A NOVEL DESIGN OF HYBRID ENERGY STORAGE SYSTEM FOR ELECTRIC VEHICLES

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ABSTRACT:

In order to provide long distance endurance and ensure the minimization of a cost function for electric vehicles, a new hybrid energy storage system for electric vehicle is designed in this paper. For the hybrid energy storage system, the paper proposes an optimal control algorithm designed using a Li-ion battery power dynamic limitation rule-based control based on the SOC of the super-capacitor. At the same time, the magnetic integration technology adding a second-order Bessel low-pass filter is introduced to DC-DC converters of electric vehicles. As a result, the size of battery is reduced, and the power quality of the hybrid energy storage system is optimized. Finally, the effectiveness of the proposed method is validated by simulation and experiment.

Keywords: BESS, Circuit breaker, switch off time period, ESS.

1. INTRODUCTION:

Nowadays, embedded energy storage systems in current generation electric vehicles are mostly based on the Li-ion batteries which, with high energy density, can provide long distance endurance for electric vehicles. While compared to the super capacitor, the response of Li-ion batteries is slower than that of super capacitors[3-4]. Therefore, in order to make electric vehicles comparable to fuel vehicles with regards to fast transient acceleration, energy, and long-distance endurance, a hybrid energy storage system(HESS) consisting of Li-ion batteries and super-capacitors is applied to electric vehicles[5]. For the development of electric vehicles, optimizing the energy storage device is critical, and it is necessary to consider increasing the capacity of the battery, while reducing the size and weight of the battery to increase the charging rate[6-8]. DC-DC converters which play an important role in hybrid energy storage system have been developed rapidly over the years. Through a series of innovations, a variety of DC-DC converters are proposed. A new zero Voltage Switch (ZVS) bidirectional DC-DC converter is proposed in [9], which has good controllability to improve conversion efficiency, but is not suitable for electric vehicles due to the complex control and higher cost. It has been shown an isolated bi-directional DC-DC converter[10] with complex structure is able to convert a large power transmission. A new zero-ripple switching DC-to-DC converter with the integrated magnetic technologies is first proposed in [11-12] by S.Cuk, and the application is very successful. Isolated interleaved DC/DC converter[13] introduces the concept of three-winding coupled inductors, but it is more suitable for power transmission. It is very important for hybrid energy storage systems to select a suitable energy management strategy. Energy management strategies have been extensively reported in literature in the recent years, including neural networks, fuzzy logic, state machine control, frequency decoupling method, on/off-line optimal strategies, dynamic programming (DP) and limitation of battery power[14-17]. The main objective of the optimal control strategies is to ensure a continuous supply by the minimization of a cost function. These strategies can be divided into off-line global optimization and on-line local optimization. For off-line global optimization, it is necessary to acquire the best power distribution between different sources. At the same time, for on-line local optimization, accurate predication driving conditions is necessary[18-20]. In this work, a new integrated magnetic structure of DC-DC converter is proposed and applied on hybrid energy storage system for electric vehicles. The proposed DC-DC converter gives the specific topology and operating modes, as well as Li-ion battery and super capacitor control. With regards to energy management strategy, the paper proposes a optimization control algorithm designed using a Li-ion battery power dynamic limitation rule-based control based on the state of charge(SOC) of the super-capacitor. In order to improve the life and reduce the size of hybrid energy storage system, the paper uses a hybrid algorithm based on particle swarm optimization and Nelder-Mead simplex approach to optimize the control parameters. Finally, the simulation and experimental analysis verify the hybrid energy storage system performance.

2. RELATED STUDY:

To reduce the sensitivity of the thresholds to the driving cycles, the fuzzy logic controller [7,8] was put forward to provide a broader rule for the operating of energy sources. However the deterministic and fuzzy rules are essentially the predetermined rules, which greatly rely on the expert experiences. In addition, the filtration based controller was developed in the literature [9,10], according to the filtration principle, which allocates the high frequency of the demand power to the ultra-capacitor and the low frequency to the battery. As all of the controllers above achieve limited economic performance enhancement, numerous optimal algorithms were applied to set up the controllers for HESS. For instance, dynamic programming (DP) [11,12], particle swarm optimization (PSO) [13,14], and convex optimization [15,16] were employed to explore the potential economic performance of HESS. However, these optimal algorithm-based controllers require the information of the driving cycles in advance, which leads to their poor real-time performance. Therefore, to enhance the real-time application of the controllers, the controllers for speed prediction and driving cycle recognition were invented. The model predictive control (MPC) was introduced to predict the future vehicle speed [17–19]. By predicting a period of the future vehicle speed, a mini-global optimal controller is constructed for the period of the driving cycle. Furthermore, some scholars summed up the characteristics of the existing driving cycles and proposed driving cycle recognition-based controllers to improve the adaptability of the controllers to the driving cycles [20,21]. However, the future speed prediction and the driving cycle recognition are completed on the basis of the existing driving cycles, which means that it is difficult to guarantee an accurate prediction and recognition in the real road all of the time. What is more, the high computing load of the MPC and the driving cycle recognition-based controller limits their further application. In all of controllers above, the traffic condition and the road grade were ignored. It can be observed in the literature [22,23] that the road grade plays a critical role in influencing the power allocation of the controllers. Through establishing the controller considering the road grade, the situation that the controllers deal with is much closer to the real road, so the real-time performance of controllers is further enhanced. Also, the traffic condition is not negligible in the real driving. In the literature [24], a predictive controller adopting the Monte Carlo approach is proposed, so as to handle the information of the traffic condition. In general, most of the research for the control of HESS does not consider the impact of the traffic information on the power allocation. Moreover, in these controllers ignoring the traffic information, some problems, such as the adaptability to driving cycles or computing load, restrict their application to the real road, and in those controllers considering traffic information, the road grade, the traffic condition and the vehicle speed are not taken into account at the same time in a controller. Furthermore, the power allocations of these controllers are mainly determined by the principle of the traditional controllers, which contributes to their poor adaptability to the driving cycles.

3. PROPOSED SYSTEM:

In proposed hybrid energy storage system composed of DC/DC converter, super capacitors and the Li-ion battery. DC/DC converters consist of four IGBT switches T1~T4 and its corresponding diode (added battery) tube D1~D4, and an integrated magnetic structure —— self inductance $L1$ 、$L2$ and mutual inductance M, which share a core inductors. The battery pack provides power to the smooth DC motor. The super capacitor deals with the instantaneous state of peak power supply. The power management system of electric vehicles determines the electrical energy flow according to the load demand. The converter has five main operating modes (mode due to the additional battery pack change). Table 1 shows the specific operation mode of hybrid energy storage system corresponding energy flows and operating mode DC-DC converter.

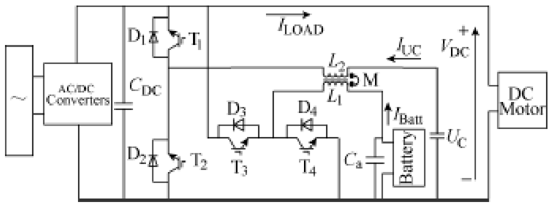

Fig.3.1. Proposed model.

Integrated magnetic structure Magnetic elements such as inductors, are the main components of energy conversion, filtering, electrical isolation and energy storage. The size of the magnetic element is a major factor in determining the size and weight of the converter. To achieve the integration of magnetic elements, an E-type magnetic core is used in this paper. Herein, a coupling inductance ($L1$ and $L2$) is used. As shown in Fig, $L2$ as the output filter inductor, $L1$ as the external inductance, and Ca as additional capacitance. In the steady state , the voltage of Ca is equal to the output voltage of $L2$ and $L1$ without regard to the capacitor voltage ripple. The DC/DC converter of Fig.1 consists of 4 IGBT switches (T1~T4) and 4 diodes (D1~D4). As a boost converter, there are two operational modes (consisting of $L1$, T4, D4 or $L2$, T2, D1); and as a buck converter, there also are three operational modes (consisting of $L1$, T3, D4 or $L2$, T1, D2). It can be seen from Table 2, a comparison of two structures of DC/DC converter is illustrates that the volume and weight of the DC/DC converter with integrated magnetic structure are reduced. In the electric vehicle, the application of the DC/DC converter with integrated magnetic structure can reduce the overall size and weight of the energy storage system. Moreover, integrated magnetic structure can reduce the output current ripple.

4. SIMULATION RESULTS:

In order to ensure enough energy from the super capacitor, when the SOC of the super-capacitor is below the limit, the super-capacitor charges from the Li-ion battery. Moreover, in the beginning of the driving cycle, a target value of super-capacitor SOC is chosen as the initial value to provide enough energy. An additional control loop based on PI controller, which controls the continuous recharge of super-capacitor from Li-ion battery during the driving phase and also when the electric vehicle is at a standstill, is designed. Fig.6 is a specific block of the additional control loop.

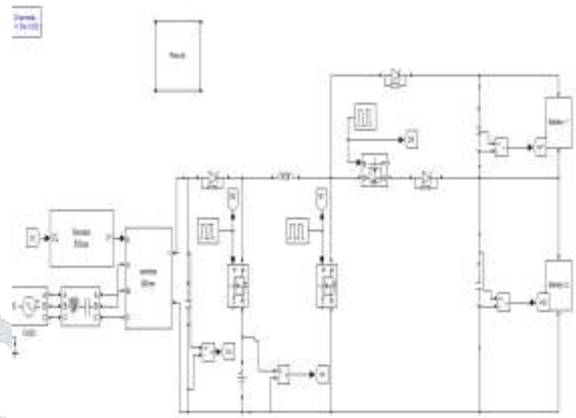

Fig.4.1.Simulation circuit.

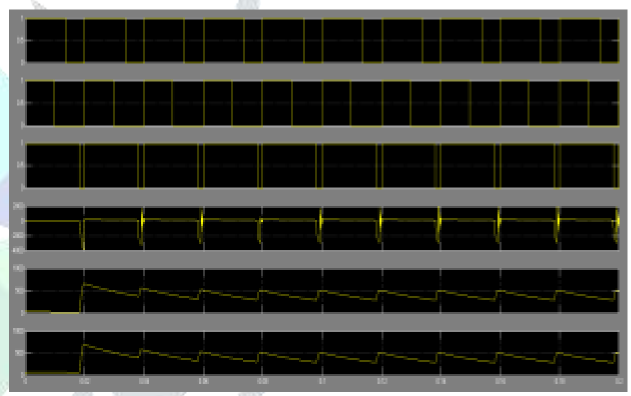

Fig.4.2. Output Results.

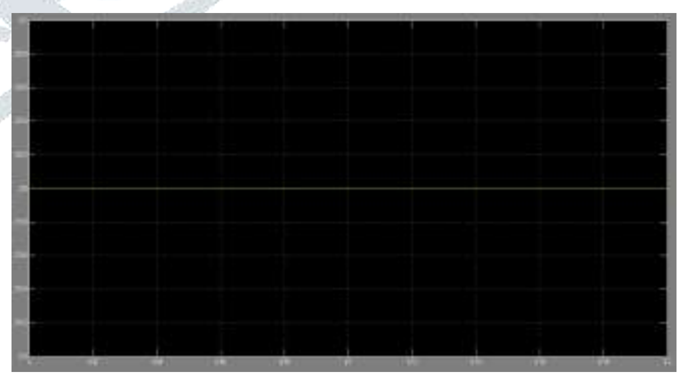

Fig.4.3. Battery rating.

5. CONCLUSION:

In this paper, a new hybrid energy storage system for electric vehicles is designed based on a Li-ion battery power dynamic limitation rule-based HESS energy management and a new bi-directional DC/DC converter. The system is compared to traditional hybrid energy storage system, showing it has significant advantage of reduced volume and weight. Moreover, the ripple of output current is reduced and the life of battery is improved.

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