Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 8, No.1, August : 2025

MODELING AND SIMULATION OF A RENEWABLE-INTEGRATED HYBRID ENERGY STORAGE SYSTEM FOR ELECTRIC VEHICLE APPLICATIONS

Priyanka Mishra, Research Scholar,
Saurabh Gupta, Associate Professor,
Devendra Sharma Assistant Professor
Department of Electrical & Electronics Engineering, Technocrats Institute of Technology and Science, Bhopal, India

Abstract- In recent years, the adoption of electric vehicles (EVs) has increased significantly, primarily due to the rising cost of conventional fossil fuels and strong policy support and incentives from governments. EVs depend heavily on energy storage systems (ESS) for propulsion. However, they face two major limitations: limited driving range and prolonged battery charging times.
To address these challenges, this research presents the design and performance analysis of a hybrid energy storage system (HESS) for electric vehicle applications. The proposed system integrates a battery and a supercapacitor to optimize energy storage and utilization. While the battery serves as the primary energy source for sustained operation, the supercapacitor complements it by handling frequent high-power demands, especially during acceleration and regenerative braking. This combination enhances the overall efficiency, lifespan, and responsiveness of the energy storage system.

Keywords: Battery Charger, EV, Ultra- capacitors/Supercapacitors, , Power, Capacity, ESS.

1. Introduction

Energy Storage Systems (ESS) refer to a collection of methods and technologies used to store energy for later use. These systems allow energy to be retained during periods of availability and utilized when demand arises, ensuring reliability and continuity of energy supply. This is particularly important for renewable energy sources such as solar, wind, and tidal energy, which are inherently intermittent and do not always produce energy when it is needed.

In many cases, the energy generated from renewable sources is not consumed immediately but must be stored for use during periods of low or no generation. This makes energy storage a critical component in the efficient integration of renewable energy into the power system.

Energy exists in various forms, including radiant, chemical, gravitational potential, electrical potential, electricity, thermal energy (elevated temperature and latent heat), and kinetic energy. Energy storage systems are designed to capture and retain one or more of these forms, converting and releasing them as needed to meet specific operational demands.

The hybridization of energy systems offers several key advantages for electric vehicles (EVs) and hybrid electric vehicles (HEVs). These include improved fuel economy, enhanced system flexibility, better management of transient operating conditions, and a reduction in cost per unit power. Additionally, hybrid systems can help mitigate challenges such as fuel cell cold-start issues and ensure smoother performance during rapid load variations.

One commonly used converter topology in electric vehicle applications achieves high efficiency by enabling zero-voltage switching (ZVS) during the turn-on of all switches. This significantly reduces switching losses and improves overall performance.

A compact two input converter for electric vehicle is present for standalone PV systems. Moreover, high voltage gain of the converter for electric vehicle makes the converter for electric vehicle suitable for low input voltage applications. However, the high number of semiconductors and passive elements reduce the efficiency. Control method preset in the vehicle's controller should control the power flow between renewable resources, battery unit and electrical motor.

Figure 1: PV based charger

Figure 1 is presenting the PV based energy storage system for the charging the electric vehicle. Optimal utilization of power resources, providing demand power permanently, operating fuel cell and PV panel in their optimum region are the main duties of control scheme. Some converter for electric vehicles has been proposed recently for PVs systems. But, the required converter for electric vehicle for HEV applications should extract power from PV and FC. Besides, in order to supply Back- up power from the battery, a bidirectional port is needed to charge and discharge the battery according to discrepancy between generated power and demanded energy. . A multi input converter for electric vehicle (MIC) can provide power to the load from different energy sources simultaneously or individually. Due to the fact that initial cost of PVs is high and in order to increase the extracted power from the PV panels, MPPT algorithm has to be utilized.

2. Proposed Methodology

The proposed model and methodology description is as following-

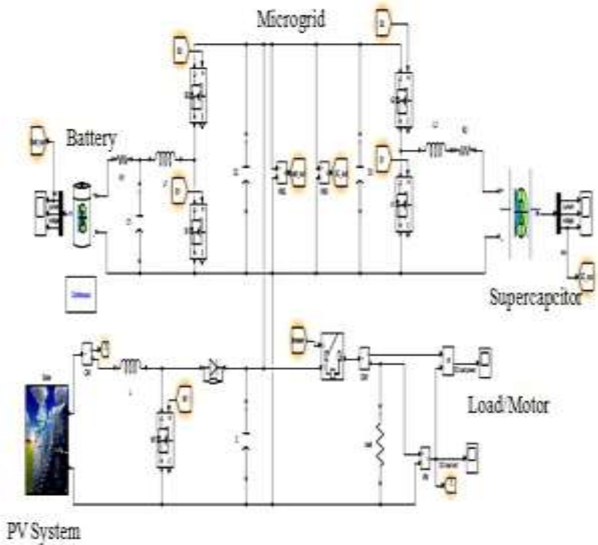

Figure 2: Proposed Model

Figure 2 is showing present HESS EV model. This model consist various sub models which is described in details.

Sub-Modules

- Solar power
- MPPT Algorithm
- Boost converter

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 8, No.1, August : 2025

- Battery
- Super capacitor

Solar Power-

Photovoltaic (PV) solar panels absorb sunlight and convert it into electrical energy through the photovoltaic effect. A photovoltaic (PV) module is a packaged and connected assembly typically consisting of 96 individual solar cells, although configurations can vary depending on design and application.

multiple PV modules are connected together to form a photovoltaic array, which serves as the primary component of a solar power generation system. These arrays are deployed in both commercial and residential settings to supply clean, renewable electricity.

MPPT Algorithm-

Maximum Power Point Tracking (MPPT) is a widely used technique in photovoltaic (PV) solar systems and wind energy systems to ensure maximum power extraction under all environmental and load conditions. In the context of PV systems, MPPT is implemented as an algorithm within the PV inverter or DC-DC converter controller, which continuously adjusts the operating point of the solar array to ensure it operates at or near its Maximum Power Point (MPP).

DC-DC Bidirectional Capacitor

Bidirectional dc to dc converter is used as a key device for interfacing the storage devices between source and load in renewable energy system for continuous flow of power. In electric vehicles also, bidirectional converter is used between energy source and motor for power supply from battery to motor. Bidirectional dc to dc converters work in both buck and boost mode and can manage the flow of power in both the direction between two dc sources and load by using specific switching scheme and phase shifted control strategy and hence generated excess energy can be stored in batteries/super capacitors.

Battery

battery is a device consisting of one or more electrochemical cells that convert chemical energy into electrical energy, and it includes external terminals to deliver power to electrical devices such as flashlights, mobile phones, and electric vehicles (EVs). When a battery supplies electrical power, its positive terminal functions as the cathode, and the negative terminal serves as the anode.

The negative terminal acts as the source of electrons, which flow through the external circuit to the positive terminal, generating electric current. When the battery is connected to an external electrical load, an electrochemical reaction occurs within the cells. This reaction transforms high-energy reactants into lower-energy products, and the difference in free energy is released as electrical energy, which is then supplied to the external circuit.

Super Capacitor

A supercapacitor (or ultracapacitor) contrasts from a common capacitor in two significant manners: its plates successfully have an a lot greater territory and the separation between them is a lot littler, in light of the fact that the separator between them works in an alternate manner to a conventional dielectric. In spite of the fact that the words "supercapacitor" and "ultracapacitor" are frequently utilized conversely, there is a distinction: they are normally worked from various materials and organized in somewhat various manners, so they store various measures of energy.

3. Simulation Results

The design and analysis of the proposed model is performed using MATLAB software with version 9.4.

Battery Discharging Mode- When the battery is fully charge then it supplies the power to the load or motor, so battery is in the discharging mode.

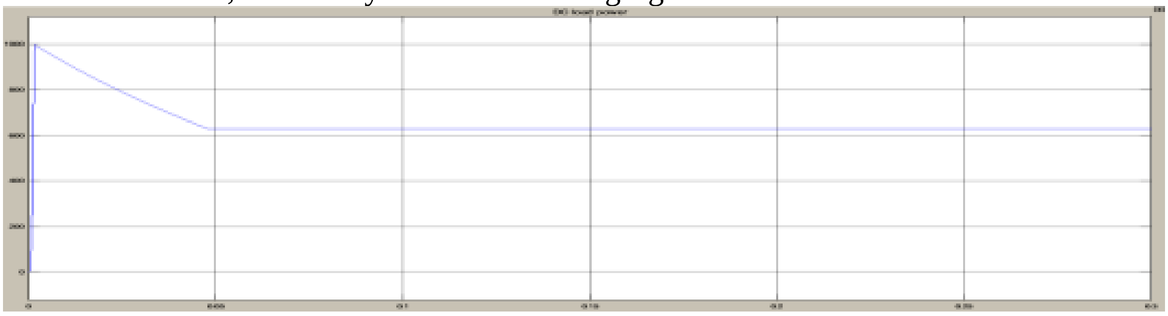

Figure 3: DC Load Power

Figure 3 is presenting the DC load power graph. The value of the DC load power is 630W.

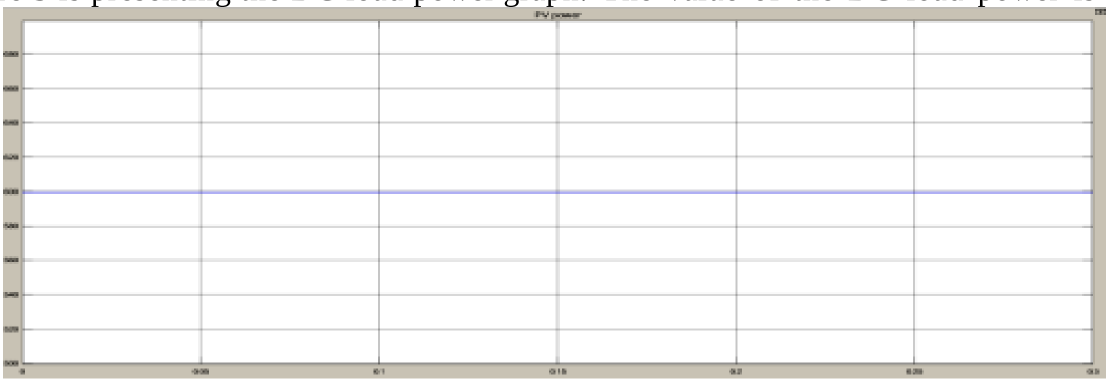

Figure 4: Solar Power

Figure 4 is presenting the solar power graph. The collected solar power value is 600W.

Load Shedding Mode (LSM)- When the battery is fully discharge then the load is disconnected and battery is stop giving the power to the load.

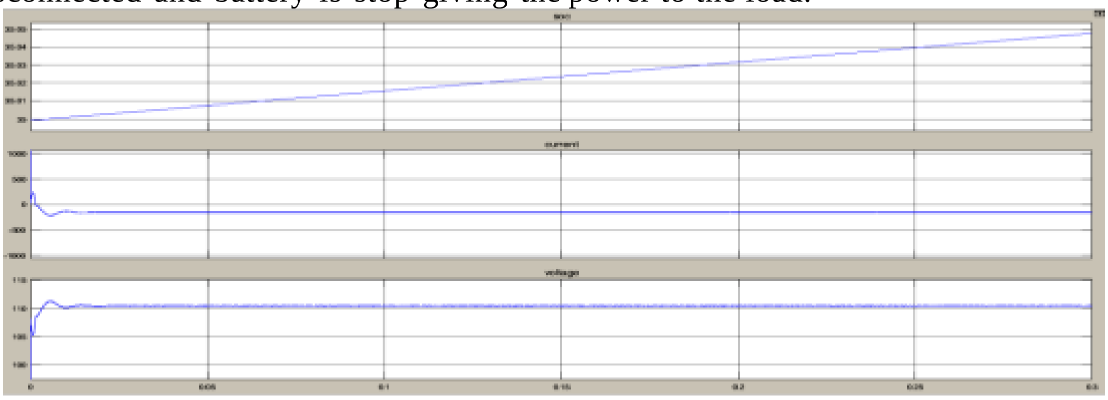

Figure 5: Battery Performance

Figure 5 is presenting the performance of the battery in terms of the state of charge, voltage and current. At the load shedding mode the state of charge of the battery is approx 30%.

Battery Charging Mode- As the battery is fully discharged, and then the solar power is start to charge the battery. Now battery charges up to the more than 80%

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 8, No.1, August : 2025

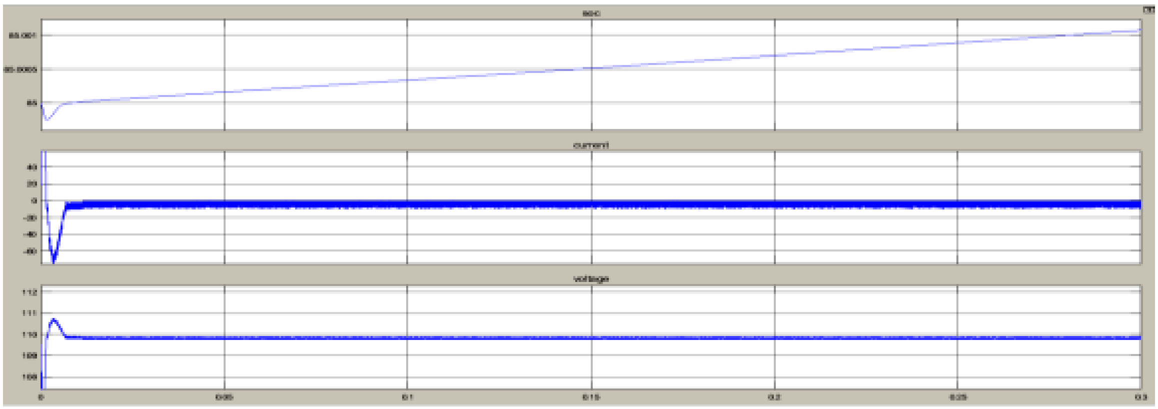

Figure 6: Battery performance

Figure 6 is presenting the battery performance during the charging state. The battery is charging and as completed charge, its start to give power to the load or motor.

Off-MPPT Mode- When the battery is fully charges then the MPPT is off. MPPT is used to track maximum power in the less time. After completion it off and when battery is discharge then it again present in the ON state.

Figure 7: MPPT output

Figure 7 is presenting the MPPT output, at the mode of off MPPT; it shows at the 0 state.

Table 1: Result Comparison

Sr No.	Parameters	Previous Work	Proposed Work
	[illegible]		
1	Lithium-ion battery	4V	110V
[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]		
3	Supercapacitor voltage	4V	32V
4	Supercapacitor Current	10A	10A
	[illegible]		
5	Renewable Source	NA	Solar

6	Control technique	Particle Swarm–Nelder–Mead	MPPT

Therefore proposed model simulation result for performance is better than previous model in terms battery, load, and super capacitor. Proposed model gives significant improved results.

4. Conclusion

This research presents the design and analysis of a hybrid energy storage system for electric vehicle applications. This EV storage system is made up of two complementary sources: chemical batteries and ultracapacitors/supercapacitors. The benefit of using ultracapacitors in a hybrid energy storage system (HESS) is to extend the extra storage. In this paper, an advanced model of a HESS consisting of a lithium- ion battery and supercapacitors has been proposed with a solar renewable energy source. The MPPT control techniques are used to control more energy in less time. As a result, a complete model of HESS in electric vehicle applications is then obtained. Future studies will be focused on the progress of improving the HESS advanced model in terms of calculation time and precision. Simulated results show a significant improvement in present model performance compared to the existing model performance. Furthermore, additional research will be conducted on the effect of temperature on battery and supercapacitor cells in order to investigate its potential impacts on model performance.

References

1. T. Mesbahi, P. Bartholomeüs, N. Rizoug, R. Sadoun, F. Khenfri and P. Moigne, "Advanced Model of Hybrid Energy Storage System Integrating Lithium-Ion Battery and Supercapacitor for Electric Vehicle Applications," in IEEE Transactions on Industrial Electronics, vol. 68, no. 5, pp. 3962-3972, May 2021, doi: 10.1109/TIE.2020.2984426.
2. M. A. Islam et al., "Modeling and Performance Evaluation of ANFIS Controller-Based Bidirectional Power Management Scheme in Plug-In Electric Vehicles Integrated With Electric Grid," in IEEE Access, vol. 9, pp. 166762-166780, 2021, doi: 10.1109/ACCESS.2021.3135190.
3. L.S. Chai et al., "An Evaluation Framework for Second-Life EV/PHEV Battery Application in Power Systems," in IEEE Access, vol. 9, pp. 152430-152441, 2021, doi: 10.1109/ACCESS.2021.3126872.
4. L. X. Zan, G. Xu, T. Zhao, R. Wang and Dai, "Multi-Battery Block Module Power Converter for Electric Vehicle Driven by Switched Reluctance Motors," in IEEE Access, vol. 9, pp. 140609-140618, 2021, doi: 10.1109/ACCESS.2021.3119782.
5. A. Avila, M. Lucu, A. Garcia-Bediaga, U. Ibarguren, I. Gandiaga and A. Rujas, "Hybrid Energy Storage System Based on Li-Ion and Li-S Battery Modules and GaN-Based DC-DC Converter," in IEEE Access, vol. 9, pp. 132342-132353, 2021, doi: 10.1109/ACCESS.2021.3114785.
6. T. Sadeq, C. K. Wai, E. Morris, Q. A. Tarbosh and Ö. Aydoğdu, "Optimal Control Strategy to Maximize the Performance of Hybrid Energy Storage System for Electric Vehicle Considering Topography
7. Information," in IEEE Access, vol. 8, pp. 216994-217007, 2020, doi: 10.1109/ACCESS.2020.3040869.

8. Y. Fan et al., "Evaluation Model of Loop Stray Parameters for Energy Storage Converter of Hybrid Electric Locomotive," in IEEE Access, vol. 8, pp. 212589-212598, 2020, doi: 10.1109/ACCESS.2020.3039343.
9. D. Qin, Q. Sun, R. Wang, D. Ma and M. Liu, "Adaptive bidirectional droop control for electric vehicles parking with vehicle-to-grid service in microgrid," in CSEE Journal of Power
10. and Energy Systems, vol. 6, no. 4, pp. 793-805, Dec. 2020, doi: 10.17775/CSEEJPES.2020.00310.
11. C. Zhai, F. Luo and Y. Liu, "A Novel Predictive Energy Management Strategy for Electric Vehicles Based on Velocity Prediction," in IEEE Transactions on Vehicular Technology, vol. 69, no. 11, pp. 12559-12569, Nov.2020, doi:10.1109/TVT.2020.3025686.
12. M. Ban, D. Guo, J. Yu and M. Shahidehpour, "Optimal sizing of PV and battery-based energy storage in an off-grid nanogrid supplying batteries to a battery swapping station," in Journal of Modern Power Systems and Clean Energy, vol. 7, no. 2, pp. 309-
13. 320, March 2019, doi: 10.1007/s40565-018-0428-y.
14. X. Hou, J. Wang, T. Huang, T. Wang and P. Wang, "Smart Home Energy Management Optimization Method Considering Energy Storage and Electric Vehicle," in IEEE Access, vol. 7, pp. 144010-144020, 2019, doi:10.1109/ACCESS.2019.2944878.
15. B. Wang, X. Zhang, U. Manandhar, H.B. Gooi, Y. Liu and X. Tan, "Bidirectional Three-Level Cascaded Converter With Deadbeat Control for HESS in Solar-Assisted Electric Vehicles," in IEEE Transactions on Transportation Electrification, vol. 5, no. 4, pp. 1190-1201, Dec. 2019, doi:10.1109/TTE.2019.2939927.
16. H. Moradisizkoohi, N. Elsayad and O.A. Mohammed, "Experimental Verification of a Double-Input Soft-Switched DC–DC Converter for Fuel Cell Electric Vehicle With Hybrid Energy Storage System," in IEEE Transactions on Industry Applications, vol. 55, no. 6, pp. 6451-6465,Nov.- Dec. 2019, doi: 10.1109/TIA.2019.2937288.
17. Q. Xu, F. Wang, X. Zhang and S. Cui, "Research on the Efficiency Optimization Control of the Regenerative Braking System of Hybrid Electrical Vehicle Based on Electrical Variable Transmission," in IEEE Access, vol. 7, pp. 116823-116834, 2019, doi:10.1109/ACCESS.2019.2936370.