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Hybrid Energy Storage System for Electric Vehicle

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Abstract: *Energy Battery/super capacitor hybrid energy storage systems have been gaining popularity in electric vehicles due to their excellent power and energy performances. Conventional designs of such systems require interfacing dc-dc converters. These additional dc-dc converters increase power loss, complexity, weight and cost.*

Therefore, this paper proposes a new direct integration scheme for battery /super capacitor hybrid energy storage systems using a double ended inverter system. This unique approach eliminates the need for interfacing converters and thus it is free from aforementioned drawbacks.

Furthermore, the proposed system offers seven operating modes to improve the effective use of available energy in a typical drive cycle of a hybrid electric vehicle. Simulation results are presented to verify the efficacy of the proposed system and control techniques.
Keywords*: Energy storage, supercapacitors, power conditioning system, regenerative braking.*

1. INTRODUCTION

Electric vehicles (EV) have been gaining unprecedented attention mainly due to the facts that our planet is on the brink of having its fossil fuel depleted and there are overwhelming concerns on pollution due to road transport. Notwithstanding such grave concerns, there are still some well-known technical issues of EVs such as battery cost and the limited drive range that limit their widespread adoption. Therefore, certain EV technologies are still being developed and more time and research are needed to conquer the market effectively. This has created a technology gap in the transportation sector.
Hybrid electric vehicles (HEV) have been emerged as the promising solution to fill the gap. In HEVs, internal combustion engine (ICE) is used as the primary source of power. Peak power required for acceleration is supplied by the combination of ICE and energy storage system. During decelerations, regenerative braking is used to recover part of the kinetic energy of the vehicle.
Therefore, HEVs are more efficient and environmental friendly compared to conventional ICE based vehicles. However, the fuel economy and all-electric range of HEVs are highly dependent on the performance of on-board energy storage system (ESS) of the vehicle. The combination of battery and supercapacitor is considered as an excellent match that can cover a wide range of power and energy requirements.

2. AIM OF THE PROJECT

The aim of this project is to develop an energy storage system that is suitable for use in Hybrid Electrical Vehicles (HEV). The goal is create an efficient system with an overall reduction in cost, size, and weight. The objective of the proposed EES system is to greatly improve the efficiency and reduce the cost of powering large-scale manufacturing and commercial sites.

The objective can be achieved by using:

- An HEES system comprised of different types of energy storage elements organized in an appropriate storage hierarchy and reconfigured on the fly,
- Energy management depending upon the power availability and cost factors.

3. LITERATURE REVIEW

The conventional method of interfacing batteries and supercapacitors is the use of two separate bidirectional dc–dc converters. Terminal voltage variations of the battery and the supercapacitor are effectively decoupled by interfacing dc-dc converters and hence the voltage across the motor drive dc-link remains constant.
However, these interfacing converters introduce considerable switching and conduction power losses. It also poses stability issues, particularly at high inrush currents. Furthermore, interfacing converters add cost and weight to the system, particularly with their large

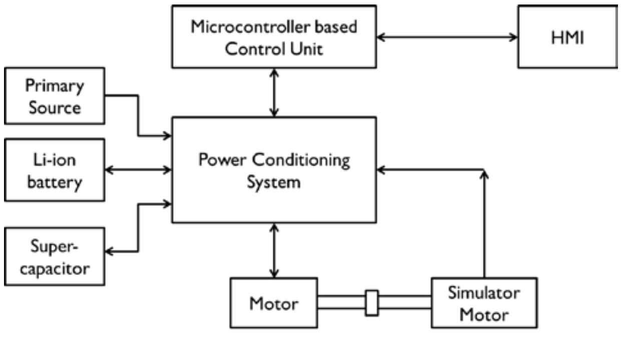
inductors rated for the peak power transfer. Therefore, the trend is to reduce the number of dc-dc converters used in the system.
One such design is the direct connection of the battery into the dc-link of the motor drive. But it suffers from several drawbacks such as, increased cell count and hence large internal resistance, lack of control over battery power flow and fixed current distribution governed by internal resistors of the battery. An alternative method is proposed in where the supercapacitor is directly connected to the dc-link and the battery through a dc-dc converter. Even though this design removes one dc-dc converter it limits the supercapacitor voltage discharge ratio to 50% and hence it is underutilized. Passive paralleling to the dc-link is the simplest way to combine a battery and a supercapacitor and eliminate afore mentioned drawbacks of dc-dc converters. But in this topology supercapacitor voltage is strictly limited to the battery voltage and thus it is severely underutilized.

Therefore, a possible direct connection scheme is found out which can remove both interfacing converters.

4. PROBLEM STATEMENT

High-performance electric energy storage is the main obstacle to development of electric equipment available at more affordable prices. In order to ensure high efficiency and good properties there are imposed many requirements on electrical energy sources, as high power and energy density, long cycle-life, reliability, wide temperature range and no emission of pollutants. The most common energy storages/sources in the electrical industry are fuel cells, electrochemical batteries and ultracapacitors. However, installing only one type of energy storage/source is often insufficient; so many applications use hybrid energy storage, consisting of more than one type, to complement the each single type drawbacks.

5. ARCHITECTURE



6. ENERGY STORAGE ELEMENTS

Supercapacitor

Electric double layer capacitors, more commonly known as supercapacitors, are widely exploited to mitigate load current fluctuations in the batteries. Supercapacitors have a superior cycle efficiency which reaches almost 100%, and long cycle life. More- over, compared with batteries, supercapacitors exhibit significant higher volumetric power density but lower energy density. Thus they are suitable for energy storage in situations with frequent charging/discharging cycles or periodic high current pulses. In a battery supercapacitor hybrid system, the supercapacitor stores surplus energy from the battery during low demand periods, and provides extra energy during peak load current demand period. However, a distinct disadvantage of a supercapacitor is its large self-discharge rate compared to that of ordinary batteries. A super- capacitor may lose more than 20% of its stored energy per day even if no load is connected to it. Another important concern of supercapacitors in energy storage systems is the terminal voltage variation coming from the characteristics of a capacitor nature whereby the terminal voltage is linearly proportional to its SOC. The terminal voltage increases or decreases accordingly as the supercapacitor is charged or discharged. This terminal voltage variation is much higher than that observed in typical batteries. This effect results in a significant conversion efficiency variation in the power converters which are connected to the supercapacitors. The hybrid energy storage systems including the supercapacitor should properly account for the above characteristics to be practical.

Li-ion battery

Li-ion battery, first demonstrated in the 1970s, is a family of rechargeable batteries in which lithium ions move from negative electrode to positive electrode through discharging, and in opposite direction during charging. It is now the battery of choice in portable electronic devices and is growing in popularity in military, electric vehicle, and aerospace applications. The growing popularity of Li-ion battery is mainly due to the following reasons: high energy density (100–250 W-h/kg or 250–360 W-h/L), high efficiency (almost 100%) and long cycle life (as high as 10,000 cycles), no memory effect, and low self discharge rate (0.1–0.3% per day). While taking over 50% of the small portable devices market, there are some challenges to build large-scale Li-ion based EES. The main hurdle is the high cost (above 600 $/kWh) due to special packaging and internal overcharge protection circuits. Several companies, such as SAFT and Mitsubishi, are working to reduce the manufacturing cost of Li-ion batteries to capture large new energy markets, especially markets for the electrical vehicles.

Primary Source

An Internal Combustion Engine (ICE) is used as the primary source. An ICE is a heat engine where the combustion of fuel occurs with an oxidizer (usually air) in a combustion chamber which is an integral part of the working fluid flow circuit. In an ICE the expansion of the high-temperature and high-pressure gases produced by combustion apply direct force to some component of the engine. This force is typically applied to pistons, turbine blades, rotor, or a nozzle. This force moves the component over a distance, transforming chemical energy to useful mechanical energy.

The first commercially successful ICE was created by Etienne Lenoir around 1859 and the first modern internal combustion engine was created in 1864 by Siegfried Marcus.

7. PROPOSED THEORY

Regenerative braking is direct power conversion from the wheel to battery and one of the most important processes that can enhance energy efficiency of EV. Power loss during regenerative braking can be reduced by hybrid energy storage system (HESS) such that super-capacitors accept high power as batteries have small rate capability. Minimize wasted energy by turning the car off when stopped and by charging the battery when braking.
The project revolves around three basic components, viz. an I.C. engine, a Li-ion battery, and a supercapacitor. The I.C. engine acts as a primary source, whereas the other two components serve as secondary sources.
Using only regenerative braking, the supercapacitor is charged. The Li-ion battery, however, is charged using conventional methods as well as regenerative braking. Use of Li-ion batteries is preferred so that the vehicle is light in weight and also due to the long life cycle of the battery. The vehicle performs all of its functions which can be classified into these seven basic modes of operation:

A. Mode 1: motor normal start

In this mode, peak power required for acceleration is entirely supplied by the supercapacitor.

B. Mode 2: motor boost start

In this mode, part of the peak power required for acceleration is supplied by the primary source. The rest is supplied by the supercapacitor. This is very useful for implementing a smooth transition from supercapacitor to the primary source.

C. Mode 3: motor super boost start

In this mode, battery is also used to supply the peak power required for acceleration. Therefore, all three sources are in operation under this mode. This is useful in rapid acceleration or uphill acceleration.

D. Mode 4: motor normal run

When the motor is in the normal run primary source is supposed to supply the whole demand. Therefore, both battery and the supercapacitor are disengaged in this mode of operation.

E. Mode 5: motor normal run with battery and/or supercapacitor charging

In this mode of operation, part of the primary source power is used to charge the battery and/or the supercapacitor

F. Mode 6: motor normal run with battery discharging

In this particular mode of operation, the primary source is assisted with the battery especially for hill climbing.

G. Mode 7: motor breaking

During motor breaking, the supercapacitor is used to absorb the kinetic energy of the vehicle.

8. CONCLUSION

This paper has proposed a novel direct integration scheme for battery and supercapacitor energy storage systems in hybrid electric vehicles. This particular arrangement eliminates the need for additional dc-dc converters and thus reduces the cost, power loss and complexity. Seven different operating modes are suggested for a typical drive cycle of a hybrid electric vehicle to improve the effective use of available energy.

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