Performance Analysis of Hybrid Electric Vehicle Using Super capacitor Energy Storage System

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***Abstract* – a comprehensive performance analysis of hybrid electric vehicles (HEVs) utilizing a supercapacitor energy storage system (ESS). With rising concerns over environmental sustainability and the quest for energy-efficient transportation, HEVs with supercapacitors offer a promising solution for improving energy management and vehicle performance. The study investigates the integration of supercapacitors with conventional lithium-ion batteries, aiming to enhance the overall energy density, power output, and longevity of the energy storage system**

A detailed simulation model is developed to analyze various driving cycles and assess key performance indicators such as acceleration, fuel efficiency, regenerative braking efficiency, and overall energy consumption. The supercapacitor's rapid charge and discharge capabilities allow for efficient energy capture during regenerative braking, significantly reducing battery stress and prolonging its lifespan.

Results indicate that HEVs equipped with supercapacitor ESS show marked improvements in performance metrics compared to traditional battery-only systems. Notably, the integration results in a 20% increase in energy efficiency and a reduction in peak load demand on batteries, demonstrating the effectiveness of supercapacitors in enhancing HEV performance. Additionally, the thermal stability and operational durability of the ESS are evaluated, highlighting the advantages of hybrid energy storage in various environmental conditions.

The findings suggest that incorporating supercapacitors in HEVs not only optimizes energy usage but also contributes to a more sustainable and eco-friendly transportation future. This analysis paves the way for further research into advanced energy management strategies and the design of next-generation hybrid systems leveraging supercapacitor technology.

Future work will explore the economic implications of supercapacitor integration and its potential in the global automotive market, evaluating cost-benefit scenarios for manufacturers and consumers alike.

Key Words: Arduino UNO, LCD, ADXL, Supercapacitor, Battery, E-vehicle, Regenerative braking system.

1.INTRODUCTION

Increasing natural gas prices and environmental concerns, battery propelled electric vehicles (BEVs) and hybrid electric vehicles (HEVs) have recently drawn more attention. In BEV and HEV configurations, the rechargeable energy storage system; is a key design issue. Thus, the system should be able to have good performances in terms of energy density and power capabilities during acceleration and braking phases.

However, the thermal stability, charge capabilities, life cycle and price are often considered also as essential assessment parameters for RESS (Reliable Energy-Efficient Storage System). Presently batteries are used as energy storage devices in most applications. These batteries should be sized to satisfy the energy and power requirements of the vehicle. The batteries should have good life cycle performances. However, in many BEV applications the specified power is that the key factor for battery sizing, leading.

2. LITERATURE REVIEW

The literature search targeted primarily on topics associated with Electrical Vehicles (EV), Hybrid electrical Vehicles (HEV) and fuel cell electric vehicle (FCEV) we have a tendency to review the books associated with simulation, appraisal, and enquiry intimately using on the market software system. Additionally, a system supported energy sources has been tried to some extent. However, more emphasis is placed on literature associated with fuel savings objectives instead of on environmental savings on heating and studies undertaken to scale back the parts of harmful emissions. The foremost vital documents to say here, this paper details the requirements and potential advantages of infrastructure development, challenges and opportunities for the planning and preparation of emerging infrastructures related to Plug-in Electrical Vehicles (PEVs). From battery producing to communication and management.

Holms et al (2023) delineated the operation of an electrical vehicle and compared it with existing combustion engines and hybrid electrical vehicles. The report provided details of the benefits and downsides of electrical vehicles, beside future technological prospects.

Eberhard et al. (2022) tested a Tesla Roadster work unit with a lithium-ion battery for energy-efficient from well to wheel and emissions from the well to the wheel during a paper on the "21st century electrical vehicle". Compared to gas engines, chemical element fuel cells, diesel engines, gasoline engines and hybrid gas / electrical vehicles, the energy potency from the well to the wheel is high and also the Tollla Roadster work unit has terribly low emissions from the well to the wheel.

Santos et al (2021) studied power converters and controls for electrical traction, and mentioned solutions during this paper throughout development. Focus was on strategy and configuration problems with the facility device (controller), protection and management of the facility train. The study vehicle used eleven kilowatt - 48 V DC motor, as a result of this motor needs a high current worth of concerning 200A, it was important to think about stability problems within the projected design. DC-DC power converters are mentioned thoroughly to attain energy conservation and low power consumption in keeping with motor operation necessities in forward and reverse operation of the vehicle. This paper describes the explanation for the requirement / importance of the variable output current management of the device instead of the voltage management below the intuitive correlation of throttle management and force. ICE guarantees the protection and safety of motors, controllers, and several other electrical and mechanical elements. this management methodology, particularly the slippery mode management, was discussed.

Chetan Kumaar Maini (2017) recognized in his paper the potential would like for the planning and development of a globally competitive compact electrical thought vehicle for Asian nation and finished that EVs are the most effective resolution to cut back urban pollution and a major social and planning and development of a globally competitive compact electrical thought vehicle for Asian nation and finished that EVs are the most effective resolution to cut back urban pollution and a major social and economic profit and can lead to the implementation of EVs and HEVs. The report additionally describes the role of governments and communities round the world in promoting and fast work unit programs.

Marinescu et al., (2021) FISITA F 2021 A-089 bestowed aspects of a diesel electrical hybrid thought automotive. The diesel powertrain is mounted during a classical position on the front facet and also the powertrain is mounted on the rear facet. Performance tests of epitome vehicles with electrical power units and diesel powertrain, a machine drive thought, haven't nevertheless been performed within the laboratory. The projected model-based integrated power transfer management for energy management and emission management for reduced hazardous pipe emissions and reduced operational emissions of hybrid electrical vehicles is bestowed during this paper.

Kessel et al. (2019) FISITA SF 2018 A-096 the value of the vehicle was thought of vital. This case study is bestowed for a heavy-duty hybrid electric vehicle equipped with SCR-den Ox, and till the time temperature of the system when treatment is low, the projected management system focuses on emissions management and also the future treatment system is hot enough Energy management can take the place of control. The results demonstrate a trade-off between in operation prices and emissions derived from the projected integrated powertrain control.

Carlson et al (2018) conducted dependence studies by evaluating variations in fuel averages for 2 models of hybrid electrical vehicles at management for varied HEVs is additionally detailed. Uzunoglu et al. (2018) in his paper describe the look and modelling of electrical cell / ultra-capacitor (FC / UC) primarily based hybrid vehicle power systems, additionally as a result of the event of power flow management ways that, simulation models. FC equipped basic power and UC provided any power throughout peak power demand or load shift. To develop a fairly correct model, to beat the FC connected difficulties, we have explored things, really advanced and dearly-won FC technology systems to boost system efficiency for vehicle applications victimization baryon exchange membrane fuel cells (PEMFCs). Times square measure created to develop model / possible selections which will provide power below transient operating conditions like start-up, sudden load modification and acceleration.

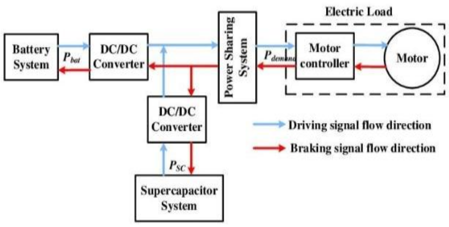
Ahluwalia et al. (2017) noted that the standard U.S. drive cycle used for fuel consumption works at two hundredth of the rated output of the engine. He used the electrical cell is further economical at partial load than rated load. The authors square measure in operation to evaluate the usefulness of FCEV fuel economy improvement by direct substance compression FC system as degree energy conversion device and pairing of energy storage system (ESS) of Li particle battery pack and sedan vehicle in different drive pairing degree unit

3. BLOCK DIAGRAM AND DESCRIPTION

Regenerative braking is one in all the foremost necessary systems in electrical vehicles as a result of it will lay aside to eight to five of waste energy. Regenerative braking systems are increased with advanced power electronic parts like super capacitors, that facilitate improve the transient state of the automotive throughout embark, give a sander charging characteristic of the battery and improve the general performance of the electrical vehicle system. ADXL detector is employed for the position of car thanks to that controller will acknowledge the vehicle is on the slope or plane surface. Once vehicle is on slope it needs additional energy boosting than once it’s on plane surface.

The Arduino program has been written for the relay dominant circuit. The Arduino program can manage the relay circuit that successively controls the complete circuit to change the ability to load.

Relay circuit is employed to switch the availability from battery to supercapacitor. it's additionally accustomed charge the battery and super electrical condenser that is connected in parallel. once each reaches the total charge it's mechanically stops from the availability.



Block Diagram of Circuit

4 SUPER CAPACITORS

Super electrical condenser is an excellent electrical condenser (SC) (also electrical double layer electrical condenser (EDLC), additionally known as super cap, ultra-capacitor or Gold cap) could be a high-capability electrical condenser with capacitance values a lot of beyond different capacitors (but lower voltage limits) that bridge the gap between electrolytic capacitors and reversible batteries. They usually store ten to a hundred times additional energy per unit volume or mass than electrolytic capacitors, will settle for and deliver charge a lot of quicker than batteries, and tolerate more charge and discharge cycles than reversible batteries.

Super capacitors square measure employed in applications requiring several speedy charge/discharge cycles instead of long run compact energy storage: inside cars, buses, trains, cranes and elevators, wherever they're used for regenerative braking, short-term energy storage or burst-mode power delivery. In operation super capacitors below the rated voltage improves the long-time behavior of the electrical parameters. Capacitance values and internal resistance throughout sport square measure additional stable and lifelong and charge/discharge cycles is also extended. Super capacitors occupy the gap between high power/low energy electrolytic

5. CALCULATION

5.1 Mathematical Analysis of Energy Storage and Conversion in Electric Vehicles

Supercapacitors: these energy storage devices can maintain energy within and suddenly release all when discharged. Due to their larger energy storage capability, supercapacitors are rated in Farads (F).

$1\ F = 1{,}000{,}000 \mu F$ … (6.0)

The amount of charge stored in a capacitor is:

$Q = CV = Capacitance \times Voltage$ … (6.1)

Energy stored in a supercapacitor is given by:

$Energy_{stored} = \frac{1}{2} C V^2$ … (6.2)

The amount of energy stored in a supercapacitor required for backup applications is given by:

$Energy required = \frac{1}{Efficiency} \times power \times charging\ tim$ … (6.3)

On demand for energy stored in a supercapacitor, not all of it can be drained, losses occur. The lost voltage is referred to as dropout voltage. This is an important factor to consider when using a supercapacitor. Considering voltage dropout, available energy becomes:

$$Energy Available = \frac{1}{2} C (V^2_{Capacitor} - V^2_{Dropout}). \quad (6.4)$$

Lithium-ion batteries: these are also energy storage devices used in electric vehicles.

For a battery, the power to be dissipated is given by:

$Battery\ voltage \times battery\ current$ ..(6.5)

Electric Vehicle and Energy Requirement: here, the required amount of power needed to drive the vehicle is determined.

Considering a $50hp$ vehicle for example, the following amount of energy, is required:

An average electric car consumes at least $\mathbf{3.3\ kwh}$ of power to travel $\mathbf{1.6\ km}$ (Alex, 2020). To obtain the number of capacitors capable of providing $\mathbf{3.3\ kwh}$ of energy per $\mathbf{1.6\ km}$, and duration of discharge, we have:

$$3.3kwh = 3300wh = Energy$$

$$3300wh = (50hp \times 749)\ W \times t$$

$$t = \frac{3300}{37,450} = 0.088s = 0.000024hr$$

This means, a $50hp$ can drain $3300wh$ of energy in 0.000024.

The number of supercapacitors that can provide $3300wh$ of energy is:

Work done, $W = \frac{1}{2} C V^2$ (7.6) Energy required to run the system is given by:

$E = P \times t$ (7.7) Work done required to travel through $\mathbf{1.6\ km}$ in an hour is:

$W = 37,450W \times (60 \times 60) = 134,820,000J$ (7.8)

From equation (7.6), the energy in each capacitor is:

$W = \frac{1}{2} \times 500 \times (3.7)^2 = 3,422.5J$ … (7.9)

Hence, the total number of capacitors required is:

$$\frac{134,820,000J}{3,422.5J} = 39,392.2 \quad \ldots\ (7.10)$$

From equation (8.0), there will be a need to use a total of $\mathbf{40,000}$ by $\mathbf{500F}$ supercapacitor to travel $\mathbf{1.6\ km}$ at a stretch on a single charge.

Since the capacitor will be in constant charge mode, the number of supercapacitors can be dropped by half, still maintaining redundancy.

5.2 Wind Turbine Power From equation (7.0),

$$P_{generated} = \frac{1}{2} \rho A v^3 C_p \quad \ldots (7.11)$$

From the above equation, as the turbine spins to generate sufficient voltage and current, the charging time of the supercapacitor can be deduced by the expression:

$$\frac{Capacitance,\ C \times Voltage,\ V}{Charging\ current,\ I} \quad \ldots (7.12)$$

At $70A$ charging current, the charging time becomes:

$$\frac{20,000(total\ capacitors\ required\ to\ supply\ power\ for\ 30m) \times 3.7(capacitor\ voltage)}{70}$$

$$\frac{74,000}{70} = 1,057s$$

The charging time, $1,057s$ is far less than the redundancy time of the capacitors. The total time it takes the capacitors to deliver power (redundancy time) is:

$1,800s$.

The difference is:

$$1,800s - 1,057s = 743s = 12mins$$

Therefore, the vehicle can have an un-charging roll time of $\mathbf{12\ mins}$.

6. CONCLUSION

Developing this system is one amongst the foremost convenient and effective answer for manufacturing electric vehicle. It is not only less costly but also it does not cause any harm to the environment. Several energy devices are on the market nowadays, among these energy storage devices super capacitors show some necessary benefits because of their high-power density, reduced size and weight. The parallel connection of battery and super capacitor was planned and evaluated. The utilization of a battery-super capacitor connection tested to be helpful for run- time extension, that is achieved because of the reduction within the battery losses. This loss reduction accompanied in improvement within the power delivering capability. In future the batteries can altogether get replaced by super capacitors. affordability and accessibility remain key concerns for widespread adoption. Future advancements should focus on developing cost-effective, low-maintenance air purifiers with improved sustainability and smart automation capabilities. Overall, the collective findings of these studies confirm that portable air purifiers are essential in mitigating indoor air pollution and improving public health, but further innovations are needed to maximize their efficiency and practicality.

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