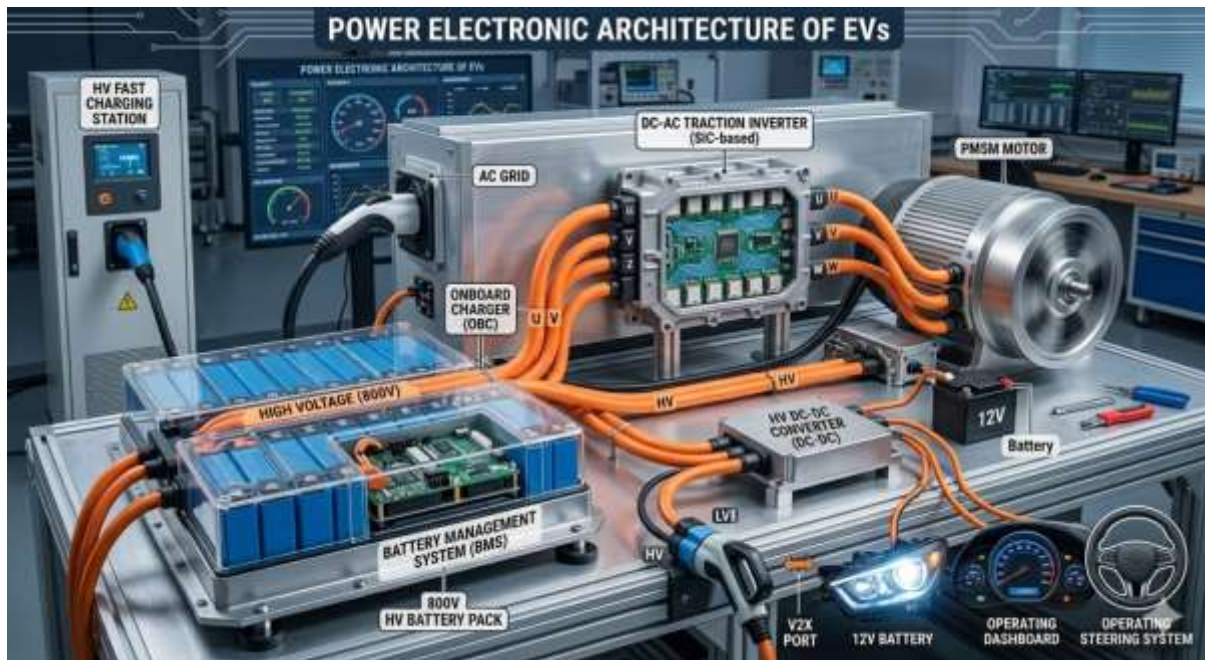


Fig. 2. EV Power Electronics Architecture (credit Gemini)

#### V. COMPARATIVE ANALYSIS

.Onboard Charger (OBC): Manages the conversion of AC from external charging stations into regulated DC to recharge the HV battery.

Parameter	Silicon Devices	SiC Devices	GaN Devices
Efficiency	Moderate	High	Very High
Switching Frequency	Low	High	Very High
Thermal Performance	Moderate	High	High
Cost	Low	High	High



High-Voltage DC-DC Converter: Acts as a step-down converter, bridging the HV battery (e.g., 400V–800V) and the LV auxiliary system (typically 12V or 48V) to power lighting, infotainment, and sensors

## VI. CHALLENGES AND FUTURE DIRECTIONS

### Current Challenges.

- High Material Costs: While Silicon Carbide (SiC) MOSFETs offer superior efficiency, their prices remain significantly higher than conventional Silicon (Si) IGBTs, largely due to the limited availability of high-quality SiC wafers.
- Reliability Concerns: Although Gallium Nitride (GaN) HEMTs provide high switching frequencies, their long-term reliability under off-state high drain bias conditions remains a major concern for manufacturers.
- Thermal Management Complexity: Extracting heat efficiently from power modules is critical to balancing efficiency, cost, and reliability. Innovations in powertrain optimization are required to achieve the same power output using less expensive material

## VII. CONCLUSION

The rapid evolution of electric vehicle (EV) power electronics marks a definitive shift from traditional Silicon-based systems to Wide-Bandgap (WBG) semiconductor technologies. As demonstrated throughout this study, the transition from Si IGBTs to SiC MOSFETs and GaN HEMTs is the primary driver behind the move toward 800-V architectures, which are essential for achieving ultra-fast charging and superior power density. While the current dominance of Si IGBTs is supported by their maturity and cost-effectiveness, they are increasingly limited by higher switching losses and thermal constraints in high-performance applications

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