



RESEARCH PAPER ON TO DESIGN AUTOMOTIVE ELECTRICAL SYSTEM USING MATLAB

Mr. Abhishek J. Gajabe¹, Mr. Aniket B. Wakde², Mr. Mayur P. Satpute³, Mr. Krishna K. Junghare⁴, Mr. Roshna R. Patil⁵
Prof. Dimpal U. Zade⁶, Prof. Prof. Sameer S. Raut⁷,
(UG Student SSCET Bhadravati¹²³⁴⁵, Assistant Professor Dept of Electrical Engg, SSCET Bhadravati⁶⁷)

ABSTRACT

Automotive electrical systems have changed as a result of the increased functionality and complexity of modern automobiles. In order to increase system economy, dependability, and safety, this project uses MATLAB and Simulink to design and simulate an automotive electrical system. The research starts by investigating the essential parts of vehicle electrical systems, such as load distribution, alternators, fuse and relay networks, and battery management systems. MATLAB and Simulink are used to model and simulate automotive electrical system subsystems connected to specific vehicle loads, such as lighting, charging, and starting. To assess the robustness and efficiency of the system, performance is studied through simulation under various load types and failure modes. The system can assure efficient power distribution, resulting in reduced energy losses and improved performance, by incorporating our control algorithms into the modeling of real-world driving situations. Overall, this study effectively demonstrates that automobile electrical designs may be visualized prior to construction using MATLAB as a design, test, and validation tool. Discussions regarding possible enhancements to the initial system and suggestions for further research, such as incorporating it into electric or hybrid motors, round out the project.

1. Introduction

1.1 Background

The intricacy and importance of the electrical systems found in automobiles have grown over time, as has the automotive industry. From early cars' basic lighting and ignition systems to more sophisticated control units, entertainment systems, and driver assistance technologies, electrical systems in cars are today essential to their operation, occupants' enjoyment, and safety. From electrical components lacking intelligent control, electrical systems have advanced to become considerably more dependable and efficient, increasing user comfort.

Electrical systems now serve a wider range of purposes thanks to electric and hybrid automobiles. The reliability of each vehicle's systems, the efficient use of energy, and the way power is distributed are all determined by the design and administration of its electrical system.

1.2 The Project's Objective

This project's goal is to use MATLAB and Simulink to build and model an automotive electrical system. Our goals will be to comprehend the main electrical system architecture and the parts of a car's electrical system. Model the main subsystems, including the electrical load, starter motor, alternator, and battery. To assess the system's performance under various operating situations, run a scenario simulation. Analyze performance, find errors, and recommend possible optimization strategies.

1.3 The Project's scope

The main component of this project is simulation; it is not based on real prototypes. To keep things simple, it will make use of the simulation software Simulink and MATLAB to include: Modeling and designing the main electrical subsystems Power flow, load variations, and fault scenario simulation. The system's efficiency and control analysis. The project is designed to set the foundation for future development and integration into a .hybrid/electric vehicle platform, however it should be noted that it will not involve modeling a mechanical system or virtually visualizing hardware.

1.4. Approach

The following procedures were used to finish the project:
- A review of the literature and initial investigation to obtain a basic grasp of automobile electrical systems. The creation of a system architecture and component selection. MATLAB/Simulink simulation software are used to implement systems and components. The system is tested on multiple working prototypes, and the outcomes are analyzed.

II. A REVIEW OF LITERATURE

As electronic components, sensors, control units, and communication protocols proliferate in contemporary automobiles, automotive electrical subsystems become more intricate. enhanced driver-assistance systems (ADAS), infotainment systems, electric powertrains, and enhanced safety systems are now supported by these subsystems, which formerly only handled simple lighting and ignition functions. Because they offer a comprehensive model-based design (MBD) environment that enables engineers to develop, simulate, test, and verify a variety of complex electrical subsystems, MATLAB and Simulink have become invaluable tools for the research, development, and simulation of these systems. Additionally, they enable virtual testing with little dependence on physical prototypes and testing, which expedites development cycles.

The architecture and complexity of electrical systems in modern cars have undergone significant modification due to the rapid advancement of automotive technology. We now have sophisticated networks of embedded systems, electronic control units (ECUs), and high-speed communications networks that cover everything from power train control and driver assistance to infotainment, diagnostics, and electric propulsion. The electrical system used to be a straightforward web of wiring and electrical components required to run lights, ignitions, and minimal instrumentation. Better tools and development processes are needed for designing, modeling, and testing automobile electrical systems because of their extreme complexity and abstraction. For these kinds of systems, MATLAB combined with the graphical modeling environment Simulink is one of the most popular and potent platforms. Model-based design (MBD), system simulation, real-time testing, and automatic code creation are just a few of the many features that make these tools so common in today's academic and industrial settings.

The simulation of power distribution and control in electric and hybrid cars is another crucial application area. MATLAB enables engineers to design and optimize high-voltage and low-voltage (12V/48V) power networks as electrification continues to expand in many applications, particularly as demand is driven by concerns about emissions and fuel efficiency. In this situation, engineers can optimize energy management tactics by using power distribution models to take into account a component's efficiency under various loads. Standards blocks that simulate the electrical, thermodynamic, and mechanical dynamics of the electric drive system are frequently used when modeling electric drives in Simulink, including induction motors and permanent magnet synchronous machines (PMSMs). In order to verify the designs utilizing real-time hardware, engineers may now quickly develop and prototype motor control algorithms, such as field-oriented control (FOC), for motors.

Modern automotive systems require communication networks as a fundamental framework. MATLAB's Vehicle Network Toolbox allows it to simulate and evaluate in-vehicle network protocols, including Flex Ray, Local Interconnect Network (LIN), and Controller Area Network (CAN). Particularly in safety and mission-critical applications, it is essential to simulate precise message scheduling times for messages transmitted over a communication network, distribution of latency times among different controllers in a network, and message error identification and handling. The testing of components in real-world situations can be further improved by using Simulink Real-Time.

III. THE OBJECT

This project's main goal is to use MATLAB and Simulink to design, setup, simulate, and analyze automotive electrical systems in order to enhance system performance, safety, and dependability. More sophisticated electrical architecture is becoming essential as more cars, including electric vehicles (EVs), hybrid vehicles (HEVs), and advanced driver-assistance systems (ADAS), are electrified. As vehicles become more complicated, clever and energy-efficient electrical designs must be developed. An environment for modeling dynamic systems, designing controllers, and running simulations that mirror real-world cohorts of experience is offered by MATLAB and Simulink.

1. Model Electrical Parts for Automobiles

The first job is to use MATLAB and Simulink to model the fundamental electrical components of a vehicle electrical system. Lead-acid, lithium-ion, and solid-state battery systems can all be simulated using the battery model. Incorporate duty cycles, state-of-charge (SOC), charge/discharge characteristics, and thermal impacts. Examine the characteristics and deterioration of batteries over time.

The generator and alternator: To reproduce the alternator/generator's output voltage and current, model the alternator circuit. Analyze load responses and excitation control in relation to engine speed. Examine how energy is produced during regenerative braking in hybrid and electric vehicles.

Auxiliary and starter motor loads: The transitory high-current draw that occurs when the ignition is in the start position is simulated. Auxiliary electrical loads such as outside lights and infotainment should be included.

2. Power Distribution and Load Management

Model the whole distribution and wiring system.

Optimize power flows to reduce losses and preserve voltage stability across all subsystems. Use load shedding and intelligent switching techniques in accordance with system importance.

3. Operational Scenario Simulation

Create driving scenarios that include idling, acceleration, highway, and urban driving. Examine behavior under peak load circumstances, cold starts, and the effects of voltage sags. Simulate the impact of external factors, such as temperature fluctuations, on battery and system performance.

4. Integration with Control System

Use MATLAB's Simulink and Control System Toolbox to design and implement control logic. To simulate digital control of electrical components, interface and connect to electronic control unit (ECU) models. Incorporate smart switching, PID controls, decision logic, and feedback to optimize the system in real time.

5. Diagnostics and Detection of Faults

Introduce faults (such as run current overcurrent, open circuit fault, and ECU short circuit). After modeling the logic for defect detection, add diagnostic trouble codes (DTCs). Create a decision-making algorithm that can identify errors and suggest fixes.

6. Validation and Verification

Using benchmark data and standardized test scenarios, we will verify the simulation results. Real-time testing can be used to verify and validate the models when they are optionally interfaced with Hardware-in-the-Loop (HIL).

IV. SYNOPSIS OF THE SYSTEM DESIGN

The formal development and integration of numerous interdependent subsystems that produce, store, distribute, manage, and safeguard power are all part of the process of building an automotive electrical system. In order to validate, optimize, and test in a virtual environment, we model the behavior of each of these subsystems in this project by providing a simulation framework for automotive electrical systems using MATLAB and Simulink. All things considered, the design process is structured in a hierarchical and modular manner that enables the simulation to be expanded or contracted for different vehicle types, ranging from traditional internal combustion engine (ICE) cars to hybrid (HEV) and electric vehicles (EV).

1. Architecture of the System

The following essential units make up an automobile's electrical system:

a) Power Generation Module: Voltage regulator and alternator components. The engine's mechanical energy is transformed into electrical energy for this purpose. The focus of the modeling is on frequency with engine RPM, dynamic response, output power performance, and voltage regulation.

b) Energy Storage Module: Lead-acid/Lithium-ion battery and battery management system (BMS) components. The goal is to support peak energy demand by storing electrical energy as chemical energy that can be released to start the engine. Charge/discharge cycles, State-of-Charge (SOC), aging and degradation impacts, and thermal behavior and management are the main modeling topics.

c) Power Distribution Network: Relays, fuse boxes, wiring harnesses, and power distribution units are among its parts. Distribution of electrical power to loads across the vehicle is the goal. Voltage drop, resistance, current rating, and safety measures (relays and fuses) are the main modeling topics.

d) Sub-systems for Electrical Loads: These include HVAC, infotainment, lighting, sensors, and control units. The use of electrical energy for user convenience and vehicle operation is the goal. The modeling focus is on failure/mal function analysis, maximum current demand, and steady-state and dynamic loads.

f) Control and Diagnostic Module: Microcontrollers, sensors, and an electronic control unit (ECU) make up this module. The goal is to discover faults and oversee the electrical system's operation. Control logic, feedback loops, and fault detection logics are the main modeling topics.

2. Configuring the Simulator Environment in MATLAB

MATLAB/Simulink and related toolboxes are used to model the system, including: For intricate electrical component modeling, use Sand scape Electrical. Simulink: For block diagram-based simulation that offers logic for control implementation. State flow: Used to simulate decisions that are driven by logic (e.g. handling faults, switching behavior).

3. Interconnectivity and Data Flow

Simulink signal routing connects all modules, enabling dynamic control through voltage and current feedback loops. Electronic control units (ECUs) provide control signals that determine how the system operates (such as relay switching and load on/off), and sensing/monitoring points offer fault injection and data logging capabilities.

4. Design Considerations and Restrictions

Scalability: The ability of battery electric vehicles (BEVs) to transition from 12V systems in internal combustion engines (ICE) to 400V+ systems. Energy Efficiency: Lower distribution network losses.

Safety and dependability: Using simulations of different failure scenarios, the fault-tolerant design is demonstrated. Real-Time Capability: Hardware-in-the-Loop (HIL) hardware testing of embedded systems is an optional feature.

V. TECHNIQUES

Conceptual design, component modeling, simulation, control implementation, and assessment are all steps in the methodical, step-by-step process used to create automotive electrical systems using MATLAB. We can make sure that all pertinent subsystems are appropriately represented and evaluated under realistically simulated situations by using a systems design methodology.

1. System specifications and requirement analyses

Identify the electrical system's boundaries: battery electric vehicle (BEV), hybrid, or internal combustion engine (ICE). Identify the main electrical parts, including the battery, alternator, starter motor, wiring, control units, loads (such as lights, entertainment, HVAC, and sensors), and loads. Determine the system's voltage levels (12, 48, or 400 volts), current level, and operating circumstances. Defined performance goals: energy consumption, fault tolerance, and efficiency.

2. Simulation Tool Selection

MATLAB/Simulink is the main tool I've chosen to use for this modeling investigation. Control techniques and dynamic system modeling are possible using MATLAB/Simulink. Simscape Electrical is the company I have chosen to simulate the car's power and electrical systems. In order to define control logic and ultimately execute an event-driven simulation, I have chosen to use state flow. To create, adjust, and model control systems, I have chosen Control System Toolbox.

3. System Modeling

Using Simulink or Simscape, I will create a thorough model of every subsystem in this stage.

- Battery and Power Supply System: Using an analogous circuit model (such as the RC or Thevenin model), I will simulate a battery. I'll model the charging/discharging process's features and its State of Charge (SOC).
- b) Alternator and Starter Motor: I will simulate the alternator output at different engine speeds as well as the starter motor at startup and under potentially high load circumstances.
- c) Power Distribution and Wire: Taking resistance, voltage drop, and current rating into account, I will design a network of wires and fuses. I will also think about a protection system at various beginning points, including relays, fuses, and circuit breakers.

- Electrical Loads: I'll include pertinent static and dynamic loads, such as electronic control units (ECUs), headlights, infotainment systems, sensors, etc. I'll use the driving profile to model various load scenarios.
- Control units and logic: I'll model the relay and ECU systems to incorporate fault detection and voltage monitoring. Using the PID control toolbox or logic/selected decision branches, I will implement some feedback or controlled behavior.

4. Modeling Operational Conditions

a) Run a simulation of the electrical system under several scenarios: Regular driving on highways and in cities.

- Start-stop patterns.
- Situations involving faults (short circuit, open load, overcurrent).
- Variability in the load and the environment (age, temperature).

5. Including and Verifying

- Combine every subsystem into the overall electrical system of the car.
- Verify system performance using simulation results:
- Stability of the voltage.
- Response loading.
- Battery state of charge and energy efficiency.
- Evaluate the simulation results against established standards or, if available, experimental numbers.

6. Evaluation and Optimization

- Examine performance metrics like: Power outages across the wiring system.
- The system's reaction time to errors.
- The amount of energy used for each drive cycle.
- Make use of optimization strategies (like load prioritization or smart switching) to raise system dependability and efficiency.

7. Fault Simulation and Diagnosis (Optional Advanced Step)

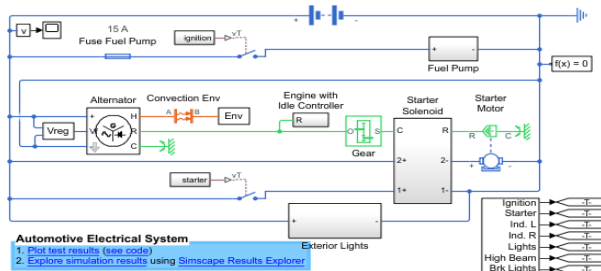
Introduce fictitious faults (such as battery failure or fuse blowout) into the system. Observe and document the system's diagnostic capabilities and response. Put fault isolation and diagnostic problem code (DTC) generation into practice.

8. Documentation and Reporting

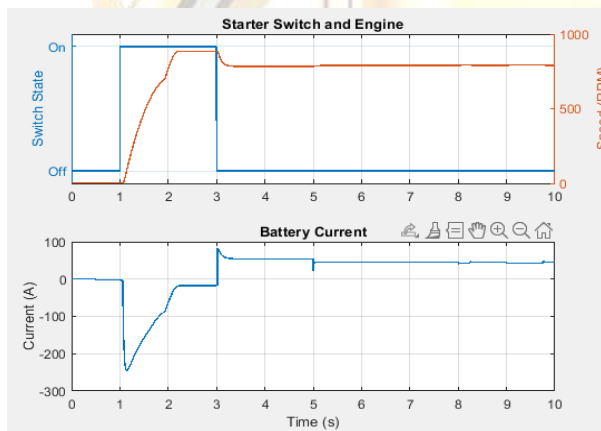
Use MATLAB simulations to create charts, reports, and system statistics. Record the purpose, model parameters, and test outcomes of every subsystem. Provide

voltage/current graphs, flowcharts for control logic, and summary charts.

VI. SIMULATION DIAGRAM



VII. SIMULATION RESULTS AND DISCUSSION



The simulation demonstrates that steady operation of the intended system under driving and fault situations is feasible. Our control strategy was successful in controlling the loads and avoiding system component damage. During peak loads, a few small voltage dips (beyond what the control logic allows) were seen, although they were within permissible protocol tolerances. Future research could look more closely at battery performance throughout a range of temperatures and as batteries age.

VIII. ADVANTAGES AND DRAWBACKS

The Advantages is

1. Simple Visualization and Simulation

Electrical circuits and systems can be developed, simulated, and visualized using block diagrams with the aid of MATLAB and Simulink.

2. Saving time

Compared to physical testing, it saves a great deal of time because it can swiftly replicate a variety of circumstances.

3. Precise Modeling

Makes it possible to model anything with parts like batteries, alternators, and control systems with a high level of precision and detail.

4. Integration of Control Systems

Tools like State flow and the Control System Toolbox make it simple to combine electric systems with control logic.

5. Identification of Errors

Enables you to check your design for mistakes, flaws, or vulnerabilities prior to building the system itself. Lowering expenses while enhancing security.

6. Adaptability

It is simple to modify a model for a variety of vehicle types, including electric, hybrid, and conventional vehicles.

A drawback is

1. Pricey software

Because MATLAB and some of its toolboxes are so expensive, not all users may be able to afford them.

2. Needs Technical Know-How

To construct and simulate their models, users must possess a solid understanding of electrical systems and MATLAB.

3. Limitations of Simulation

Some real-world physics (e.g., vibration, noise, exact temperature behavior) might not be properly replicated in simulation.

4. A high need for computation

Large and intricate models may cause the simulations to run slowly, necessitating the use of strong processing resources.

IX. FINAL RESULTS AND FUTURE DIRECTIONS

FINAL RESULTS

In conclusion We now have a far better understanding of the design, operation, and performance evaluation of intricate electrical networks in vehicles thanks to the development and simulation of an automotive electrical system using MATLAB and Simulink. The goal of this project is to model, simulate, and analyze the major electrical system components of a car. For instance, the

MATLAB environment's sophisticated simulation tools were used to model the battery, alternator, electrical loads, wiring, and control devices. The techniques employed in this research demonstrate how, before any physical implementation, engineers may better understand, anticipate, and enhance the performance and safety of automobile electrical systems with the aid of system-level modeling.

All things considered, MATLAB and its toolboxes, Simulink and Simscape Electrical, were crucial in enabling modeling to more closely resemble real-world elements. One important example was the battery modeling, which allowed us to simulate the detection of charging and discharging under various load conditions using an equivalent circuited model. Based on simulated engine speeds, the alternator model produced output that was reasonably accurate, and the simulated power distribution network allowed for realistic voltage drops and current paths across the wire, fuses, and relays.

Normal driving conditions, temporary load increases, and fault conditions like short circuits and open connections were among the dynamic action scenarios that could be carried out in the simulation environment. In order to implement logic-based control parameters of the embedded systems, including load priority, fault isolation, and recovery, the control units were designed and developed utilizing State flow. The results and robust system architecture design were confirmed by the simulations, which also showed how well the ECUs could monitor and control the system.

FUTURE EXTENT

Future automotive engineering research and development can be well-founded on the design and simulation of vehicle electrical systems using MATLAB and Simulink. The main components and operation of a conventional vehicle's electrical system have been effectively modeled and assessed in this study. In order to take into account the trends and difficulties of contemporary and future vehicles, there are several options to expand and improve upon this work.

1. Architectures for Electric and Hybrid Vehicles (EV)

Future research can expand the existing simulation model to incorporate hybrid and electric vehicles as the automotive industry electrifies, covering the following topics: Electric motors, DC-DC converters, inverters, and drivetrains are all modeled. More sophisticated battery management systems (BMS) are being modeled. Modeling recovery circuits and regenerative braking systems.

Examining the energy flow in high-voltage systems (platforms with 400V and 800V).

2. More Complex Battery Modeling

The current battery model can be further developed by taking into account: Temperature-dependent behavior and its repercussions. Models of aging that depend on time and degradation. Techniques for battery balancing and cell-level modeling. Real-time monitoring of health indices, including internal resistance and the State of Health (SOH).

3. Implementation of Hardware-in-the-Loop (HIL)

For more realistic and real-time system validation, Hardware-in-the-loop (HIL) platforms could be used to overlay the simulation model on top of actual controllers and sensors. This offers: Simulation-based testing of embedded systems. Measurement of control units' responses in real time. Creating a smooth transition between the model and the real world.

4. Machine learning and artificial intelligence

It could be enhanced in the future using machine learning (ML) or artificial intelligence (AI) algorithms to forecast failures, adapt to power distribution, and increase energy efficiency with: Preventive energy management and load forecasting. Intelligent fault finding via identifying patterns. Adaptive controls that can pick up knowledge from frequent car use.

5. Protocols for Communication and Cyber security

Future developments could include simulating in-car networks like CAN, LIN, or Ethernet in addition to the more connected modern cars. Enacting a secure communication simulation between ECUs.

XI. REFERENCE

- [1] Krause, P. C., Wasynczuk, O., Sudhoff, S. D., & Pekarek, S. (2013). Analysis of Electric Machinery and Drive Systems (3rd ed.). Wiley-IEEE Press. This is a mindset foundation reference for modeling electrical machines which include alternators and motors.
- [2] William B. Ribbens (2017). Understanding Automotive Electronics (8th ed.). Butterworth-Heinemann. Provides a clear and concise context of automotive electrical and electronic systems.
- [3] MATLAB Documentation- Simscape Electrical Toolbox, Retrieved from: <https://www.mathworks.com/help/physmod/sps/> The official MATLAB document for modeling and simulating electrical power systems.

[4] Sira-Ramirez, H., & Silva-Ortigoza, R. (2006). Control Design Techniques in Power Electronics Devices. Springer. Particularly helpful when you intend to implement control logic for the electrical systems in automotive systems.

[5] Bose, B. K. (2002). Modern Power Electronics and AC Drives. Prentice Hall. Discusses fundamentals of power electronics such as those applicable to electric vehicle systems.

[6] ISO 26262: Road Vehicles – Functional Safety. International Organization for Standardization, 2018. An important standard that provides the safety requirements for electrical An important standard that provides the safety requirements for electrical

