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# Development of a Supercapacitor-Aided Hybrid Energy Storage system to Enhance Electric Vehicle Battery Life Cycle

**Prof. Manjiri M. Tamhankar [1], Prof. Priyanka Khade [1], Pritam Bopalkar[2]**

[1]Assistant Professor, Electrical Engineering, WCE, Sangli, Maharashtra, India

[2]P.G. Student, Electrical Control System, WCE, Sangli, Maharashtra, India

*ABSTRACT*

*— Supercapacitors are now mostly used. Ultracapacitors, also known as electrochemical double-layer capacitors (EDLC), are high-energy storage devices. Their advantageous properties, also they can have charge and discharge capacity without losing their properties, make them suitable for use in energy storage systems. The supercapacitor pack can be used successfully in HESS by combining various energy storage technologies with a unique control strategy that maximizes the benefits of each energy source to improve and achieve overall performance. (Battery-supercapacitor system). This paper describes a hybrid battery/ultracapacitor hybrid energy storage system (HESS) for all kinds of electric vehicles. In contrast to the traditional HESS design, which uses a larger dc/dc converter to interface between the ultracapacitor and the battery/dc-link in to order to meet real-time peak power demands, the proposed design uses a much smaller dc/dc converter to act as a controlled energy pump to keep the ultracapacitor voltage higher than the battery voltage under most urban driving conditions. When the voltage of the ultracapacitor falls below that of the battery, the battery will only provide direct power. As a result, the battery's load profile is relatively constant. Also battery is not get directly connected to regenerative supply because of charges during charging and discharging.*

***Keywords:*** Battery, Control, Dc-Dc Converter, Ultra-Capacitor, Permanent Magnet Synchronous Motor, Inverter, Electric Vehicle, Sinusoidal PWM technique.

## I. INTRODUCTION

The Energy storage systems (ESSs) are very significance in all types of the vehicle system. The battery is one of the pleasant strength garage systems. Still, battery-primarily based totally strength garage machine faces such a lot of challenges. To meet excessive energy needs battery-primarily based total strength machines ought to face up to fulfil excessive energy needs. Batteries with excessive energy densities are to be had withinside the marketplace however their fees are a great deal better in place of that we use opposite numbers to conquer the price of batteries. If the dimensions of an unmarried battery are bulky, However, this could growth costs. Thermal control is likewise a crucial element for batteries for paintings appropriately in excessive energy load situations now no longer handiest to hold the temperature of batteries to quiet down the battery however additionally to excite the batteries in bloodless situations. In addition, molecular balancing of the battery is every other problem to be resolved. Individual molecular voltage may also generally tend to go with the flow from the authentic voltage value. This reasons the potential of the entire % then decreases unexpectedly throughout the operation, which may bring system failure. This machine is especially noticeable while using batteries to perform excessive rate charging and discharging. Also, the equipment which requires unbreakable supply input and output usually suffers from frequent battery charging and discharging. This negatively impacts battery life. In these systems, it's important to maintain a somewhat extra system for better efficiency. HESS & suggested solving the above problem. Performance can be increased by combining UC and battery. UC admires high power density rather than high energy density. This interface between UC and battery provides significantly good characteristics than when used alone. Several configurations are proposed for HESS design, from basic configuration to complex configuration. When battery undergoes frequent charges problem, this condition deteriorates. Also, the batteries with continuous charge and discharge are subject to frequent charge and discharge operations, which shorten battery life. These systems require more system to handle surge current. As a solution to the identified problem HESS designed. Combination of two systems will give improved performance. This is due to the fact that UCs have a higher power density but a lower energy density when compared to batteries. This combination by definition provides Several HESS design configurations, ranging from simple to complex circuits, have been proposed. There is direct connection between UC and DC link, the most widely used conventional HESS designs, UC and dc link having between converter However, in order to take advantage of the UC's benefit of power density though power density should be equal to UC and converter. In most cases, the half-bridge converter accounts for a sizable percentage of the general cost. Even though this design addresses the issue of peak power demands, the battery still suffers from frequent charge and discharge operations. The energy management system give confirmation that UC has enough SOC, while also having a sufficiently low SOC to function properly. This paper proposes a new HESS to solve all of the problems mentioned above. The proposed HESS will be presented and thoroughly verified in this paper.

## II. METHODOLOGY

Both sources from this project are categorized as electrochemical devices. However, because of operating principles of these devices differ, their characteristics are vastly different. Table I has shown some of the key characteristics of the various battery types with various energy densities and ultra-capacitors with varying power densities.

TABLE I
TYPICAL CHARACTERISTIC OF BATTERY CELLS

| Chemistry | Nominal Cell Voltage (Volt) | Energy Density (Wh/Kg) | Power Density (kW/kg) | Cycle life (Times) |
|---|---|---|---|---|
| Lead Acid | 2 | 30-40 | 0.18 | Up to 800 |
| Ni-Mh | 1.2 | 55-80 | 0.4-1.2 | Up to 1,000 |
| Li-Ion | 3.6 | 80-170 | 0.8-2 | Up to1,200 |
| Li-Polymer | 3.7 | 130/200 | 1-2.8 | Up to 1,000 |
| Li-Iron Phosphate | 3.2/3.3 | 80-115 | 1.3-3.5 | Up to 2,000 |

TABLE II
TYPICAL CHARACTERISTIC OF ULTRACAPACITOR CELLS

| Chemistry | Nominal Cell Voltage (Volt) | Energy Density (Wh/Kg) | Power Density (kW/kg) | Cycle life (Times) |
|---|---|---|---|---|
| UC | 2.5/2.7 | 2-30 | 4-10 | Over 1,000,000 |

In Battery-Ultracapacitor configuration most of time battery voltage can be maintained Low/High than Ultracapacitor. The ultracapacitor is directly connected to the DC link and serves as a low pass filter. The management strategy used in this topology allows the DC link voltage to vary within a range, allowing ultracapacitor voltage to be more effectively utilised. If (battery voltage corresponds to ultracapacitor voltage), the battery and ultracapacitor are paralleled and connected to the DC link. The DC/DC converter is not working.

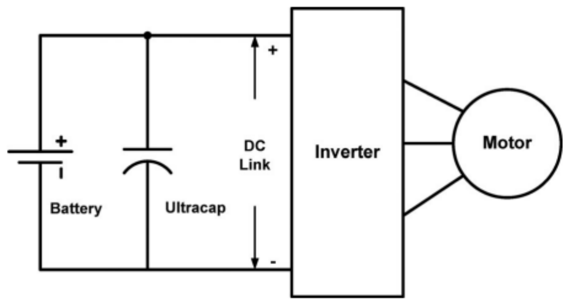


Fig. 1. Basic passive parallel hybrid configuration.

Voltage strategy is linked to the properties of Ultracapacitor and battery. If requirement of voltage is high the cells which are connected in series their voltage is also increases. Cells are designed in such a way that less performance variation to maintain capacity internal resistance, self-discharge Rate.

If the UC voltage is lesser than the battery voltage and equal to the DC link voltage, the battery pack has direct link to the DC link and the UC. DC/DC converter connects to DC link. In that case, the power ratings of the converter and the ultracapacitor should be matched order to utilize the power capability. The main benefit of this voltage approach is that you can use the comprehensive scope of UC when a lower voltage UC bank is needed.

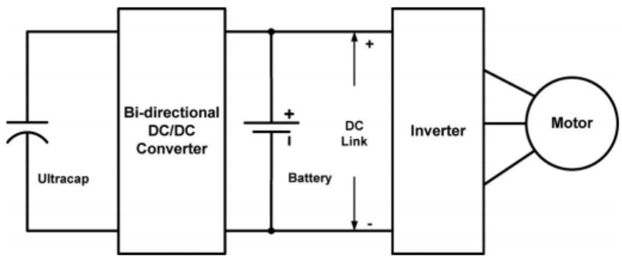


Fig. 2. UC/battery configuration.

If it seems like voltage of battery is lesser than ultracapacitor, the previous operation is turned off. There is direct link between UC and DC link. A DC/DC converter connects the battery to the DC line. Battery voltage can also be reduced. (There is less of a balancing issue)

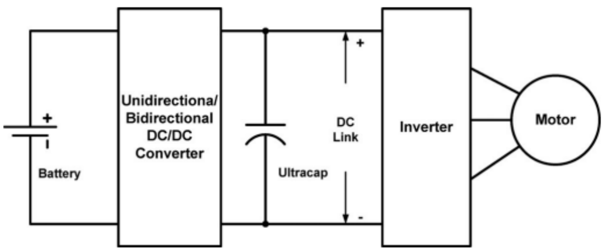


Fig. 3. Battery/UC configuration.

Considering all these aspects we have designed newly designed hybrid ESS. For all kinds of electric vehicles. The newly developed design is much more compact and efficient than the previous system, the interlink between dc/dc converter and battery system is done through a large dc/dc converter. Use a DC/DC converter. The regulator controls UC voltage greater than battery voltage under most operating conditions. The battery supplies energy when UC voltage falls down below the battery voltage system. Also, the battery which is in a passive state collects energy from regenerative braking. This separates thermal management and allows the battery to operate safely in high current conditions. In addition to cooling the battery, it can also warm up at low temperatures to reach the desired performance limits. Take. Also, balancing the cells of the battery system is a problem related to battery life. In the absence of a balancing system, individual voltage differs from its original voltage state. Then, during operation, the AH capacity of the entire battery drops sharply, which can cause the complete battery system to fail. Mostly it happens when the battery is used for fast charging and fast discharging. Traditional HESS connects UCs via DC / DC converters to meet real-time peak power requirements for powertrain control. Which needs the same capacity of UC and battery, or maybe more than higher performance than required.

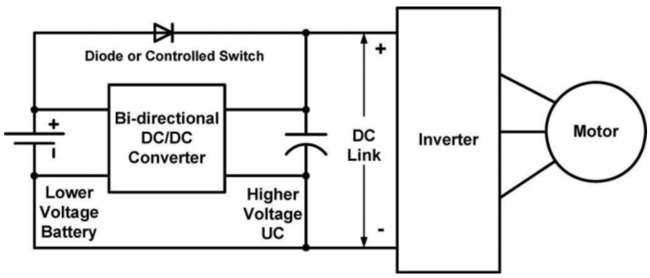


Fig. 4. Proposed HESS configuration.

The vehicle's constant speed operation was divided into two parts based as to whether the dc/dc converter's power Pconv could meet Pdmd's power demand. We name it as but at operating mode of low constant if Pdmd is equal to or less than Pconv. When the vehicle is travelling at a higher speed and Pdmd is greater than Pconv, the high constant speed mode is used. Because the power demand in practical vehicle driving is changing constantly, both the low and high constant speed operating modes are ideal.

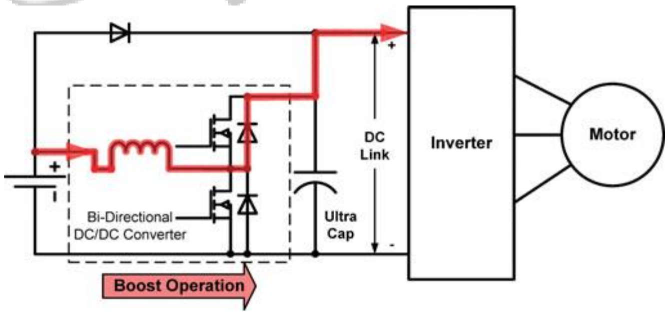


Fig. 5. Low constant speed operation energy flow.

Because Pconv > Pdmd in a reduced speed operating mode, the UC VUC voltage can be kept greater than the battery voltage. VBatt; Vdc from dc link can also be kept greater than voltage of battery, the UC does not absorb or even provide supply to PMSM. Because the UC voltage higher than battery terminal voltage, the reverse bias operation will be of main power diode. The diode is not trying to conduct any energy. The battery does not directly supply energy to the motor inverter.

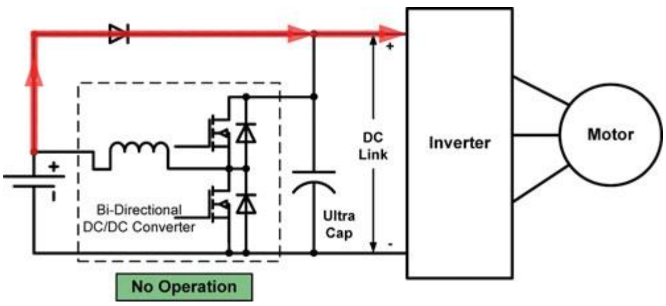


Fig. 6. High constant speed operation energy flow.

Ultracapacitor voltage drops down below battery voltage in the operating mode of high constant, Pdmd > Pconv. As a result, the primary power diode is biassed forward. The motor inverter is powered directly by the battery. In this mode, the dc/dc converter is disabled. Figure 6 presents the energy flow of further process

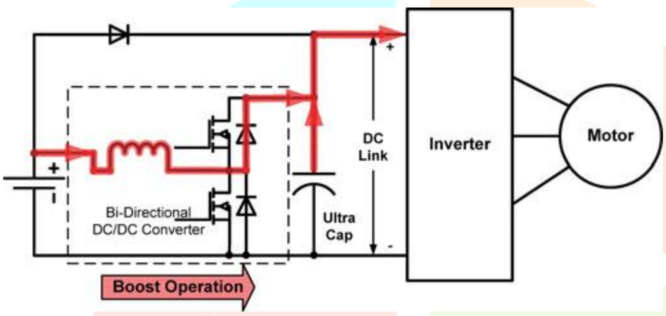


Fig. 7. Acceleration mode phase I energy flow.

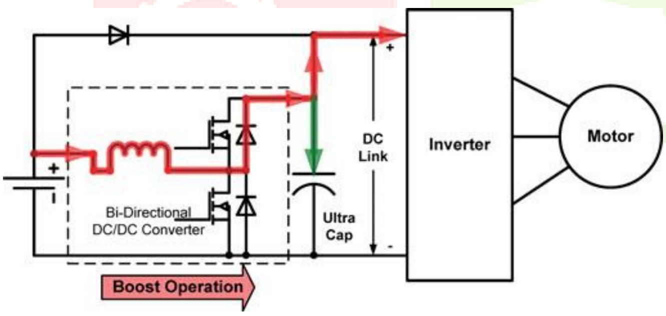


Fig. 8. Acceleration mode phase II energy flow.

During acceleration, demand power is more than converter power. ultracapacitor and DC/DC converter are both supporting to acceleration. As ultra-capacitor voltage is decreasing it becomes equal to battery voltage so UC and battery paralleled through the diode so system enters into operation mode with high constant speed. If converter power is more than demand power the power difference between demand power and converter power is used to charge the ultra-capacitor.

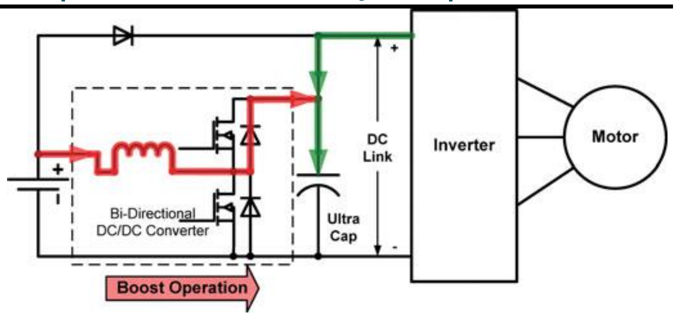


Fig. 9. Regenerative braking phase I energy flow when $V_{UC} < V_{UC\,tgt}$.

In deceleration mode, there are two phases. Only during phase I regenerative power will be given to UC During phase I, the dc/dc converter may or may not be in boost mode, depending on whether VUC is less than or equal to the targeted UC voltage. tgt VUC The flow of energy diagrams for the two conditions are shown in Figs.9 and 10, respectively

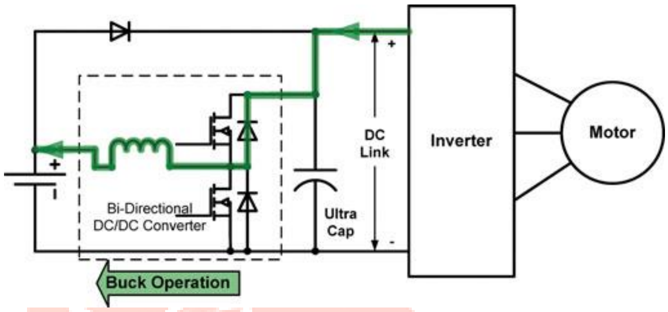


Fig. 10. Regenerative braking phase I energy flow when $V_{UC} \geq V_{UC\,tgt}$.

Figure 11 depicts the energy flow during regenerative braking phase II. Phase II describes how the continuous regenerative braking system works. The dc/dc converter will transfer energy from the UC regenerative breaking VUC within a safe SOC to the battery in buck mode. The ESS components can be properly sized when designing the proposed HESS so that Phase II of regenerative braking is used as little as possible. This will prolong the battery's life and improve the accuracy of battery SOC estimation.

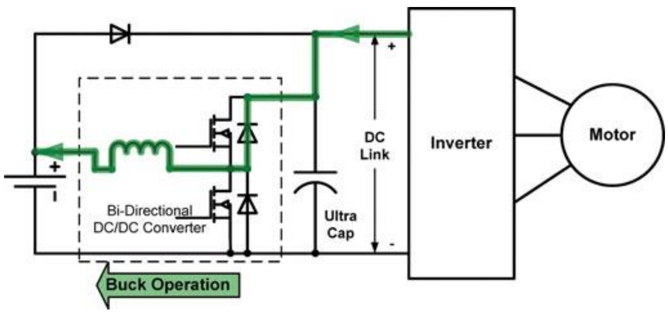


Fig. 11. Regenerative braking phase II energy flow

## III. CASE STUDY AND SIMULATION RESULTS

In order to provide the study of hybrid energy storage system we have to design the proposed energy storage system that has shown below

## A. Simulation Setup

| The UC's design goal is to use energy supplied by the dc/dc converter to cover the vehicle's city driving power demands. The HESS battery is sized to provide the same range as the EV ESS; the UC is set to meet the design goal of using the UC to cover the vehicle's city driving power demands with energy from the dc/dc converter. Multiple combinations are available for UC and Battery configuration.Component | Specifications |
|---|---|
| Battery Pack | 24v, 18Ah, initial SOC=80% |
| UC Bank Configuration | 25.8F, 32.8Vrated |
| DC/DC Converter | rated 32.8 V |
| DC/AC Converter | Snubber Resistance 1e6 |
| PMSM Configuration | Flux Linkage=0.01827 |
| DC Link | Voltage rated 32.8V |
| Diode | Snubber Resistance 500 |

falls down below the battery voltage system. Also, the battery which is in a passive state collects energy from regenerative braking. This separates thermal management and allows the battery to operate safely in high current conditions. In addition to cooling the battery, it can also warm up at low temperatures to reach the desired performance limits. Take. Also, balancing the cells of the battery system is a problem related to battery life. In the absence of a balancing system, individual voltage differs from its original voltage state. Then, during operation, the AH capacity of the entire battery drops sharply, which can cause the complete battery system to fail. Mostly it happens when the battery is used for fast charging and fast discharging. Traditional HESS connects UCs via DC / DC converters to meet real-time peak power requirements for powertrain control. Which needs the same capacity of UC and battery, or maybe more than higher performance than required. The revised HESS works in another way.

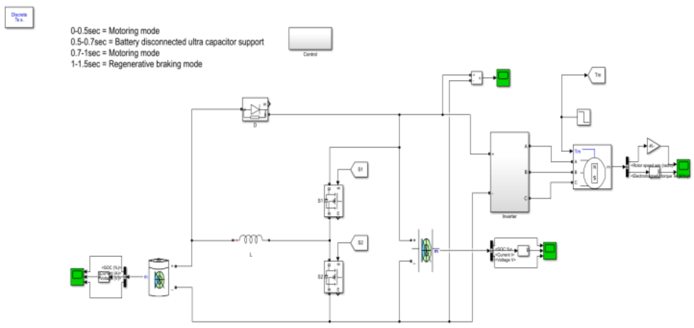


Fig. 12. Simulation Setup

The project's simulation setup is depicted in the figure. The battery is connected to the motor via DC-DC here. converter and ultracapacitor is connected with hybrid combination to the motor. Battery is connected to the converter via forward bias switch so the reverse current will not flow back to the battery. The inverter is connected to the PMSM motor. The control block is providing supply regulation. The voltage block is connected across the dc link and ultracapacitor also where we have measured SOC, voltage, and current across the DC link.

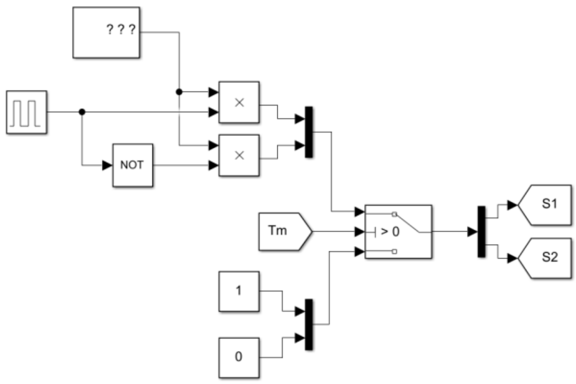


Fig. 13. Control Block

The above diagram is of block diagram of uc-battery configuration where stair generator and step generator are connected which are generation pluses for the positive torque generation where we have used mux, we have combined result from the above set and for the negative torque we have given fix value that are zero and one and that is compared with torque of the motor and combined result is given to the S1 and S2 block that are further connected to the Dc-Dc converter.

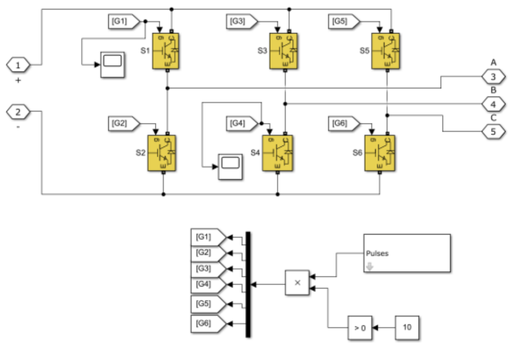


Fig. 14. Inverter Block

The inverter block is connected between Dc-Dc converter and PMSM inverter block do energy conversion, such as DC to AC, at the desired frequency and voltage. o/p. This can be classified based on the power source as well as the topology of the power circuit. As a result, they are classified into two types: voltage source inverter and CSI inverter (current source inverter). The VSI type inverter has a lower impedance DC voltage source at the inverter's input terminals. CSI inverters have a high impedance DC current source. The circuit, operation, and applications of a three-phase inverter are described in this article. Three-phase inverters are made up of three inverter switches, each of which is connected to load. Waveform has zero voltage stage during its inverting stage. The three switches can be synced for the basic control system so that a single switch operates at every 60 degrees of the basic o/p waveform, resulting in a six-step line-to-line o/p waveform.

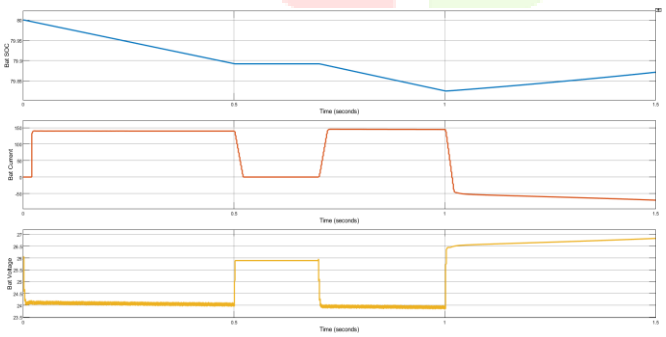

Fig. 15. Battery Scope Output

During discharging mode of battery, the soc of battery is decreasing and voltage of battery is slightly falls down whereas current is increasing, when ultracapacitor is in operation mode then battery SOC is remains constant and battery is in charging mode so the voltage of the battery is increasing and current is falls down to maintain power constant and charging mode of the battery, SOC of battery increases also voltage of battery increases.

Figure No 16 shows ultracapacitor scope output in this figure SOC of ultracapacitor is slightly decreases during its first mode that is discharging mode and after one second ultracapacitor will charge in next of charging during that phase voltage across capacitor will increase and current will decrease exponentially

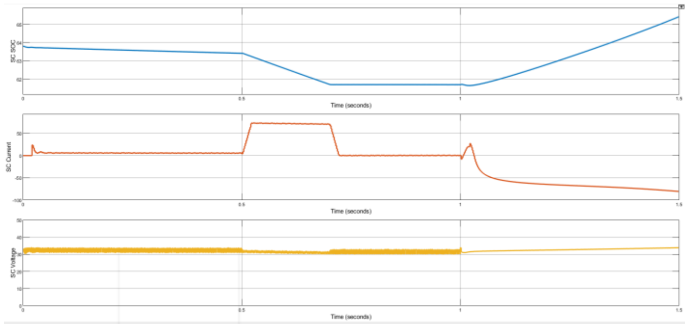

Fig. 16. Ultracapacitor Scope Output

The Dc Link output voltage is maintained constant during charging and discharging mode of both battery and UC configuration.

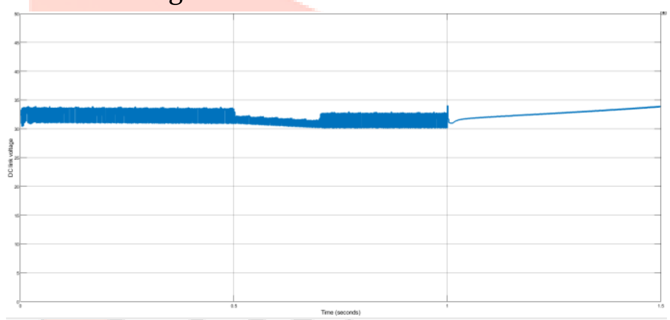

Fig. 17. DC link Scope Output

The diagram below depicts a three-phase inverter circuit. This type of inverter's primary function is to covert DC supply to required AC supply. single-phase inverter switches, each of which can be connected to 3 phase loads make up a three-phase inverter. The arms of inverter are delayed with 120 phase shifts. Every switch occurs at 60-degree angle having 50 percent ratio. The inverter switches have a 50 percent ratio, and switching can occur at every 60 degrees angle. The switches S1, S2, S3, S4, S5, and S6 will combine. Three single-phase inverters are linked across a similar DC source in this configuration. Voltages in three phases Single-phase and three-phase voltages have two conduction modes: 120 and 180 modes of conduction.

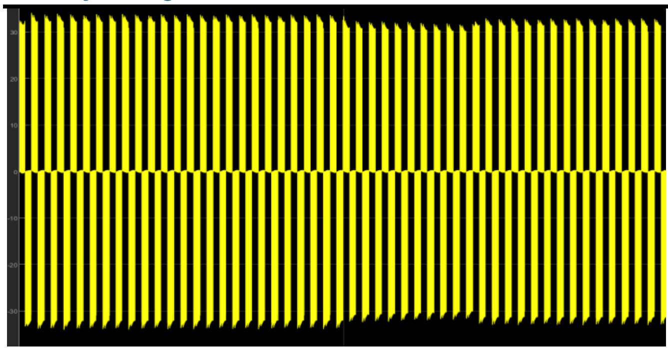

Fig. 18. Inverter Scope Output

The torque and speed of permanent Magnet synchronous motor are inversely proportional to each other so during regenerative breaking mode the torque of motor is negative so speed increases gradually during this mode that has shown below

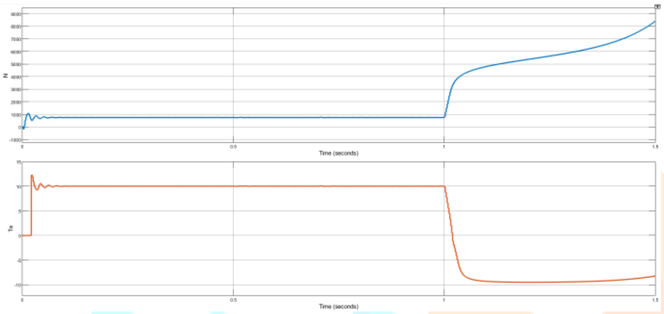

Fig. 19. PMSM Scope Output

## IV. RESULTS AND DISCUSSION

In this paper, a new hybrid energy storage system design is proposed. In comparison to traditional HESS, the new design can fully utilise the UCs' power capability while minimising power consumption. The need for a matching power dc/dc converter. Simultaneously, the battery pack's load profile becomes much smoother. As a result, the power consumption of the battery pack can be reduced. The vehicle's ability to drive in cold temperatures can also be improved. The proposed HESS's operating principles were thoroughly explained. in four different modes of operation the concept of the new HESS was demonstrated using a case study and simulations. The newly designed hybrid energy storage system can work in all modes. In order to address the benefits and drawbacks of the newly designed HESS, a comparative analysis was performed.

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