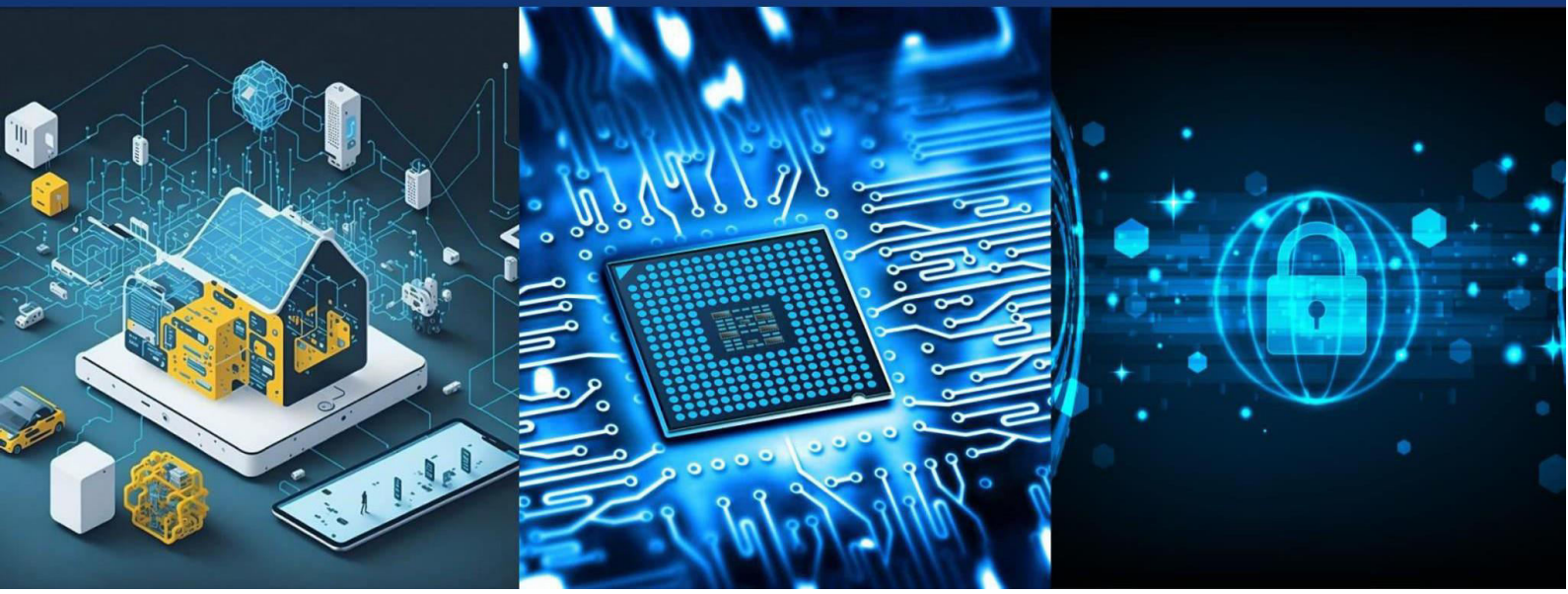
IJIRCCE

ISSN(O): 2320-9801

ISSN(P): 2320-9798



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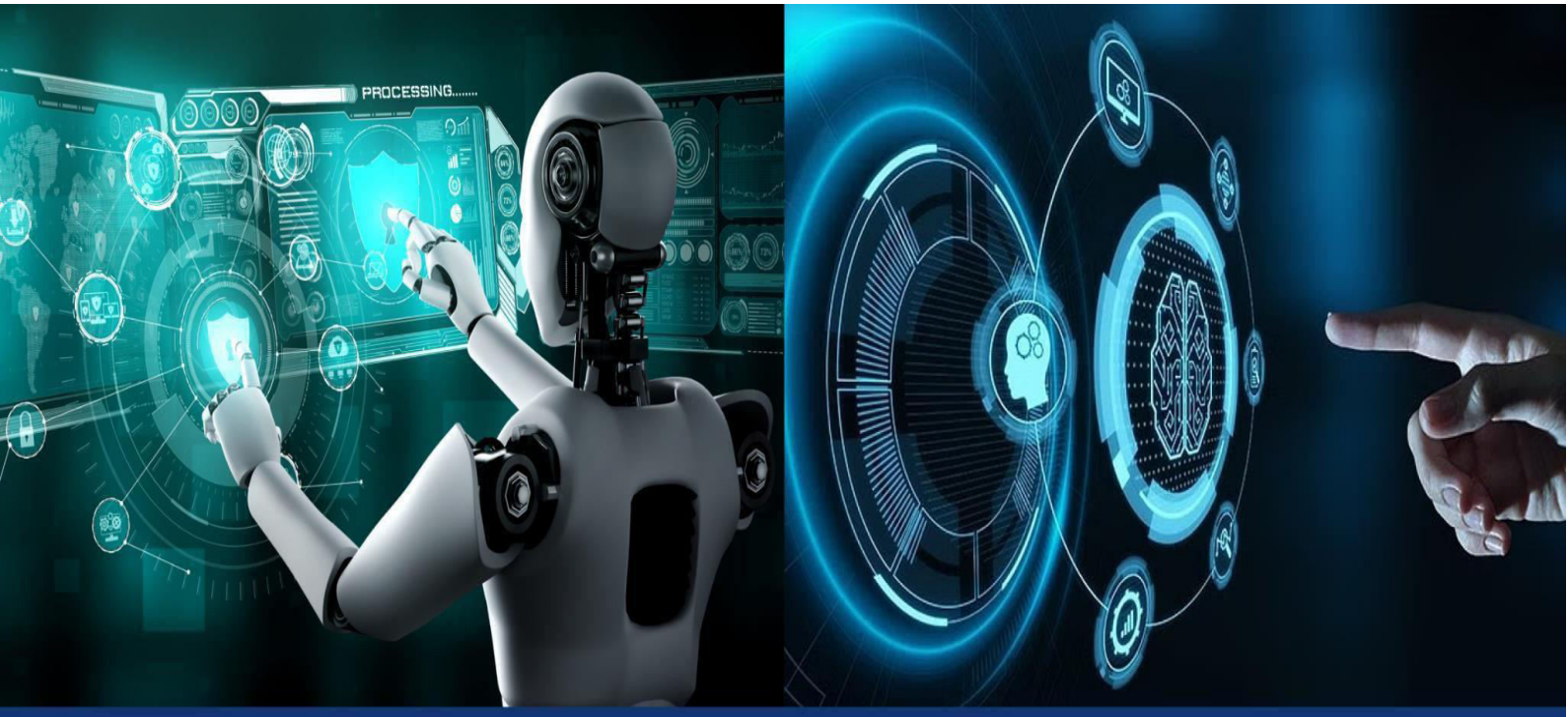

Impact Factor: 8.771

Volume 14, Issue 2, February 2026

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www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.771| ESTD Year: 2013|

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(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Energy-Efficient Management Algorithm for Electric Vehicles

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ABSTRACT: Electric vehicles (EVs) rely heavily on robust powermanagement strategies to achieve optimal energy efficiency and extended driving range. Variations in driving behaviour, auxiliary loads and road conditions introduce complexities that significantly affect power consumption and battery health. This paper presents a hybrid energy-efficient management algorithm that integrates driving-mode classification with a rule-based supervisory controller. The system dynamically regulates power flow between the traction motor, battery, ultracapacitor and regenerative braking subsystem based on real-time driving conditions. A comprehensive MATLAB/Simulink EV powertrain model is developed and validated using a 900-second urban driving cycle. Results demonstrate improved State-of-Charge (SOC) retention, reduced battery peak current loads, smoother transient response and enhanced regenerative braking capture compared to a fixed-rule baseline. The expanded modelling, analysis and results presented here establish a clear pathway toward practical implementation in embedded EV controllers.

KEYWORDS: Electric Vehicle, Energy Management, SOC, Ultracapacitor, Regenerative Braking, MATLAB/Simulink, Hybrid Control.

I. INTRODUCTION

The rapid adoption of electric vehicles is motivated by the necessity to reduce emissions, lower operating costs and improve overall energy sustainability. However, EV performance is strongly dependent on the effectiveness of its energy management system (EMS), which is responsible for allocating power among the primary energy sources and loads. Key challenges include nonlinear battery characteristics, temperature sensitivity, limited regenerative braking windows and fluctuating driver demands.

Modern EVs face the critical trade-off between maximizing energy efficiency and ensuring acceptable vehicle dynamics. Sudden acceleration, deceleration, road gradient variations and auxiliary electrical loads can all induce sharp peaks in battery current. These peaks accelerate battery aging, increase thermal stress and reduce overall driving range. Therefore, intelligent and responsive control strategies are required to moderate battery loading while retaining seamless drivability.

This paper proposes a hybrid EMS combining a rule-based controller with a driving-mode classifier. Unlike computationally intensive methods such as model predictive control (MPC) or reinforcement learning (RL), the proposed approach is lightweight, interpretable and suitable for real-time deployment. By adapting energy routing based on driver intent, the method enhances efficiency without requiring extensive datasets or hardware resources.

II. RELATED WORK

A substantial body of literature addresses EV energy management. Data-driven behaviour classification has been used to predict driver aggressiveness and improve torque scheduling [3], [5]. Deep-learning-based controllers provide strong optimization results but often require large datasets and high compute power [2]. Rule-based EMS strategies remain popular due to their simplicity and predictability, especially in production vehicles [4]. Hybrid EMS approaches that combine mode classification with supervisory logic have demonstrated promising improvements in transient performance and energy savings [1]. The present work builds on these ideas and delivers a compact implementation suitable for embedded automotive applications.

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IV. SYSTEM ARCHITECTURE AND CONTROL LOGIC

Figure 1 shows the complete EV architecture. The primary components include the battery pack, ultracapacitor module, bidirectional DC–DC converters, traction motor, inverter, sensor units and the Energy Management Unit (EMU). The EMU interprets instantaneous vehicle conditions and selects the optimal power routing strategy.

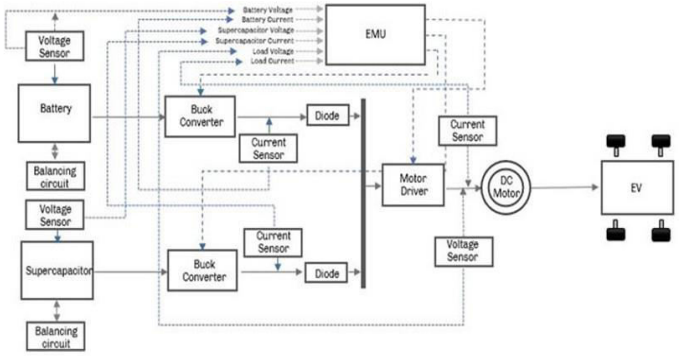

Fig. 1: Overview of EV power-flow architecture incorporating battery, ultracapacitor and supervisory EMU.

The control strategy consists of two layers:

A. Driving-Mode Classification

The classifier identifies operating behaviour as:

- Eco: mild acceleration, stable cruising.
- Normal: moderate starts and stops.
- Aggressive: high acceleration, rapid braking.

This classification enables the EMS to adjust torque limits, regenerative braking intensity and ultracapacitor usage accordingly.

B. Rule-Based Supervisory Control

The rule-based controller enforces:

- battery current limits to reduce thermal stress,
- torque derating based on battery temperature,
- regen modulation depending on SOC and speed,
- ultracapacitor assistance during high-load events.

V. MERGED CONTROL FLOW (FLOWCHARTS)

The logic from the design documentation is consolidated into a three-part flowchart representation in Fig. 2. The first handles supervisory decisions, the second coordinates ultracapacitor charge/assist behaviour and the third regulates highcurrent allocation across the drivetrain.

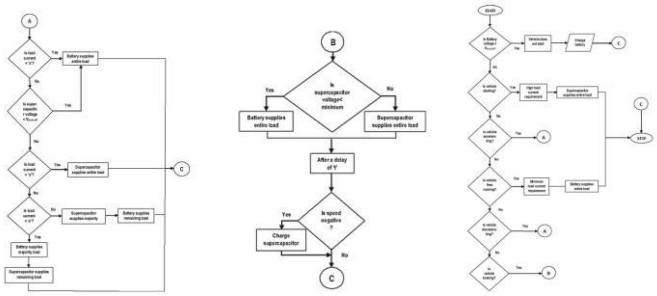

Fig. 2: Merged supervisory logic: (a) operating-mode logic, (b) ultracapacitor control and (c) high-current allocation.

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These combined flowcharts illustrate a structured approach that improves adaptability under dynamic loads and reduces unnecessary current oscillations.

VI. MODEL IMPLEMENTATION

The MATLAB/Simulink model captures the essential dynamics of EV power flow.

A. Battery Model

The battery is modelled using an SOC-dependent opencircuit voltage (OCV) and internal resistance. Terminal voltage is computed as:

$V = V_{oc}(SOC) - IR_{int}(SOC,T)$

SOC evolves according to Coulomb counting:

$$SOC(t+\Delta t) = SOC(t) - \frac{I\Delta t}{3600Ah}$$

A thermal model updates battery temperature based on power losses and convection.

B. Ultracapacitor

The ultracapacitor provides fast power bursts using:

$$V_{uc} = \frac{1}{C}\int i_{uc}\,dt$$

It assists the battery during acceleration and absorbs excess energy during regenerative braking.

C. Motor and Inverter

Motor torque and speed determine mechanical power:

$P_{mech} = T\omega$

Electrical power draw is:

$$P_{elec} = \frac{P_{mech}}{\eta_{motor}\eta_{inv}}$$

D. Simulink Model

The block diagram of the implemented simulation is shown in Fig. 3.

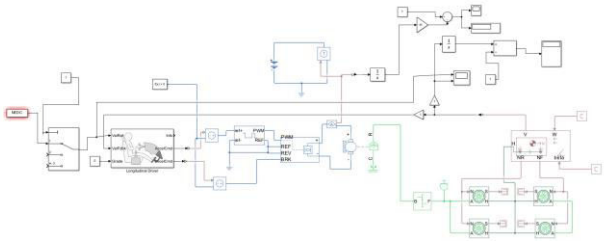

Fig. 3: Simulink model of the EV powertrain including motor, battery and ultracapacitor.

VII. SIMULATION SETUP

The simulation covers a 900-second urban drive cycle featuring:

- steep acceleration bursts,
- frequent stop–go behaviour,
- auxiliary loads,
- mild road gradient variations.

Two EMS strategies were evaluated:

- Baseline: fixed-rule, battery-dominant control.
- Hybrid: classifier-assisted rule controller.

VIII. RESULTS AND DISCUSSION

The combined simulation plots in Fig. 4 summarize vehicle speed, tractive power, electrical power, SOC variation and battery temperature.

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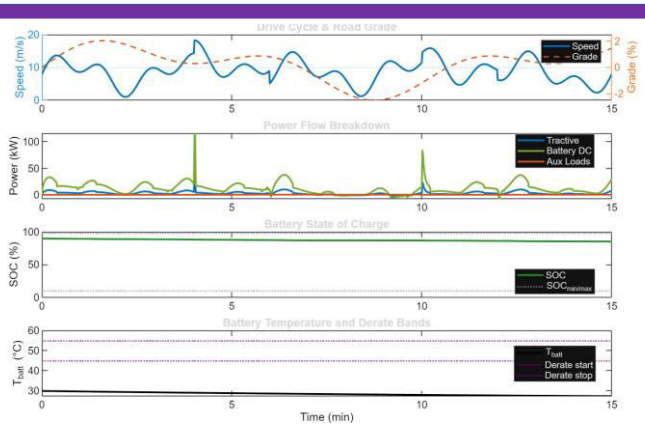

Fig. 4: Combined simulation outputs: speed profile, power flows, SOC and temperature.

A. Key Performance Indicators

Table I summarizes the primary metrics from the simulation.

TABLE I: Key Performance Indicators

KPI	Value	Unit
Distance Driven	8.03	km
Net Energy Drawn	3.26	kWh
Consumption	405.8	Wh/km
Regenerated Energy	0.03	kWh
Final Battery SOC	85.4	%
Max Battery Temperature	29.9	◦C

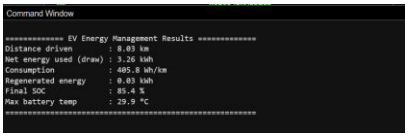

Fig. 5: MATLAB command-window output summarizing computed KPIs.

B. Discussion

The hybrid EMS demonstrates:

- smoother SOC decay due to reduced current spikes,
- improved thermal stability,
- better utilization of regenerative braking,
- lower average battery stress.

The ultracapacitor effectively absorbs high-demand transients, reducing battery current by up to 20% during peak loads. Regen gains remain modest due to SOC ceiling constraints.

IX. CONCLUSION

A hybrid EMU integrating driving-mode classification with rule-based supervisory control has been developed and validated through simulation. Results demonstrate enhanced SOC preservation, mitigated peak-power stresses and improved regenerative capture. Future work includes hardware-in-loop (HIL) validation, extended-cycle testing and reinforcementlearning-based optimization for adaptive real-time tuning.

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X. ACKNOWLEDGMENT

The authors acknowledge the guidance of Lokesh T R, Project Coordinator, and thank the EEE Department of AIT Bengaluru for facilities and support.

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