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Proceeding Paper

Energy Optimization of Hybrid Energy Storage System (HESS) for Hybrid Electric Vehicle (HEV) †

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Abstract: A Hybrid Energy Storage System (HESS), consists of two or more types of energy storage technologies, mostly includingbatteries, flywheels, super-capacitors, and fuel cells. The complementary features of HESS make it outperform any single energy storage device depending on the application energy requirements in different scenarios/conditions. To overcome the opposing limitations of battery and supercapacitor, the battery has relatively high energy density but low power density as compared to the supercapacitor, an active battery/supercapacitor hybrid energy storage system (HESS) with dc/dc converter is proposed. However, the main issue with an active battery/supercapacitor HESS is current flow control to accomplish two goals: minimizing the magnitude fluctuation of current flowing in/out of the battery and minimizing energy loss experienced by the supercapacitor/s. The purpose of this article is to perform optimization of an active battery/supercapacitor HESS for a Hybrid Electric Vehicle (HEV). The HESS topology used for the optimization consists of a parallel connected battery and supercapacitor/s to drive the load through the respective dc/dc converters. In this article, an efficient multiplicative-increase-additive-decrease concept-based algorithm is used to ensure an optimal solution. MATLAB simulations are used to demonstrate that the proposed scheme can optimally minimize the magnitude fluctuation of the battery current and the SC energy loss.

Keywords: hybrid electric vehicle (HEV); battery; SC (supercapacitor); HESS (hybrid energy storage systems); MIAD (multiplicative increase additive decrease)

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1. Introduction

Conventional energy resources such as fossil fuels have been identified as the primary origin of global warming recently, so renewable energy has got a lot of attention. One of the benefits of this energy is that it may be produced in an environmentally friendly way, such as through wind and solar power. Smart home energy systems and electric vehicles (EVs) are two example products that use electricity and require storage devices like batteries and supercapacitors (SC). Since the functionality of such applications is heavily reliant on storage devices of electric energy, it is critical to design an effective approach for battery and supercapacitor (SC) energy management.In comparison to a battery, an SC has a higher power density but a lower energy density. SCs are rarely employed alone in energy storage systems due to their low energy density. Hence, there is a need to develop such a hybrid energy system to provide a high density along with high power ratings. A hybrid energy storage system (HESS) provides a solution to fulfill this requirement.HESS is divided into two types: passive HESS and active HESS. Although the passive architecture is simple to apply in electric systems, passive HESS has a power flow limitation [1–5]. The power-sharing ratio between a supercapacitor and battery is dictated by their internal resistances because both share the same volts. Bidirectional DC/DC converters are utilized in the active HESS to solve this constraint [1]. The DC/DC converter allows the supercapacitor and battery to have separate volts while also controlling the flow of energy.Active HESS also provides a number of configurations to connect the two sources.

2. Methodology

A battery, numerous SCs and loads make up the architecture under consideration as shown in Figure 1. A real-time controller is used that measures the flowing current and also controls the DC/DC converters.

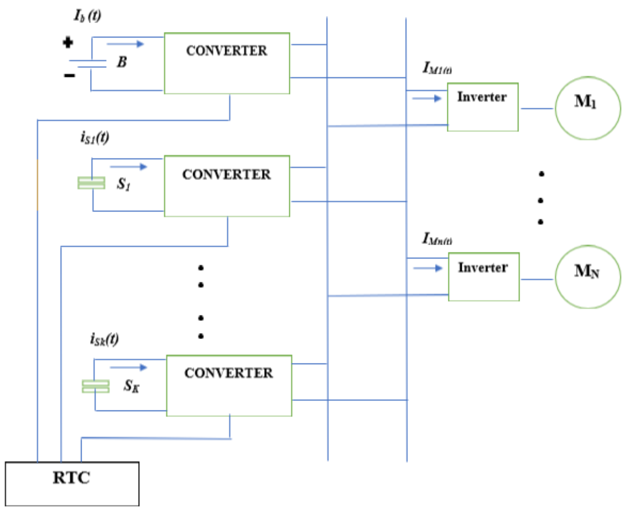


Figure 1. Block diagram of considered HESS Topology.

Loads can have a range of current profiles, allowing them to operate as both sinks and generators.

2.1. HESS Energy Optimization

Three problems will be presented as optimization problems in this section in order to reduce: (a) the amount of current going in/out of the battery; (b) the energy loss generated by the SCs; and (c) both of the above at the same time [6–8]. The goal is to figure out how to calculate the battery and the supercapacitor current for the best HESS energy management. Thebattery, a group of SCs and a group of heterogeneous loads are referred to as B,S = {S_K ∣ K € K}, and M = {M_n ∣n € N}, while K and N are the number of SCs and number of loads, respectively. The battery current, SC current and SC voltage, which can be denoted $i_B(t)$, $i_{Sk}(t)$ and v_{Sk} are dynamically controlled by the DC/DC converters. The charging/discharging of the SCs causes losses.

2.1.1. Minimization of Magnitude/Fluctuation of Battery Current (P_1)

The amount and fluctuations of current cause a rise in the internal resistance of the battery, whichreduces its longevity. The original problem is recastedas an optimization to reduce the magnitude/fluctuation of a current going in/out of the battery. The magnitude of the battery's current and the battery's current fluctuation are denoted by $|i_s(t)|$ and $|i_s(t) - |i_s(t-1)||$. The sum of these two variables can be used as the objective function in the preparation of P_1. The penalty function ψ can be used to define the objective function. The penalty function might be utilized as: 1. l_p—norm function; 2. deadzone-linear penalty function; 3. log barrier penalty function.

2.1.2. Minimization of the Energy Loss (P_2)

Because of energy loss in HESS caused by the supercapacitor ESR, battery discharge time is reduced. As a result, to extend the battery discharge phase, the energy loss in the HESS must be minimized. The total power loss is caused when, during operation, a supercapacitor's $\sum_{k \in K} R_{S_K} |i_{S_k}(t)|$ is proportional to the energy loss in HESS. As a result, the optimization problem's objective function (denoted as P) that reduces energy loss in HESS can be presented as

$$minimize \qquad \sum_{k \in K} R_{S_K} \| i_{S_k}^{out} - i_{S_k}^{in} \|_1$$

2.1.3. Dual-Objective Function Minimization (P_3)

Two objectives must be considered simultaneously while managing energy flow in HESS: minimization of the magnitude/fluctuation of battery current and reduction of energy loss [2]. The desired goals are achieved when we define the optimization problem (abbreviated as P_3) by combining P_1 and P_2 as follows

$\mathbf{P_3}$ minimize

$$\gamma(\Psi\varepsilon(I_B, \sigma_1) + (1-\varepsilon)\Psi(FI_B, \sigma_2)) + \delta \sum_{k \in K} R_{S_K} 1^T L_K$$

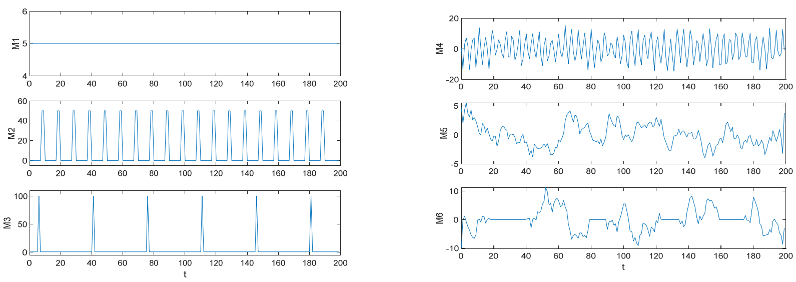
subject to

$$I_B + \sum_{k \in K} (i_{S_k}^{out} - i_{S_k}^{in}) - \sum_{n \in N} I_{M_n} = 0,$$
$$(A - I)v_{s_k} - D_k^{out} i_{S_k}^{out} - D_k^{in} i_{S_k}^{in} = 0,$$
$$Ev_{s_k} = 0,$$

3. Results

This designed system works with the help of RTC, converters and inverters. The RTC will work simultaneously in between the batteries, SCs and loads. The RTC will read data received from the loads and, by analyzing those data, it will adjust the current values with the help of bidirectional DC/DC converter to anoptimum value to decrease the amount of current flow which can cause battery degradation and produce a huge amount of loss in SCs. The data will be generated randomly in this project for M1 to M3. Then, those data will be used to create the load profiles for loads M4 to M6 by reverse engineering. These load profiles will be given to RTC that will analyze them using the MIAD technique and will limit the current to an optimum level.

Figure 2 shows that energy management optimization reduced the magnitude/fluctuation of battery current and minimized energy loss. The changing pattern of the battery current is shown in Figure 2a. The log barrier between σ_1 and σ_2 penalty function has been applied to P_3. The shifting of SC currents controlled by algorithm P_3 is seen in Figure 2b. The supercapacitor currents fluctuated more frequently than the battery current. This conclusion is consistent with the properties of SCs, which include the ability to produce a high peakcurrent and highly fluctuating current. Net voltage change of SCs is equal to zero. As a result of considered optimization strategy, the SC's SoC can be maintained as consistently as possible, allowing the SCs to operate more reliably as depicted in Figure 3.



(**a**) Current Load Profile of M1–M3 (**b**) Current Load Profile of M4–M6

Figure 2. Current load profiles of load. We assumed some possible current load profiles so that an effective result can be obtained.

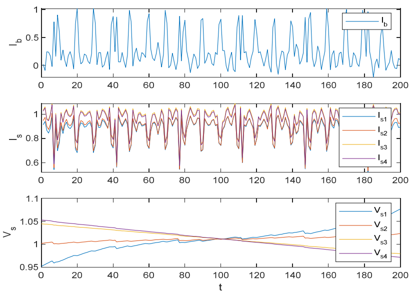


Figure 3. Simulation Results showing V_s, I_s and I_B, respectively.

4. Conclusions

The optimization of energy management in battery and supercapacitor hybrid energy storage systems is investigated in this work. We discussed optimization methods for achieving two goals: reducing the magnitude/fluctuation of battery current and reducing energy loss in HESS. Based on the multiplicative-increase-additive-decrease (MIAD) principle, an algorithm to alter the boundary parameters was devised. Within a few iterations, the suggested technique can ensure a feasible optimal solution. As a result, HESS energy flow can be precisely controlled. Because this technique efficiently decreases the magnitude/fluctuation of battery current, the battery life can be extended and the battery size can be reduced.

Conflicts of Interest: The authors declare no conflict of interest.

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