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A NOVEL DESIGN OF HYBRID ENERGY STORAGE SYSTEM FOR ELECTRIC VEHICLES

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ABSTRACT:
Hybrid energy storage system (HESS) with the combination of lithium-ion batteries and super capacitors has been recognized as a quite appeal solution to face against the drawbacks such as, high cost, low power density and short cycle life of the battery-only energy storage system, which is the major headache hindering the further penetration of electric vehicles. A properly sized HESS and an implementable real-time energy management system are of great importance to achieve satisfactory driving mileage and battery cycle life, however, the introduced sizing and energy management problems are quite complicated and challenging in practice. 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: Hybrid energy storage system, integrated magnetic structure, electric vehicles, DC-DC converter, power dynamic limitation.

1. INTRODUCTION

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, 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 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 by S.Cuk, and the application is very successful. Isolated interleaved DC/DC converter 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, and state machine control, frequency decoupling method, on/off E line optimal strategies, dynamic programming (DP) and limitation of battery power. 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. 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.

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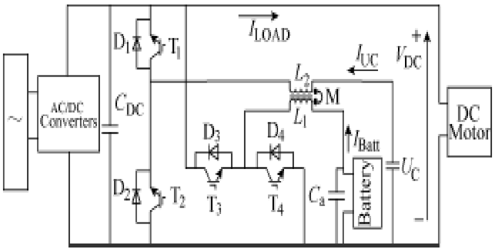

Fig.1.1. Model diagram.

2. RELATED STUDY

The continuous previous efforts have improved the overall performances of HESS considerably. However, most of the aforementioned work researched only on either the sizing or the energy management problem, in which case, the global optimal performance cannot be achieved since the design and control problems of HESS are mostly coupled in fact. Only sub-optimal solution is available when try to optimize the sizing and control parameters separately due to the reduced searching space. Some of the existing approaches in literature are off-line which are quite useful as the reference in designing real-time EMS but not appropriate for real implementation. Besides, most of the real-time implementable EMSs are mostly manually devised in the existing efforts which are not able to achieve the optimal performances. Considering the drawbacks of the state-of-the-art methods, this work will investigate the HESS sizing and realtime control problem as a coupled problem. In particular, the HESS of an electric race car is investigated as a case study. Although win the race is the only ultimate goal on a circuit, we should try to minimize the cost for a racing team and the environmental impact caused by the waste battery as much as possible during a race or for the offline training, which can match the spirit of the electric racing better. Our goal of this work is to introduce the HESS with proper sizing parameters and optimized real-time EMS to improve the cycle life of the battery without scarifying the mileage of the electric race car too much. A multi-objective optimal sizing and control framework incorporating the battery model, supercapacitor model, evaluation model and a devised vectorized fuzzy inference system is proposed in this work. With this framework, the Pareto optimal solutions of the formulated multi-objective optimal sizing and control problem can be obtained, besides, both the optimal sizing and the static parameters of a fuzzy logic control (FLC) based EMS can be achieved simultaneously for all the solutions on the Pareto frontier which then can be implemented for real-time application.

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. Then, the maximum number of laps can be obtained when both the battery and supercapacitor arrives at the minimum state of charge values set in the constraints, while the capacity loss of the battery is evaluated with the average current of the battery during the whole scenario. There is quite a lot of existing literature to model the capacity loss of the lithiumion battery. The capacity loss model is mostly validated by discharging the battery with constant current C rate, and we havent find any work that can predict the battery capacity loss dynamically with validated experimental work. Thus, we choose to estimate the capacity loss of the battery with average load as much previous work did. When the Pareto-frontier of the two evaluation indexes is obtained, the above iteration will terminate, otherwise, it will continue.

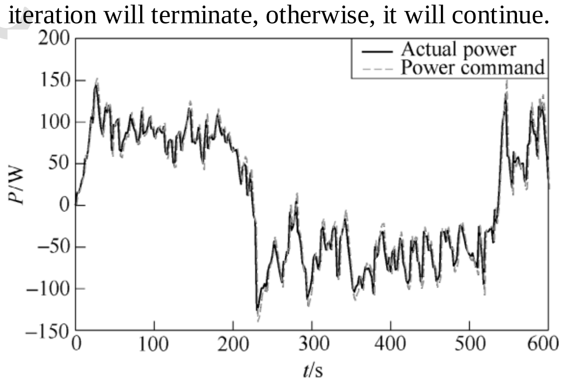

Fig.3.1. Voltage and currents at fault condition.

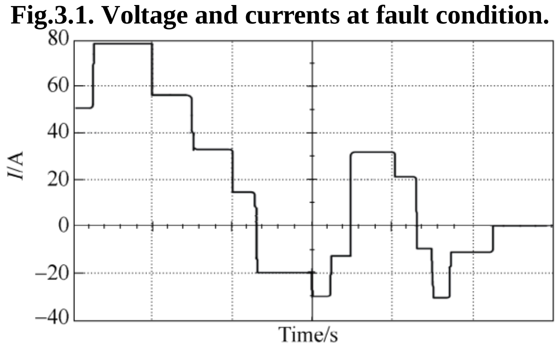

Fig.3.2. Load current.

For energy storage systems with super-capacitors, when t =3 and the load step ups, the battery current is smooth and doing a slow controlled ramop, meanwhile, the super-capacitor repeatedly high-current discharge and DC voltage is stabilized at 20V which the overall volatility is less than 5%;

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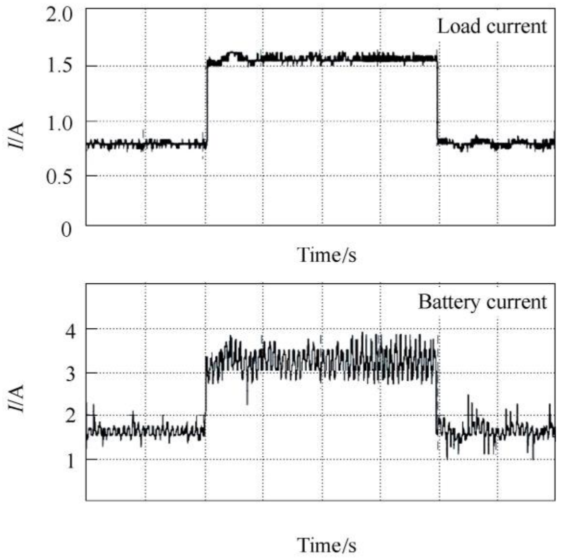
When t =7 the load set down, super-capacitor recovered the braking energy, as we can see, the super-capacitor current is negative. For energy storage system without super-capacitors, the battery pack as a single storage is responsible for the set change in the load and has high fluctuation and ripple in current, which will reduce the life of battery. Compared with the proposed HESS, it is not suitable for electric vehicles.



(b) Without super-capacitor

Fig.3.3. Battery current.

4. CONCLUSION

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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