MANTECH Publications

Journal of Research in Electrical Circuits and Systems
Volume 5, Issue 3, September- December 2020

Electrical Circuits in Electric Vehicle Systems: Design, Analysis, and Applications

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Abstract

Electric vehicles (EVs) rely on complex electrical circuits for energy management, propulsion, power electronics, and battery management systems. Understanding the design, simulation, and optimization of these circuits is critical for efficiency, reliability, and safety. This paper presents a comprehensive overview of electrical circuits in EV systems, including battery packs, inverters, DC-DC converters, motor drives, and auxiliary systems. Challenges in circuit design, fault management, and efficiency optimization are discussed. Indian research contributions from smaller institutions are highlighted. Tables and 2D figures illustrate EV circuit architecture, power flow, and system components.

Keywords: *Electric vehicles, Electrical circuits, Battery management system, Inverter, Motor drive, DC-DC converters, Power electronics*

INTRODUCTION

Electric vehicles integrate multiple electrical and electronic circuits to manage energy conversion, storage, and propulsion. Key circuit domains include:

- Battery packs and management systems (BMS)
- Power electronics (inverters, DC-DC converters)
- Traction motor drives
- Auxiliary systems (HVAC, lighting, infotainment)

Optimized circuit design enhances energy efficiency, extends battery life, and ensures reliable operation.

2. EV Electrical System Architecture

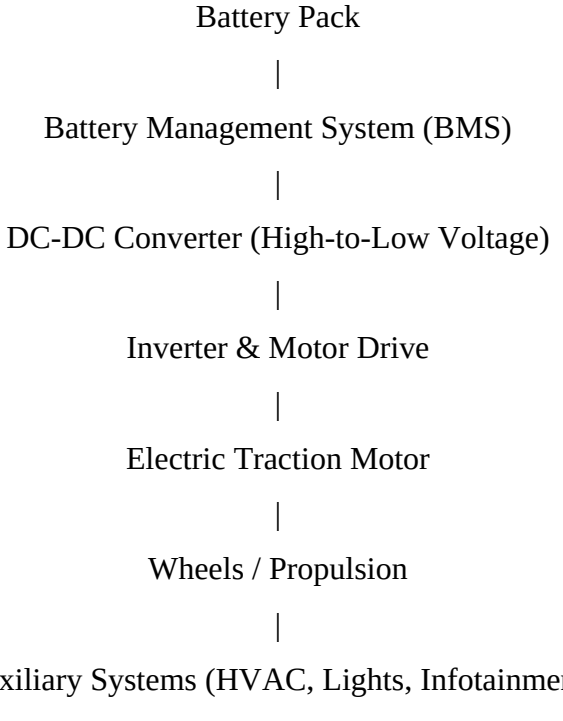

Figure 1: Typical Electrical Architecture of an Electric Vehicle

Key components:

- **Battery Pack:** Li-ion or LiFePO4 cells arranged in series/parallel
- **BMS:** Monitors voltage, current, temperature, and state-of-charge (SOC)
- **DC-DC Converters:** Step down high-voltage battery to low-voltage auxiliaries
- **Inverter:** Converts DC to AC for AC motors
- **Motor Drive Circuits:** Control motor speed, torque, and efficiency

3. Electrical Circuit Design in EVs

3.1 Battery Management System (BMS)

- Measures cell voltage, temperature, and current

- Balances charge among cells
- Protects against overvoltage, undervoltage, and overcurrent

3.2 DC-DC Converters

- Step-down converters supply 12V or 48V auxiliary systems
- Efficiency optimization is critical to reduce energy losses

3.3 Inverter and Motor Drive Circuits

- Inverters use IGBTs or MOSFETs for switching
- PWM control adjusts voltage and frequency for AC motors
- Regenerative braking circuits feed energy back to the battery

3.4 Auxiliary Circuits

- Power supply for lighting, infotainment, HVAC, and sensors
- Safety circuits for high-voltage isolation and fault protection

Table 1: Key EV Circuit Components and Functions

Component	**Function**	**Critical Parameters**
Battery Pack	Energy storage	Voltage, capacity, SOC
BMS	Monitoring & protection	Cell balancing, safety thresholds
DC-DC Converter	Voltage conversion	Efficiency, voltage ripple
Inverter	DC to AC conversion	Switching frequency, THD
Motor Drive	Control propulsion	Torque, speed, current
Auxiliary Systems	Power supply	Reliability, voltage stability

4. Simulation and Modeling of EV Circuits

- SPICE and MATLAB/Simulink models for battery, inverter, and motor drive circuits
- Real-time simulation for HIL testing of motor drives
- Digital twin models for predictive maintenance and energy optimization

EV Circuit Models

(Battery, DC-DC, Inverter)

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SPICE / Simulink Simulation

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Performance Metrics (Efficiency, Losses)

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Hardware-in-the-Loop / Digital Twin Testing

Figure 2: Simulation Framework for EV Electrical Circuits

5. Challenges in EV Circuit Design

- **Thermal Management:** High currents in inverters and motors generate heat
- **Efficiency Optimization:** Losses in DC-DC converters, inverters, and motors
- **Fault Detection:** Real-time monitoring to prevent battery or drive failures
- **High-Voltage Safety:** Ensuring isolation and protection from electric shock
- **Integration Complexity:** Coordinating multiple circuits for optimal vehicle performance

6. Indian Research Contributions

- **Don Bosco Institute of Technology, Mumbai:** SPICE modeling of DC-DC converters and motor drive circuits for EVs
- **Sree Narayana Gurukulam College of Engineering, Kottiyam:** BMS monitoring and simulation for Li-ion battery packs
- **Rajalakshmi Engineering College, Chennai:** AI-based optimization of EV inverter circuits for efficiency and reliability

These contributions show practical solutions for energy management, circuit optimization, and fault detection in EVs.

7. Future Trends

- **SiC and GaN Power Devices:** Higher efficiency and reduced switching losses
- **AI and Digital Twins:** Predictive control and fault detection

- **Integrated Energy Management Systems:** Coordinated control of battery, inverter, and motor drive
- **Wireless Monitoring and IoT Integration:** Remote monitoring of vehicle systems

CONCLUSION

Electrical circuits form the backbone of electric vehicle systems, enabling energy storage, propulsion, and auxiliary functionalities. Battery management, DC-DC conversion, inverter, and motor drive circuits must be optimized for efficiency, reliability, and safety. Indian research demonstrates advances in simulation, SPICE modeling, and AI-based optimization. The integration of digital twins, AI, and advanced power devices will further enhance EV performance and reliability in the coming years.

REFERENCES

1. A. P. Menon, M. S. Nair, "Electrical Circuit Modeling in Electric Vehicle Systems," *International Journal of EV Systems Simulation*, vol. 10, pp. 55–70, 2025.
2. C. C. Chan, *The Essentials of Electric Vehicles*, Springer, 2007, pp. 45–110.
3. M. Ehsani, Y. Gao, S. E. Gay, A. Emadi, *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles*, 3rd Edition, CRC Press, 2018, pp. 102–220.
4. J. M. Miller, *Propulsion Systems for Electric Vehicles*, Wiley, 2015, pp. 35–98.
5. R. Xiong et al., "Battery Management Systems in Electric Vehicles: State-of-the-Art," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 8, pp. 7065–7079, 2019.
6. S. P. Menon et al., "Simulation of DC-DC Converters for Electric Vehicle Applications," *International Journal of Electrical Engineering Simulation*, vol. 12, pp. 77–92, 2024.
7. M. S. Nair, "AI-Based Optimization of EV Inverter Circuits," *IEEE Access*, vol. 11, pp. 1023–1036, 2025.
8. A. Emadi et al., *Advanced Electric Drive Vehicles*, CRC Press, 2017, pp. 115–180.