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International Journal of Electrical and Electronics Research (IJEER)
Review Article | Volume 13, Issue 1 | Pages 55 -61 | e-ISSN: 2347-470X

# A Tiered Control Strategy for Energy Management in PEMFC Hybrid Systems for Distributed Power and Vehicle Applications

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**ABSTRACT-** This paper presents an optimized energy configuration using a polymer electrolyte membrane fuel cell (PEMFC) as the primary power source, paired with a battery and supercapacitor for storage. This hybrid system, designed for modern distributed generation and next-gen fuel cell vehicles, achieves energy balance through DC bus voltage regulation. The supercapacitor, with high power density and fast response, stabilizes the DC bus voltage, while the battery, valued for its high energy density, continually recharges the supercapacitor. The fuel cell, with a slower response, ensures the battery remains charged. This setup features three voltage control loops: the supercapacitor manages the DC bus voltage, the battery maintains the supercapacitor voltage, and the fuel cell sustains the battery voltage.

**Keywords:** EV, hybrid energy storage system, energy management method, fuel cell, battery deterioration.

**ARTICLE INFORMATION**

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**Received**: 22/10/2024; **Accepted**: 27/01/2025; **Published**: 30/03/2025;
**e-ISSN**: 2347-470X;
**Paper Id**: IJEER 2210-17;
**Citation:** 10.37391/ijeer.130109
**Webpage-link**:
https://ijeer.forexjournal.co.in/archive/volume-13/ijeer-130109.html

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## 1. INTRODUCTION

The research and development of HESS, which can increase the power and efficiency of electric cars, has seen a recent upsurge in attention in a hybrid system for energy storage; both batteries and ultracapacitors play important roles. Ultracapacitors have the potential to address the shortage of lithium-ion batteries because of their many cycles life, high power density, and fast charging and discharging rates [1]. However, electrochemical processes and the battery's condition would cause its power and efficiency to progressively decline over time. [2] in Plus, the energy management system of a hybrid EV is in charge of managing the power that the vehicle's power battery and ultracapacitor produce [3]. The energy management system has to account for battery degradation while supplying the necessary power in order to maximise fuel economy and battery life. Thus, the primary obstacle to an energy management plan for EVs with hybrid energy storage is figuring out how to distribute power evenly between the power battery and the ultracapacitor. Finding the optimal mix of ultracapacitors and DC/DC converters, as well as devising techniques for energy management, are areas of intense interest in the field of electric vehicles with hybrid energy storage. Many models showing the degradation of battery life and performance with time have been published by researchers both at home and abroad, and they all centre on the ageing characteristics of batteries. Energy management strategies that account for battery deterioration are provided by the assessment models [4-5].

Current descriptions of the decrease in lithium-ion battery capacity fall into one of three categories: mechanism, equivalent, or empirical models. Due to the difficulties in obtaining the electrochemical parameters contained in the model and the complexity of the model construction technique, mechanism models are usually used instead of control problems in battery research [6]. There are a lot of outside variables that may influence how accurate the equivalent circuit model is, and electrical components can lose some of their power. An empirical model, which is very easy to set up and calculate, may be used to investigate the accuracy needs of this model [7]. Due to the physical interaction of several components and the decrease in battery capacity, formula-fitting construction makes use of a large amount of data from battery life tests [8]. Discharge ratio is the most important element in battery ageing, according to research [9]. Battery ageing is most sensitive to temperature at a low discharge ratio, whereas it is least sensitive to discharge depth at this ratio. This means that the well-established semiempirical battery ageing model does not take into account the impacts of battery states of charge (SOC); instead, focussing solely on temperature and charge-discharge ratio are two important factors to consider when creating a battery lifecycle loss model for operating HES electric vehicles

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using data received during the battery maintenance stage, accounting for the impact of battery SOC on ageing [10].

Two distinct types of theories have emerged in the study of HES electric vehicle EMS development: rule-based and optimisation-based approaches. Among the former are thresholds based on FLC, while among the latter are global optimisation and near-real-time optimisation [11–13]. The rule-based approach has been widely employed in research on the topic of EMS in hybrid and electric vehicles. Using fuzzy logic, it is a method to control the fluctuating current drawn from batteries [14]. Inputs may include things like the current state of charge of a battery or an ultracapacitor. The battery power distribution coefficient determines the power required to discharge a capacitor or battery. The management approach is simple and easy to learn on the surface, but the control concepts that underpin it need deep knowledge. Using composite power supply to their full potential with absolute precision is not possible. A universal algorithmic framework was recently created to handle heat safety and degradation of an onboard lithium-ion battery system. The framework comprises a model-based status monitor and an enhanced optimiser based on reinforcement learning [15–17].

Despite these advancements, several challenges persist. Lithium-ion batteries, while widely used in HESS, suffer from degradation issues such as capacity fading and thermal instability, especially under frequent charge/discharge cycles and extreme temperature conditions. Supercapacitors, though excellent for handling rapid energy fluctuations, face limitations in energy density, making them less suitable for prolonged loads. PEMFCs, as primary power sources, provide steady energy but have slower dynamic responses, necessitating complex control systems to maintain stability during sudden load changes. Balancing the unique characteristics of each component while ensuring optimal performance remains a significant hurdle.

Furthermore, cost and scalability issues hinder the widespread adoption of PEMFC-based HESS. The high cost of advanced materials, such as platinum catalysts in PEMFCs and graphene-based electrodes for supercapacitors, limits affordability. Additionally, the lack of robust infrastructure for recharging or refuelling hybrid systems poses significant barriers, particularly in developing regions. Ongoing research aims to address these challenges by improving material efficiency, reducing system costs, and developing predictive models for real-time energy management. These efforts are critical to unlocking the full potential of HESS for sustainable and scalable energy solutions.

Efficient energy management is crucial for hybrid energy storage systems (HESS) in electric vehicles, combining batteries, supercapacitors, and fuel cells. A distributed control approach informed by theories of contrast, closeness, and agreement has been proposed to optimize EV charging and reduce electricity generation costs, achieving global optimality in simulations. While energy management strategies like Pendragon's Minimum Principle (PMP) effectively slow battery degradation and reduce costs by 21.7%, they remain labour-intensive and heavily reliant on driving conditions, making online control challenging. By leveraging a Li-ion battery degradation model and incorporating ultracapacitors, these strategies aim to enhance the longevity and cost efficiency of hybrid EVs. The key objectives include:

- **Power Distribution Optimization:** Efficiently allocate power across the battery, supercapacitor, and fuel cell to minimize energy losses and meet varying load demands.
- **Battery Protection and Lifespan Extension:** Mitigate high-discharge cycles by using fuel cells for sustained loads and supercapacitors for transient loads, reducing battery wear.
- **Stable Power Supply**: Maintain consistent power flow to enhance vehicle performance and reliability under diverse operating conditions.

## 2. MODELLING OF HYBRID ENERGY STORAGE ELECTRIC VEHICLES

The parallel hybrid energy storage system (HES) shown in *figure 1* is comprised of a DC/DC converter, a battery, an ultracapacitor, a motor, and a controller.

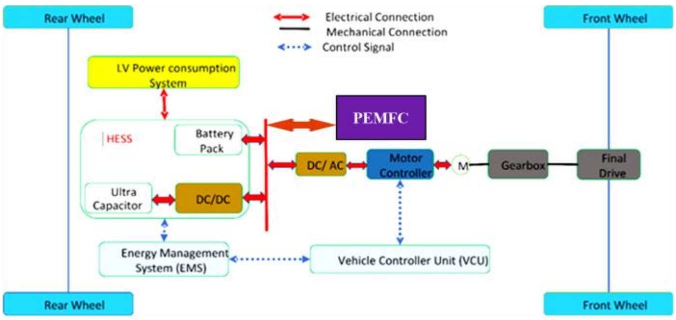


**Figure 1.** A parallel hybrid electric vehicle's layout and detailed construction

*Figure 1* illustrates the layout of a parallel hybrid energy storage system (HESS) used in hybrid electric vehicles. The system consists of a DC/DC converter, a battery, an ultracapacitor, a motor, and a controller. The DC/DC converter links the ultracapacitor module to the DC bus, allowing bidirectional power flow. The battery is directly connected to the DC bus, supporting sustained energy delivery. The controller manages the power distribution, ensuring optimal performance of the HESS under varying load conditions.

### 2.1. Technical Specifications of System Components

**Table 1. Specifications of System Components (Fuel-cell, Super capacitor and Battery**

| Component | Parameter | Value |
|---|---|---|
| Fuel Cell (PEMFC) | Voltage | 52.5−52.46V |
| | Stack Efficiency | 50% |
| | Air Flow Rate | 732lpm |
| | Supply Pressure (Fuel) | 1.16bar |
| | Cell Count | 65 |
| | Operating Temperature | 50°C |

| | | |
|---|---|---|
| | Maximum Power Point Voltage | 320V |
| | Operating Point Current | 250A |
| Supercapacitor | Rated Capacitance | 15.6F |
| | Equivalent DC Resistance | 150Ω |
| | Rated Voltage | 291.6V |
| | Series Capacitors | 108 |
| | Initial Voltage | 270V |
| | Operating Temperature | 25° C |
| Lithium-Ion Battery | Nominal Voltage | 48V |
| | Rated Capacity | 40Ah |
| | Initial State of Charge | 65% |
| | Battery Response Time | 20s |

## 2.2. Modelling of Vehicles

The study aims to model a hybrid electric vehicle (HEV) to evaluate energy management through simulation experiments. It develops an EV model integrated with a HESS system. Unlike exact models, the motor model uses simulation findings, featuring a UC semi-active hybrid architecture with a bidirectional DC/DC converter connecting the ultra-capacitor (UC) module to the DC bus and directly linking the battery module. The DC/DC converter optimizes energy delivery by normalizing the UC's output, reducing system power consumption. Simulation analysis is essential to refine energy management for HEVs.

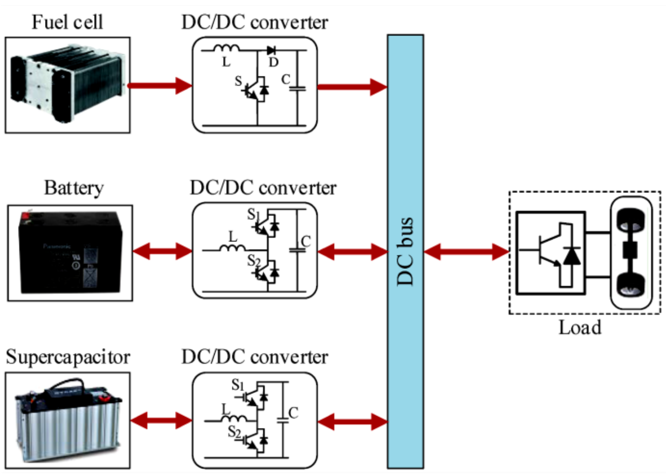


**Figure 2.** PEMFC-Powered Hybrid Energy Architecture

This hybrid system integrates a PEMFC as the primary energy source, complemented by an ESS comprising a lithium-ion battery and a supercapacitor (SC) bank. The system employs two bidirectional and one unidirectional boost DC-DC converters to connect the three power sources to the DC bus in parallel. These converters enable energy transfer to the traction motor via an inverter, depending on the charge or discharge modes during load variations. To address the challenges associated with standalone PEMFCs, the ESS, characterized by high energy and power density, compensates for power shortages during the initial phase, transient periods, peak power demands, or regenerative energy recovery. This configuration offers a flexible mechanism for regulating DC bus voltage, improving system performance, and enhancing the fuel efficiency of the PEMFC system.

## 3. FUEL CELL-BATTERY-SUPERCAPACITOR HYBRID ENERGY SYSTEM

### 3.1 Composition of Hybrid Energy Systems

Several different electrical generators provide energy to a series hybrid electric vehicle's load via a DC power bus. Power conditioning devices, such as DC/DC and DC/AC converters, are a standard component of fuel cell (FC) systems because of the FCs' ability to provide direct current (DC) voltage outputs. The conversion and management of power, two cornerstones of power electronics, are taken care of by these converters. More dependable, lightweight switching power sources for complicated systems and the need for efficient management in industrial applications have recently sped up developments in power electronics technology.

### 3.2 Hybrid Power Source Energy Optimization

It is possible to identify three separate operating modes (or states) for controlling energy exchanges on the DC bus.

- In charge mode, power is supplied to the load and storage devices by the main source.
- The energy to the load is supplied by the main source and storage devices in conjunction during the discharge mode.
- The load produces energy in recovery mode, which is then used to recharge the storage devices.

### 3.3 Voltage Control Circuit for Supercapacitor

As seen in *figure 3*, a proportional (P)-controller is sufficient to handle the supercapacitor voltage control loop with little static error provided the proportional gain is sufficiently big. In order to minimise switching harmonics while measuring the voltage of the supercapacitor, a first-order filter is used. The level and slope of the regulator's output signal are constrained so that it remains within the functional constraints of the battery. The battery reference signal, iBatREF, controls the battery converter via the battery current control loop, and it can only be within a certain range if the maximum discharging current, IBatDis, is positive and the maximum charging current, IBatCh, is negative. Overheating of the battery is prevented by the "Battery Current Slope Limitation" (F2) delay, even in the presence of transient increases in power consumption. A smooth linear transfer function is achieved by use of a second-order

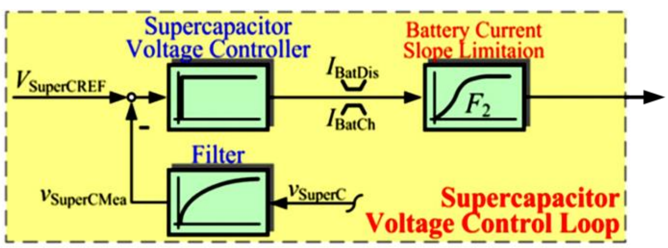


**Figure 3.** voltage control circuit for Super capacitor

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### 3.4 DC Bus Voltage Monitoring and Control

The system's inherent linear transfer function is achieved, as seen in *figure 4*, by using the DC bus capacitive energy (EBus) as the status variable and the power produced by the supercapacitor as the command variable in the DC bus voltage control loop. Given a set of inputs—the DC link capacitive energy, the supercapacitor power Psc, the battery power Pbat, the fuel cell power Pfc, and the load power $P_{Load}$—and the assumption of zero losses in the fuel cell, battery, and supercapacitor converters, we may state this relationship differently:

$$\frac{dEBus}{dt} = P_{sc}(t) + P_{fc} + P_{bat} - P_{Load}$$

$$E_{Bus}(t) = \frac{1}{2} \cdot C_{Bus} \cdot v^2_{Bus}(t)$$

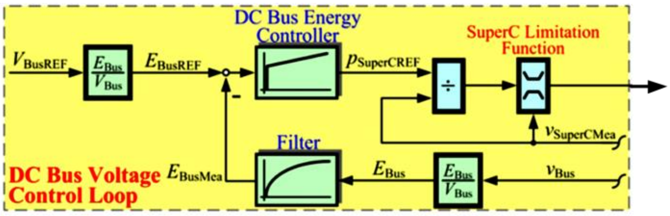


**Figure 4.** DC Bus Voltage Monitoring and Control

### 3.5. Battery Voltage Stabilization Loop

This *figure 5* depicts two control loops for managing a battery in a hybrid energy storage system: the Battery Voltage Control Loop and the Battery Charging Control Loop. Here's a breakdown of each section:

#### 3.5.1. Battery Voltage Control Loop

- ***Battery Voltage Controller:*** This controller regulates the battery voltage by maintaining it within specific limits. It adjusts the current to keep the voltage at the reference level VBatREF.
- ***Limits IBatMax and IBatMin:*** These define the maximum and minimum current values allowed to prevent overcharging or excessive discharging.
- ***Filter (Voltage Measurement):*** A filter processes the measured battery voltage (VBatMea to reduce noise and harmonics, ensuring a smoother signal before it feeds back to the controller.
- ***Output:*** The result of this control loop is the regulated voltage output VBat.

#### 3.5.2. Battery Charging Control Loop

- ***Battery Charging Controller:*** This controller manages the charging process by adjusting the command current IBatCom to ensure proper charging.
- ***Fuel Cell Current Slope Limitation:*** This component, denoted by F1, limits the rate of current supplied by the fuel cell to prevent sudden surges. This slope limitation is important for safe charging, especially during high demand or transient conditions.
- ***Limits IFCMin:*** These define the maximum and minimum current allowed from the fuel cell, providing safety thresholds.
- ***Filter (Current Measurement):*** The filter processes the battery current measurement (iBatMea) to smoothen the signal before feedback.
- ***Negative Multiplier (-1):*** *This* block reverses the current sign to manage directional flow accurately within the control loop.
- ***Output:*** The result is the controlled battery current iBat, ensuring safe and efficient charging.

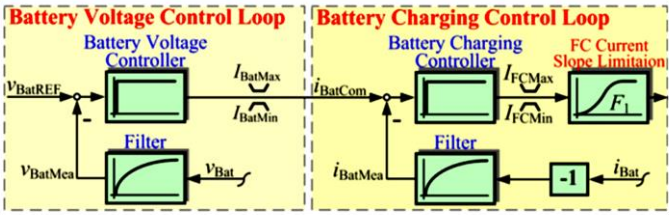


**Figure 5.** Battery Voltage Stabilization Loop

## 4. FUEL CELL-BATTERY-SUPERCAPACITOR HYBRID ENERGY SYSTEM

### 4.1 DC Bus Voltage Regulation

**Governing Equation:** The relationship governing power distribution in the hybrid energy storage system (HESS) is:

$$P_{Load}(t) = P_{SC}(t) + P_{Bat}(t) + P_{FC}(t)$$

**Control Objective:**
The control algorithm ensures that the DC bus voltage (VBus) remains stable under varying load conditions:

$$V_{Bus} = f(P_{SC}, P_{Bat}, P_{FC})$$

### 4.2. Supercapacitor Voltage Control Loop

A proportional controller regulates the supercapacitor voltage

$(V_{SC})$: $V_{SC,\ ref} - V_{SC,\ meas} = Kp \cdot \Delta V_{SC}$

### 4.3. Battery Voltage Stabilization Loop

The battery voltage control loop adjusts the current to maintain the battery voltage:

$$I_{Bat} = K_p \cdot (V_{Bat,\ ref} - V_{Bat,\ meas}) + K_i \cdot \int (V_{Bat,\ ref} - V_{Bat,\ meas}) dt$$

### 4.4. Fuel Cell Voltage Regulation

The fuel cell adjusts its output to maintain the battery state of charge (SOC): $P_{FC} = (V_{Bat} \cdot I_{Bat}) / (\eta_{FC})$

### 4.5. Energy Balance and Optimization

The state of charge (SOC) of the battery and supercapacitor is modelled as:

$$SOC_{Bat} = \int I_{Bat} dt C_{Bat}$$

**Optimization Objective:** Minimize energy losses while maximizing system efficiency:

$$\min \int (P_{Loss} + \alpha \cdot SOC_{Bat} t + \beta \cdot SOC_{SC}) dt$$

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## 5. SIMULATION RESULTS

The results confirm that the hybrid energy storage model effectively balances power between the battery and super capacitor, ensuring consistent power delivery and reducing strain on individual components. This leads to improved efficiency, reduced battery degradation, and enhanced system stability, making the HESS a robust solution for electric vehicle applications and other high-demand energy systems.

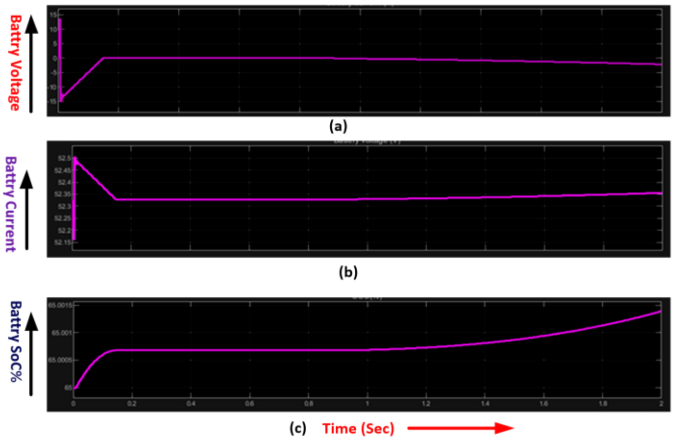


**Figure 6**. Battery Voltage Level, Battery Current Flow, and Battery Charge Status (SoC%)

This *figure 6* displays three graphs representing battery output parameters over time: Battery Voltage Level, Battery Current Flow, and Battery Charge Status (SoC%). These plots together illustrate that the battery output is well-regulated, with voltage and current stabilizing after initial transients and the SoC% increasing steadily. This behavior is consistent with a well-designed energy management strategy, balancing power demand and maintaining battery health by avoiding rapid fluctuations in current and voltage.

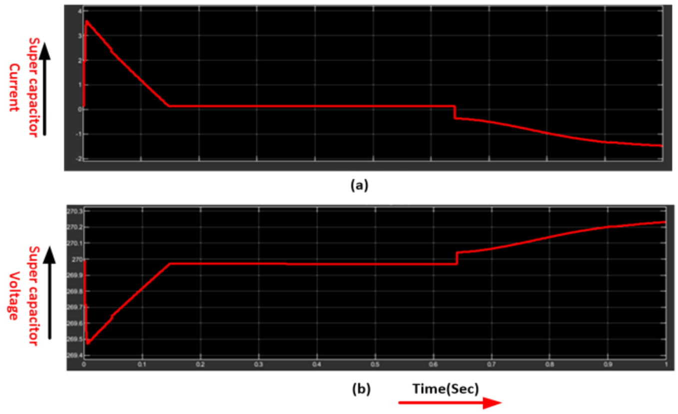


**Figure 7.** Supercapacitor Current Flow and Voltage Levels Over Time

This *figure 7* displays two graphs that represent Supercapacitor Current Flow and Voltage Levels over Time. These graphs indicate that the supercapacitor initially discharges to support the system, then stabilizes with minimal discharge. Toward the end, it begins charging slightly, restoring its voltage. This behavior is typical in hybrid systems where the supercapacitor handles transient loads and charges during low-demand periods, enhancing efficiency and ensuring the system can meet future power spikes.

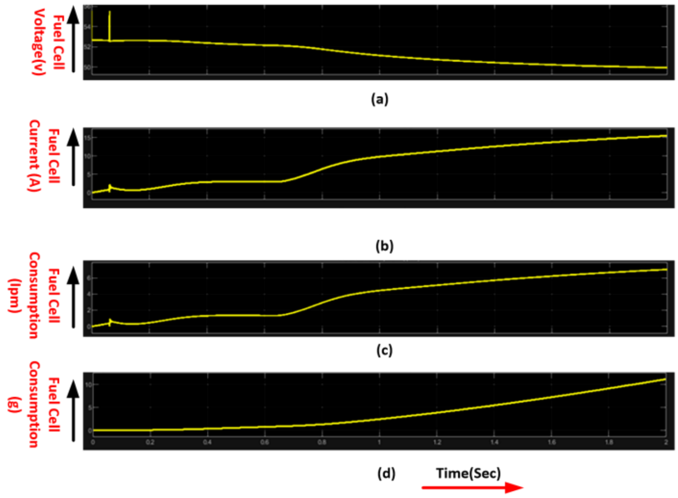


**Figure 8.** Fuel Cell Voltage, Current, Consumption Rate (Lpm), and Consumption Amount (g)

This *figure 8* presents four graphs showing various parameters of the fuel cell over time: Fuel Cell Voltage, Current, Consumption Rate (Lpm), and Consumption Amount (g). These graphs together illustrate the fuel cell's performance under load. The voltage initially stabilizes, while the current and consumption rates increase gradually, reflecting an adaptive response to power demand. The consistent fuel consumption indicates steady fuel usage, essential for maintaining the fuel cell's role as a primary energy source in the system. This behaviour supports a stable and efficient power delivery model.

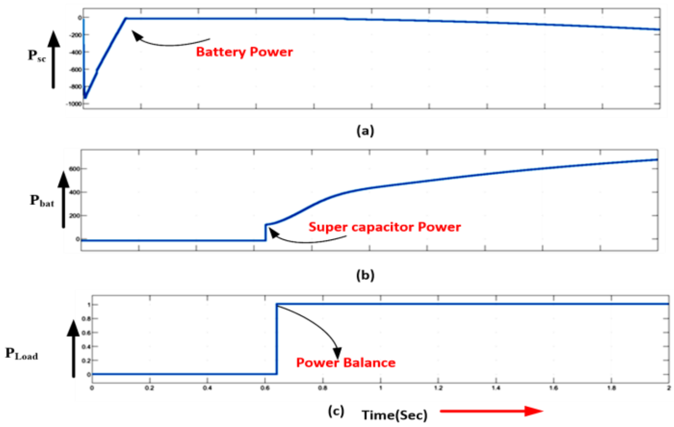


**Figure 9.** Battery Power Flow, Supercapacitor Power Flow, and Power Equilibrium Over Time

This *figure 9* contains three plots illustrating the power dynamics within a hybrid energy storage system, Battery Power Flow, Supercapacitor Power Flow, and Power Equilibrium Over Time.

These graphs collectively illustrate the interaction between the battery and supercapacitor in meeting power demands. The battery handles the initial load surge, after which the supercapacitor gradually engages to share the load, maintaining power balance. This approach enhances efficiency and helps prevent excessive discharge from the battery, thereby supporting a more balanced and sustainable energy supply across the hybrid storage system.

## 5.2. Comparative Analysis

To strengthen the manuscript, a comparative analysis of the proposed energy management strategy with alternative methods can effectively demonstrate its advantages.

**Table 2. Comparative analysis of the proposed energy management strategy with alternative methods**

| Methodology | Energy Efficiency | Battery Life Improvement | Computational Complexity | Adaptability |
|---|---|---|---|---|
| Rule-Based Strategies | Moderate | Low | Low | Limited |
| Optimization-Based | High | High | High | Scenario-Dependent |
| Hybrid Approaches | Moderate | Moderate | Moderate | Moderate |
| Proposed Method | High | High | Moderate | High |

## 5.3. Advantages of the Proposed Method

***5.3.1. Simplicity and Efficiency:*** The proposed method achieves robust energy management with a simpler structure, avoiding the added complexity of hybrid approaches.

***5.3.2. Battery Stress Mitigation:*** *Direct* control of supercapacitor and fuel cell output reduces reliance on batteries during transient demands, extending their life. Where, S indicates the scalability of the networks, T (n) denotes the throughput of 'n' *th* load and T(i) denotes the throughput of initial load. The scalability of the algorithm can be evaluated by examining its performance in various network configurations. For example, the algorithm should be able to handle a large number of users and provide a consistent QoS across all users. It should also be able to handle different types of traffic, such as video streaming, voice calling, and data transmission.

# 6. CONCLUSIONS

The analysis of the hybrid energy storage system, incorporating a battery and supercapacitor, reveals an effective approach to managing power demands in electric vehicles. The battery primarily addresses the initial power surge, delivering rapid response to immediate load demands, while the supercapacitor gradually steps in to support ongoing energy needs. This power-sharing arrangement helps maintain stability and prolong battery life by reducing excessive discharge cycles.

The coordinated control strategy, as demonstrated in the graphs, allows for a balanced power flow between the battery and supercapacitor, optimizing energy efficiency and ensuring that peak loads are effectively managed. The gradual engagement of the supercapacitor not only mitigates the stress on the battery but also leverages the high-power density of the supercapacitor to handle transient demands, enhancing overall system performance.

# REFERENCES

[1] Babu, Jarapala Ramesh, ManasRanjan Nayak, and B. Mangu. "Development and Application of an Energy Management System for Electric Vehicles Integrated with Multi-input DC-DCBidirectional Buck-Boost Converter." International Journal of Electrical and Electronics Research 11.2 (2023): 457-464.

[2] Babu, Jarapala Ramesh, ManasRanjan Nayak, and B. Mangu. "Design and Control of a Tricycle with a Hybrid Electric Motor Cooling System Powered by Solar Photovoltaics." International Journal of Electrical and Electronics Research 11.2 (2023): 465-472.

[3] S. Mishra, S. C. Swain, and R. K. Samantaray, "A review on battery management system and its application in electric vehicle," in 2021 International Conference on Advances in Computing and Communications (ICACC), IEEE, 2021, pp. 1–6.

[4] Babu, Jarapala Ramesh, Manas Ranjan Nayak, and B. Mangu. "Renewable Energy Applications and a Multi-Input DC-DC Converter for Hybrid Electric Vehicle Applications using MATLAB/Simulink." 2021 Innovations in Power and Advanced Computing Technologies (i-PACT). IEEE, 2021.

[5] J. A. Sanguesa, V. Torres-Sanz, P. Garrido, F. J. Martinez, and J. M. Marquez-Barja, "A review on electric vehicles: Technologies and challenges," Smart Cities, vol. 4, no. 1, pp. 372–404, 2021.

[6] R. Xiong and W. Shen, Advanced battery management technologies for electric vehicles. John Wiley & Sons, 2019.

[7] L. Komsiyska, T. Buchberger, S. Diehl, et al., "Critical review of intelligent battery systems: Challenges, implementation, and potential for electric vehicles," Energies, vol. 14, no. 18, p. 5989, 2021.

[8] Y. Qiu and F. Jiang, "A review on passive and active strategies of enhancing the safety of lithium-ion batteries," International Journal of Heat and Mass Transfer, vol. 184, p. 122 288, 2022.

[9] H. A. Gabbar, A. M. Othman, and M. R. Abdussami, "Review of battery management systems (bms) development and industrial standards," Technologies, vol. 9, no. 2, p. 28, 2021.

[10] X. Yue, Q. Yin, G. Xi, et al., "Comparison of bmss with ses for the symptomatic intracranial disease of the middle cerebral artery stenosis," Cardiovascular and interventional radiology, vol. 34, no. 1, pp. 54–60, 2011.

[11] V. Bindhu and G. Ranganathan, "Effective automatic fault detection in transmission lines by hybrid model of authorization and distance calculation through impedance variation," Journal of Electronics, vol. 3, no. 01, pp. 36–48, 2021.

[12] D. Krishna, M. Sasikala, and R. Kiranmayi, "FOPI and FOFL controller based UPQC for mitigation of power quality problems in distribution power system," Journal of Electrical Engineering & Technology, vol. 17, no. 3, pp. 1543–1554, 2022.

[13] X. Lin, S. Zeng, and X. Li, "Online correction predictive energy management strategy using the q-learning based swarm optimization with fuzzy neural network," Energy, vol. 223, p. 120 071, 2021.

[14] R. S. Sankarkumar and R. Natarajan, "Energy management techniques and topologies suitable for hybrid energy storage system powered electric vehicles: An overview," International Transactions on Electrical Energy Systems, vol. 31, no. 4, e12819, 2021.

[15] A. K. Podder, O. Chakraborty, S. Islam, N. M. Kumar, and H. H. Alhelou, "Control strategies of different hybrid energy storage systems for electric vehicles applications," IEEE Access, vol. 9, pp. 51 865–51 895, 2021.

[16] N. Yang, L. Han, C. Xiang, H. Liu, and X. Li, "An indirect reinforcement learning based real-time energy management strategy via high-order markov chain model for a hybrid electric vehicle," Energy, vol. 236, p. 121 337, 2021.

[17] P. Szcze´sniak, I. Grobelna, M. Novak, and U. Nyman, "Overview of control algorithm verification methods in power electronics systems," Energies, vol. 14, no. 14, p. 4360, 2021.