Optimization Techniques Using Battery, Supercapacitor And Fuel Cell Hybrid Energy Storage Systems In Electric Vehicles

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Keywords	**Abstract**
Classic PI Control, Simulink, Hybrid Energy Storage, Li-ion Battery, Fuel Cell, Ultra Capacitor.	High electric traction motors are engaged in the electric vehicles in order to deliver required high torque to the vehicle to maintain the essential torque. Generation of high torque require high amount of current to be delivered at the traction motors. In the existing system power pack in the form of lithium-ion battery is engaged to provide the required power to the traction power. The continuous high traction power delivery causes multiple problems like aging mechanism causing speedy worsening of the battery performance and even sometimes causes thermal runaway. Hybrid energy storage system is the way to address this issue in an effective way. The present research work is the verified means for providing constant energy source for high power delivery to the traction motors. In the research work multiple energy sources like lithium-ion battery source, fuel cell and ultra capacitor are used for development of the hybrid energy source. These energy sources are intelligently engaged through different control strategies in order to ensure confirmed required power delivery at the traction motors. Different modules from the Simulink are used for the development and analysis of the targeted system.

I.INTRODUCTION

Technical revolution caused every dimension of the life to be rethink and redesigned. This revolution has also changed the global transportation mechanism by entering into the sphere of electric vehicles from IC engine to the vehicles driven by traction motors. The modern high electric charge density lithium-ion batteries are engaged as a power bank to deliver the required high current to the traction motors which are highly capable of delivering required high torque in the range of thousands of Nm. Such electric vehicles are capable of transporting to the long distances on a single charge basis which results into cost effective transportation of the products. EVs are also considered as the solution to the traditional petrol or diesel-based vehicles.

Apart from having long list of pros of the EVs, it has certain research areas which are to be addressed. The primary issues with such vehicles is like vehicle sometime have to travel over steep ascend which required gradual or sudden power delivery to the traction motor; sometimes sudden acceleration, emergency stops and different unpredictable situation which require super quick charging and discharging this causes battery aging, degradation in charge holding capacity. This issue can be partially be addressed at the manufacturing end by improving the material used and improving the operating conditions like through proper condition by providing proper coolant and other necessary provisions.

This isn’t the full proof solution to maintain the power delivery at long distance travelling and prolong the battery degradations. Through this paper, a solution based on control strategy is demonstrated for intelligent utilization of the power source by giving solution at the system topology level.

The proposed hybrid energy storage system for electric vehicles is the solution to prolong the energy source degradation and extend the battery life by intelligently managing the power delivery to the electric traction motors of the electric vehicles. In the hybrid energy storage system, different energy sources like lithium-ion battery, fuel cell and ultra capacitor is used and intelligently brought into action for delivering the required power to the traction motor. A dedicated control unit is used for the overall management of the different components in the hybrid management system. A brake control provision along with the bus selector module is available to demonstrate the change in the load conditions of the vehicles. Different parameters like rpm, current, power, stator current torque, back EMF and other ascendency parameters are used to analyze the system performance. The total development of the system is discussed through the detailed literature review, system design and development, results and discussion in the subsequent sections.

II. Previously Reported Technology

For optimized energy consumption in transportation systems, hybrid electric vehicles are becoming more prominent due to their eco-friendly performance and assistance in smart grid notation. The alteration of energy storage systems in hybrid electric vehicles with many control policies generates alteration in hybrid electric vehicle types. In this paper, the authors [1] have discussed important information on energy storage systems associated with hybrid electric vehicles and the best optimization topologies. This work categorizes several control policies employing four configurations such as battery fuel cell ultra-capacitor, fuel cell ultra-capacitor, battery ultra-capacitor and fuel cell battery. The comparison is provided for several hybrid configurations based on energy effectiveness, robustness, dynamic performance, fuel consumption and battery lifetime.

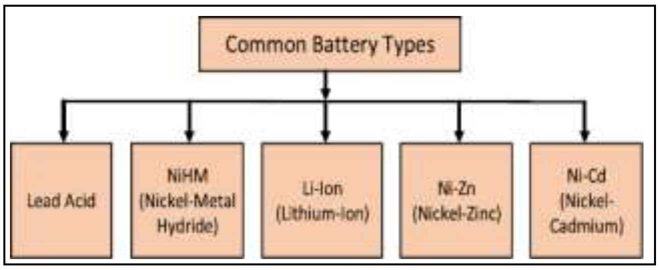

Fig. 1. Preferred Batteries in Electric Vehicles

The authors [2] have proposed a hierarchical energy management strategy and a multi-dimensional size optimization framework to reduce the component size and increase the power of a plug-in hybrid electric vehicle with a hybrid energy storage system. To calculate the dimension and the power efficiency, a plug-in hybrid electric vehicle with a battery energy storage system is utilized as a reference. The dimension optimization technique provides the best possible configuration of the system, including the maximum power and capacity of the supercapacitor, the maximum power and capacity of the battery and the maximum power of the system. When compared with a battery energy storage system, the dimension optimized hybrid energy storage system decreases the capacity of the system by 33.8% and enhances the economy by 39.3%. The hierarchical energy management strategy can concurrently smother battery life and optimize vehicle fuel consumption.

The authors [3] have presented several literatures to investigate the role of energy recovery and energy harvesting in the development of fuel-cell hybrid electric vehicles and battery electric vehicles. Recovery energy and harvesting energy can considerably enhance energy effectiveness and decrease fuel utilization. Regenerative braking system drivers' movement effects on energy recovery are investigated and the perspective of energy harvesting in electric vehicles is also studied. This paper recognizes important research gaps, some challenges and future scope for research in this field.

For electric vehicles, the authors have proposed an energy- efficient management system including a battery supercapacitor hybrid energy storage system. The key goal of this paper is to enhance the performance of the hybrid energy storage system by integrating battery and supercapacitor characteristics to guarantee constant hybridization during the drive cycle. The slope of the road is determined by the counter location system. Two algorithms are designed to handle the energy shared between the supercapacitor and the battery. The hybrid energy storage system model, electric vehicle and controllers are tested by employing a simulator at different speeds. The experimental outputs show that the controllers enhance the battery life cycle by reducing the stress on the battery for the drive cycle. [4]

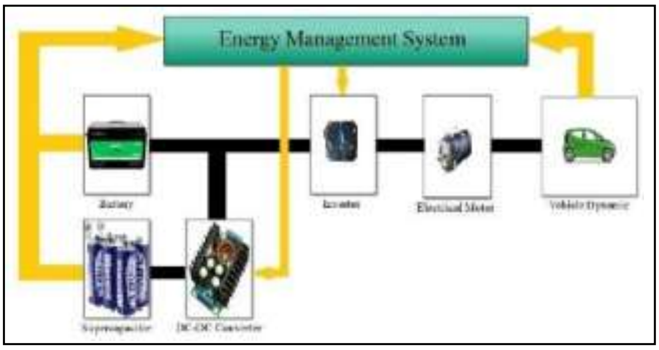

Fig. 2. Disclosed Architecture by the authors in [4]

In the global atmosphere, traditional internal combustion engine-based vehicles are the main cause of greenhouse gas emissions. The best alternative to replace the traditional internal combustion engine-based vehicles is electric vehicles due to the insignificant emissions and the probability of the renewable energy incorporation. However, the selection of a proper storage system is a key task in electric vehicles as they need separate storage systems. The authors [5] have evaluated the conventional storage techniques for electric vehicles based on a multi-criteria decision-making model on several criteria including protection, health, cost, compatibility, atmosphere, and technical characteristics. Super decision technique is employed to solve the analytic hierarchy procedure model. In most cases, an analytic hierarchy procedure model recommended the consumption of hybrid sodium nickel chloride batteries and supercapacitors for electric vehicles.

The saturation of electric vehicles in the transportation sector is increasing but traditional fuel engine-based vehicle dominates. To fast-track the acceptance of electric vehicles and to attain supportable transportation, the blockages need to be estimated that primarily contain the high cost of electric vehicles, variety concerns, lack of electric vehicle charging substructure and the pollution of the grid due to electric vehicle chargers. This paper provides a comprehensive examination of electric vehicle technology that mainly includes electric vehicle supply equipment, energy storage systems and electric vehicle chargers. Dissimilar topologies are discussed with low and high-frequency transformers. The diverse accessible power levels for charging are discussed. To decrease the range, concern the electric vehicle chargers based on inductive power transfer are discussed. The last part of the paper focuses on the negative effects of electric vehicle chargers along with the remedies that can be accepted. [6]

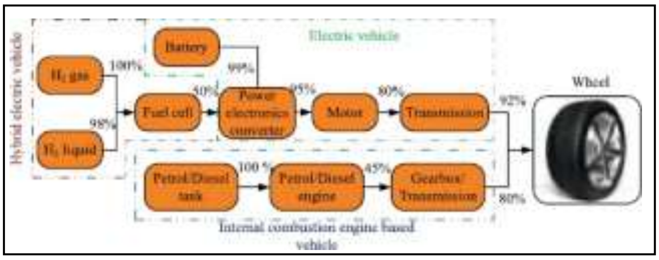

Fig. 3. Demonstration of Efficiency of Different Vehicles

In this paper, the authors [7] have proposed an energy effective management framework for fuel cell hybrid electric vehicles employing machine learning techniques. In traditional fuel engine-based vehicles, petroleum-based fuels are used to provide good performance and long-distance speed. However, there are some limitations to using petrol and diesel, and the merger of these different optimization methods is capable of providing the best possible performance. The other aim of the proposed research is to develop an effective energy controlling scheme by integrating the K-nearest neighbor, support vector machine and Naive Bayes method. Finally, these classifiers comprising of K-nearest neighbor, support vector machine and Naive Bayes provides accuracy percentages of 94%, 92% and 96% respectively.

A real instant average power technique based on a power split framework is implemented for enhancing the power output of the battery and mode switching frequency of a multi- mode hybrid energy storage system. A law-based framework is constructed based on the high frequency power demand, to attain power allocation and mode switching for the multi- mode hybrid energy storage system. Moreover, a generally real time average power technique is accepted to procedure the high frequency power demand. The ultra-capacitor functions as an improved low-pass power filter and the battery can supply constant and smooth resultant power to the motor inverter. The benefits of the proposed power split framework for enhancing the power result of the battery and the mode switching frequency of the multi-mode hybrid energy storage system in electric vehicles are indicated under three typical driving cycles. [8]

The rising requirement to slow down the environmental variation for atmospheric security demands further modifications towards sustainable mobility and regenerative energy. To overcome this problem, fuel cell hybrid electric vehicles is the most efficient way for high energy applications. This consists of a fuel cell system for energy supply and buffering energy storage. The authors [9] have presented recent modifications regarding fuel cell hybrid electric vehicles in several heavy-duty systems. To enable system consumption and energy management strategy design, functionality techniques for fuel cell system, ultra-capacitor and battery related subsystems are discussed. Finally, for the energy management strategies, the authors have proposed a model predictive control technique which deals with the mitigation of degradation effects.

A battery ultracapacitor hybrid energy storage system is one of the most dependable techniques to reduce the limitations of a single power source system for its corresponding characteristics of power and energy in plug-in hybrid electric vehicle applications. An incorporated energy management process, which contains three layers to allocate the ultra-capacitor packs and the power of the battery packs is proposed. Initially, a hybrid energy storage system constraint match technique is produced under various driving cycles with optimization objectives of weight and cost. Then, several layers of wavelet transform algorithm are used to separate the dissimilar frequency elements of power demand. Finally, artificial intelligence is implemented to control power flows between different elements to ensure the hybrid energy storage system performance. [10]

The authors [11] have proposed an ultra-capacitor hybrid energy storage system for pulsed load in which ultra-capacitors simulate the pulse part and the battery runs the steady portion of the load.

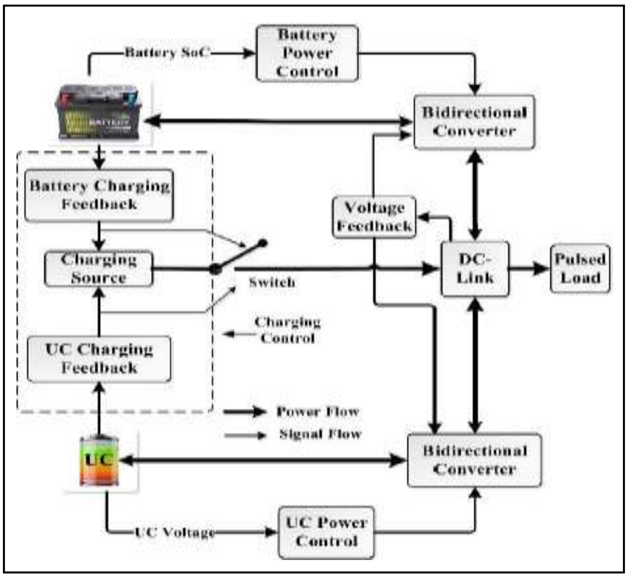

Fig. 4. Proposed Architecture of the System in [11]

The energy stored in ultra-capacitors is directly proportional to its square of voltage so an active parallel hybrid topology with two bidirectional converters is used that provides ultra-capacitors an individual bidirectional converter to handle its lower and upper voltage limits. To give a distinct control of the battery, another converter is associated with the DC link and the battery. Steady output voltage across the load is retained through a feedback control loop. A comparison investigation amongst ultra-capacitor alone, battery alone and battery ultra-capacitor hybrid mode is done which clarifies that the proposed system is 57% lower in price than its counterparts.
Electrical variable transmission is a new electromechanical energy converter that can be applied in hybrid electrical vehicles. The authors [12] have investigated the hybrid electrical vehicle based on electrical variable transmission and the effectiveness optimization policy of regenerative braking system. Initially, this article

investigates the dynamic coupling mode of the electrical variable transmission-hybrid electrical vehicle and develops the expression of the dynamic coupling relationship between the electrical variable transmission and the engine. Then, several braking modes including new ones are divided. Finally, a hierarchical controller was proposed for braking mod switching and a neural network algorithm was employed for the best possible effectiveness control for the system.

The Internet of Things is a rapidly growing technology to provides detailed correspondence employing simplicity and strength of creativity used in the vehicles. Several patients who for the reason of adaptability problems might need an immediate response in case of an accident. Such a situation raises the need for additional staff to speedily and accurately find accident exploited human beings. The authors [13] have elucidated the braking and accident prevention systems in a vehicle. For the collection of information concerning accidents, cloud computing is employed.

A huge number of articles have been published in the last few years applying reinforcement learning algorithms to the optimization of battery storage in houses, industries, energy harvesting energy of things networks, micro-grids, plug-in hybrid electric vehicles, renewable generation and electric vehicles. This application can be investigated in four different steps 1) The kind of optimization issue is investigated and the literature can be divided into approaches that optimize either energy efficiency or financial targets. 2) The strategy for controlling consumer comfort is investigated for applications that may affect consumers. 3) The presented article discusses the method to model and decrease battery deprivation. 4) The papers are divided by application context and applications likely to catch the attention of a huge number of researchers are recognized. [14]

The vehicle atmosphere supportive control shows a huge amount of potential to enhance vehicle performance. Therefore, it is advantageous to further analyze the incorporation of the vehicle atmosphere supportive control. In this paper, the authors have proposed a new technique to forecast the velocity profile. The key goal of the proposed technique is to enhance the energy management performance of plug-in hybrid electric vehicles. For merging the cloud server, onboard vehicle control unit and mobile edge evaluation server to give more precise outputs, a compound velocity prediction algorithm is developed. Finally, a case discussion is carried out on the proposed compound velocity prediction algorithm compound velocity prediction algorithm technique for energy management of plug-in hybrid electric vehicles. [15]

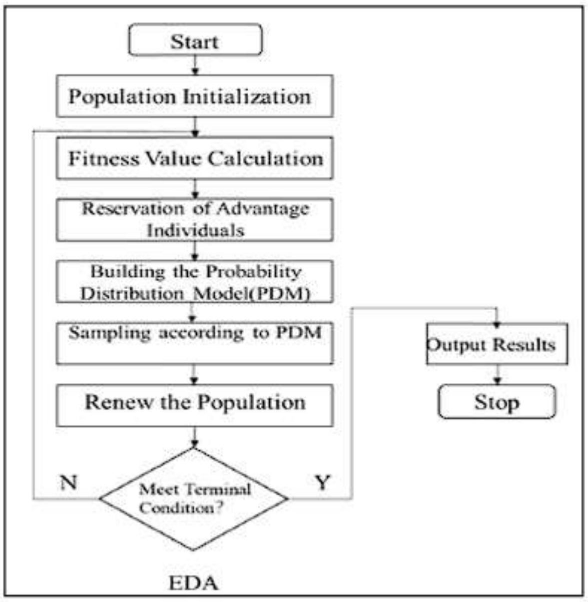

Fig.5. Estimation of Distributed Algorithm as Disclosed in [15]

To avoid vehicle collisions caused by sleepiness and, an intermediary circumstance between attentiveness and drowsiness, several investigations have been done by making the use of different supervision techniques and identification approaches. The Electroencephalogram technique was found as the most frequently employed supervision technique due to its benefits compared to other techniques. Moreover, Deep Learning approaches have been extensively employed and have given outstanding outputs. In this paper, the authors have done a detailed analysis of different deep-learning techniques. The main objective was to reveal the best possible deep-learning technique for identifying Electroencephalogram sleepiness utilizing a minimum information set. The authors

[16] have calculated the performance of the techniques employing the hold-out technique and left single subject out cross-validation methods. The hold-out technique shows an efficiency of 80% and the leave single-subject-out cross- validation method shows an efficiency of 75.42%.
A switching bi-directional buck-boost converter is proposed for vehicles to the grid system. The proposed technology is capable of giving an energy bi-directional flux way for the exchange of energy amongst supercapacitors or lithium batteries of the hybrid energy storage system of the electric vehicle and the grid. Also, the state space averaging technique is employed to investigate the stability of the topology in both buck and boost modes.

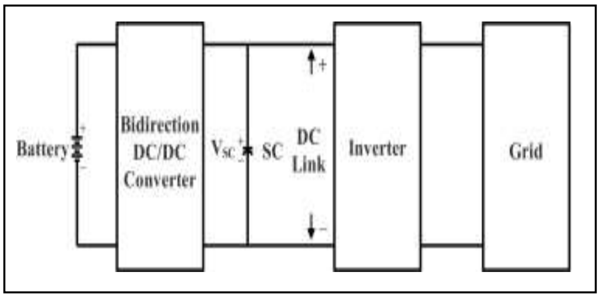

Fig. 6. Hybrid Energy Storage System Discussed in Cited Paper

The lithium battery is charged in steady voltage and steady current mode. The control policy is provided to the state of charge of the energy storage system to guarantee that the resultant current and voltage are constant. Based on bode plots, the current and voltage controllers are designed in the frequency domain. [17]
This article implemented a loss reduction control policy for an integrated multi-drive topology utilized in hybrid electric vehicles. In this integrated multi-drive, the integrated multi-drive stator section of the winding induction machine is interfaced with the storage units through three-phase inverters. The most important aim is to optimize the management of multi-directional power flows in an integrated multi-drive configuration, decreasing the energy storage units and the power losses of the induction machine maintaining the execution complication low. The proposed strategy frequently looks for the best compromise between the power ability and the torque response of every storage unit. Employing such a kind of topology provides a considerable enhancement in the overall effectiveness. [18]

In this paper, a novel regenerative braking handle strategy based on braking energy optimization handler and trajectory optimization handler to improve braking power recovery under sliding situations for electric vehicles. Braking systems of electric vehicles including regenerative braking systems and mechanical braking systems are employed. To enhance the regenerative braking performance of the sliding braking situation of electric vehicles, braking influence and current variations are considered as indicators. Moreover, the trajectory optimization handler and braking energy optimization handler are constructed employing multi-object optimization outputs. [19]

An emerging supporter of global decarbonization is green hydrogen. Green hydrogen can diminish the burden of electrification of heat and transport on energy networks and gives a sustainable energy resource. The authors [20] have proposed a standalone hybrid green power system to provide on-line charging of electric vehicles. The standalone hybrid green power system contains fuel cells, electrolytes, photovoltaic arrays and wind turbine units. The proposed technology uses the particle swarm technique to calculate the importance of economics and dependability indices for the standalone hybrid green power system. The experimental outputs show that electric vehicle charging with peak loading has considerable effects on the standalone hybrid green power system.

Nowadays, the mode of transportation is switching towards electric vehicles rapidly. In this paper, the authors [21] have discussed the real-time barriers obtained in E- vehicles due to several energy storage devices. Several problems related to raw materials, charging time and efficiency of the battery were discussed. The system achieves intense temperature levels during energy conversion with power electronic circuits which decreases the system performance. To sustain the most favorable temperature level, it is very important to analyze the temperature effect of the system. Due to the employment of power electronic components, some noise is produced known as electromagnetic interference. Therefore, to moderate the electromagnetic interference effect, the low pass filter based electromagnetic interference filter is introduced in the system such that the noise level is suppressed.

The authors [22] have proposed an actual moment vehicle speed-controlling system known as the actual moment energy deceleration controlling system. Navigation technologies such as traffic light details and front identification sensor information are developed to recognize deceleration incidents. The proposed actual moment energy deceleration controlling system has employed two speed controlling tactics with dissimilar levels of the controlling horizon. If the vehicle is identified within a threshold range, then a model prognostic planning-based energy proficient slow down approach that integrates the crowd condition in front of the vehicle and develops vehicle-to-vehicle communication with the prior vehicles is initiated to reevaluate the speed route of the vehicle to assure a collision avoidance.

Hybrid e-vehicles need an energy management policy to acquire fuel economy performance. In the equivalent minimization technique, a parameter known as the equivalent factor should be calculated to attain the best possible control strategy. In this paper, the authors [23] have proposed a reinforcement learning based technique to identify the equivalent factor. The authors have proved that the equivalent factor can be indirectly removed from the reinforcement learning outputs by employing a specific driving cycle. Additionally, a new technique that combines the equivalent consumption minimization and reinforcement learning strategy is proposed. A model-based reinforcement learning technique is employed. The proposed technique is validated for vehicle simulation using a parallel hybrid electric vehicle.
After reviewing different technology, reported by different esteemed authors, the research work can be summarized through the following table.

Table 1. Summarization of the Cited Technology

Methodology	Description	Hurdles
Control Strategies of Different Hybrid Energy Storage System [1]	Fuel cell batteries, battery ultra- capacitor, fuel ultra- capacitor and battery fuel cell ultra- capacitor are discussed	Vehicle with an internal combustion engine result in greenhouse effect
Maximize the performance of Electric Vehicle using Topography Information [4]	Improved the performance by combining battery and super capacitor characteristics	Energy storage systems need to employ renewable energy resources instead of relying on fossil fuels
Effective Energy Management for Hybrid Electric Vehicles using Classifier Fusion Technique [7]	Petroleum based fuels are employed in cars to achieve better performance and long-distance speed	Utilization of petrol or diesel gives poor fuel economy and pollution causing exhaust gas emission
Hybrid Energy Storage System to Increase Battery Life Under Pulse Load [11]	Ultra-capacitor run the pulse portion of the load while the battery powers the constant part of the load	A pulsed load causes a current /voltage ripple that rapidly discharges the battery
Hybrid Energy Storage System Based on Li-Ion Battery [16]	Employed Lithium- Titanate-Oxide battery to guarantee high power capabilities	The use of Li-Ion batteries can be limited in cars with a high demand for peak power and very high energy density
Heuristic Based Programmable Controller for Effective Energy Management in Smart Grid [19]	The energy storage system is proposed for photovoltaic and electric vehicles in the smart grid	Traditional energy storage management systems are unable to provide sustainable solution in terms of decrease carbon emission
Bidirectional Charging Policy for Electric Vehicle [21]	Low pass filter-based EMI filter is proposed which surpasses the noise level and controls the various ranges	Several real time issues are occurred in electric vehicles due to the various ranges of energy storage devices
Reinforcement Learning Based on Strategy for Optimal Control of Hybrid Electric Vehicles [23]	Reinforcement learning based policies are developed to identify the equivalent factor	HEV needs an energy management strategy to attain competitive fuel economy performance

III. Proposed Hybrid Energy Storage System

A hybrid energy storage system is disclosed through this paper in order to meet different challenges posed through the traditional power pack systems in the electric vehicles. In this hybrid energy storage system, different energy sources are used to provide uninterrupted energy to the traction motors. The hybrid energy sources which are used in development of the system are Lithium-Ion battery, Fuel Cell and Ultra Capacitor.

These sources are intelligently activated to regulate the power supply to the traction motor. This system and intelligent management of the hybrid energy source is self- sufficient to provide the large current requirements in the situations of sudden acceleration, steep ascent and other similar situations where large amount of current is drained out from the energy source. The subsequent figure discloses the systematic block diagram of the proposed hybrid energy storage system. The proposed hybrid energy storage system is comprising of brake control unit, control module, bus selector and load performance analysis block.

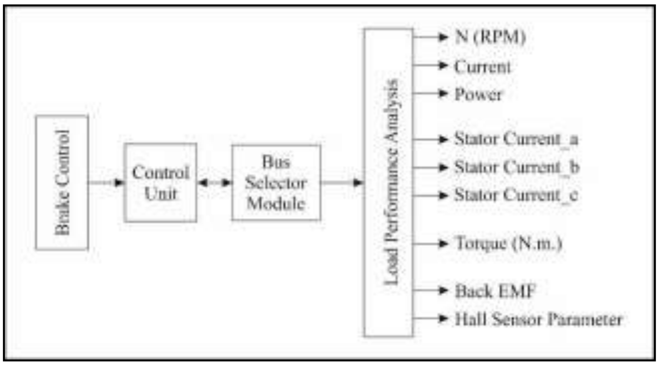

Fig. 7. Overall System of Hybrid Energy Storage System

In the proposed hybrid energy storage system, the brake control unit is the means through which variable load can be applied on the traction motor in controlled environment. Here braking is done through the control unit which is heart of the system. Inside the control unit, pulse control mechanism is provided which drives the Pulse Width Modulation module.

Regenerative braking system is another module added to demonstrate the braking effect on the traction motor. The PWM modulator unit and the Regenerative Braking Unit drive the gate control unit which logically generates the pulse pattern to control the IGBT gates in order to drive the traction motor. The energy management system is directly connected to the IGBT control unit which intelligently manages the source from which the current is to be driven through the driver circuit for traction motor of EV. The subsequent figure depicts different power sources and individual driving circuit for them.

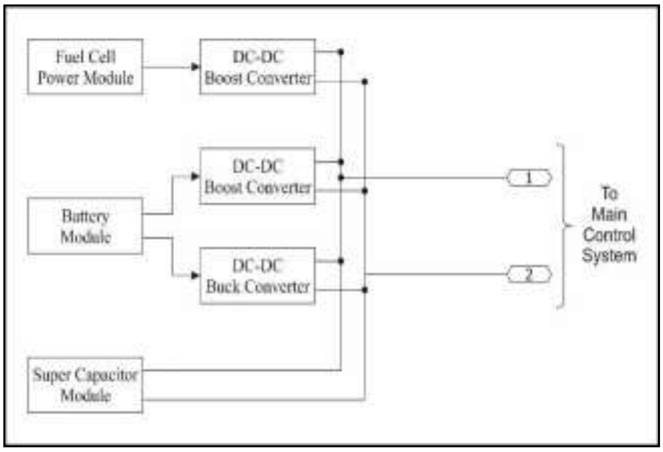

Fig. 8. Power Sources and Individual Driving Circuit

As shown in the above figure, Fuel Cell, Battery Module and the Super Capacitor are the three different sources which are perceptively deployed to fulfill the real time power demand of the EV. Each of the power source is fed to the Buck or Boost converter. These converters are DC-DC converter which generates the output power which is either greater or smaller than that of the input power. The converted output is fed to the control unit, which is shown in the fig.7. Some of the output which are recorded during the simulation is disclosed in the subsequent section.

IV. Results and Discussion

The implementation of the above proposed system is carried out using the Simulink toolbox of the Matlab tool.

The overall system is depicted in the following figure.

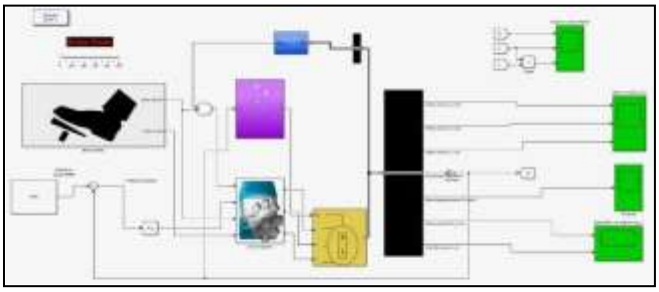

Fig. 9. Overall System Implemented in Simulink

Above fig.9 depicts the brake pedal unit, control unit, traction motor, bus bar section for load performance analysis along with different analytical output measurement units. After simulating the above module, performance of the power sources is recorded as shown in the below figures.

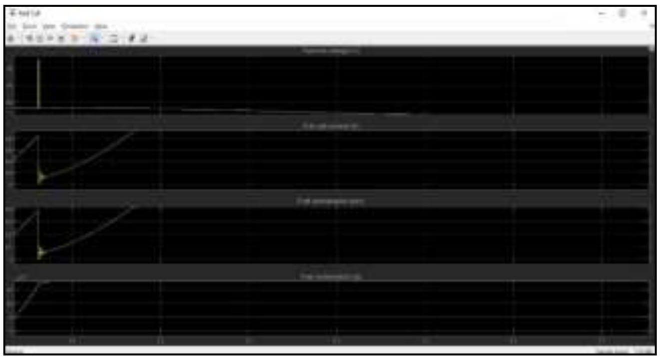

Fig. 10. Fuel Cell Performance

Performance of the fuel cell power source is carried out with respect to the fuel cell voltage, fuel cell current and fuel consumption. These different parameters are depicted through the above fig.10.

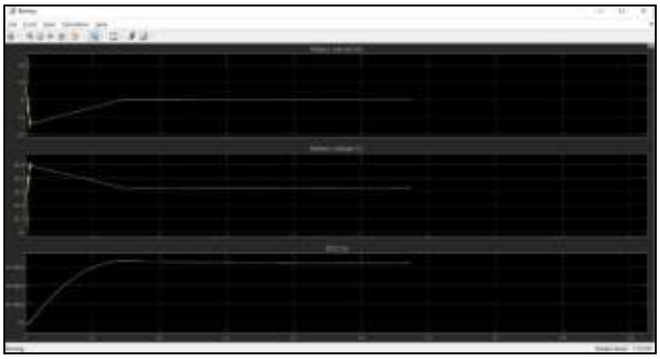

Fig. 11. Lithium Ion Battery Performance

While the performance of the lithium-ion battery is analyzed by considering the battery current, battery voltage and state of charge. While the system is turned on, upper and lower swings are observed till t = 0.01 duration after which gradual increase in the battery current till t = 0.15 and gradual decrease till t = 0.15 simulation period is recorded; after this simulation period, battery current and voltage reaches constant level from t = 0.15 simulation periods. Battery voltage gains the level of 52V and SOC remains to 65%, as shown in the above figure.

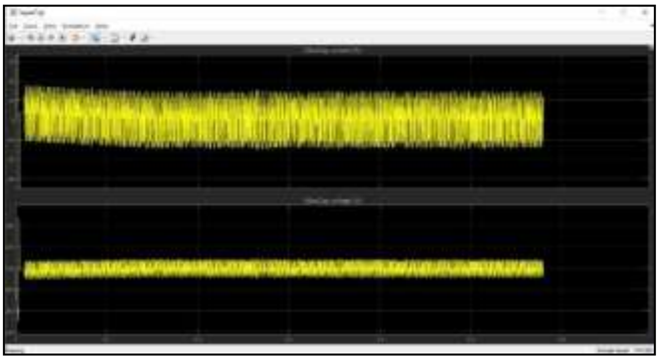

Fig. 12. Super Capacitor Performance Analysis

The super capacitor or the ultra-capacitor is the high current delivering power source which can be engaged at the time of sudden acceleration or steep ascend or in any situations which high current is required to be delivered at the traction motor. This power source is analyzed with respect to the ultra-capacitor current and voltage. In the initial duration of the simulations, sudden spikes are observed till t = 0.01 simulation period after which continuous charging and discharging is recorded between ± 15A of current and in the range of 267V to 272V. Subsequent section concludes the findings of the preliminary research work.

V. CONCLUSION

Through this research paper, an energy management system is disclosed which is able to fulfill the random requirement of the power through different power sources and for longer time. This assures high power delivery to the electric vehicle to run it for longer distances. In the proposed system, lithium-ion battery along with the fuel cell and ultra- capacitor is engaged to provide the expected power at any instance of time. Dedicated control unit along with IGBT triggering unit with regenerative braking system and gate control unit intelligently select either of the power source and fulfills the power demand of the traction motor. System modeling is carried out using the Simulink module of the Matlab software. Performance of the fuel cell, battery and the ultra-capacitor is critically analyzed and disclosed through the figures in previous section.

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