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Energy Procedia 142 (2017) 3697–3702

Energy Procedia

www.elsevier.com/locate/procedia

9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK

A SC/battery Hybrid Energy Storage System in the Microgrid

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Abstract

The major challenges in power systems are driven by the energy shortage and environmental concerns, namely facilitating the penetration of renewable energy and improving the efficiency of the renewable powers. Due to the variable nature of renewables, the generated power profile may not be able to match the load requirement. Accordingly, much attention has been focused on the development of energy storage technologies to guarantee renewable power penetrations. Recently, advances in the supercapacitor (SC) have made the SC and battery hybrid energy storage systems (HESS) technically attractive. Compared with other energy storage technologies the principal advantages of SC are: the high power density, high cycling life, and high peak current handling capacities. However, SC is also deficient in low energy density. The battery is characterised by large energy density but low in power capacity. In the microgrid systems, high-frequency power fluctuations will cause a significant degree of battery power cycling. This, in turn, has been shown to lead to a significant reduction in battery service life. Therefore, the concept of the SC and battery hybrid scheme is proposed. A case study of the HESS based on a microgrid is introduced in this paper. A simplified microgrid system is established to test the performance of the proposed design.

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.

Keywords: Battery, supercapacitor, hybrid energy storage system, microgrid.

1. Introduction

The microgrid is regarded as an effective system formation [1-3]. However, to maintain the stability of the MG is still challenging. Nowadays, the power system has both the AC and DC components [4-6] and energy storage units are always needed to compensate the power disturbances and maintain the system stability. The supercapacitor has outstanding power density and ability to respond to the power requirements very quickly has been investigated using in the microgrid with the function of power flow stabilization, electrical vehicles and voltage restoring [7-10]. The

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Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy .
10.1016/j.egypro.2017.12.264

battery energy storage system which has relatively lower price than the SC was reported to be used in the microgrid by many papers [11-13]. The advantages of the battery make it an effective method to tackle the power balancing issues in the microgrid [14, 15]. Nevertheless, the battery system has limited service lifetime[16, 17]. Hence, it comes to the concept of the hybrid energy storage in this study.

A detailed scheme of the SC and battery hybrid energy storage is presented, which has the advantages of both primary energy storage systems meanwhile complementing the disadvantages of each ESS. An overall power management strategy with the SC acting prior to the battery is developed. Then based on the power management strategy, a new HESS control method is proposed to share the power between the SC and the battery. The real time digital simulator is used to give the real time performance of the SC and battery hybrid system in this study.

The main function of the proposed hybrid energy storage system is to compensate the unbalanced power between the generation and the load demand. In order to obtain an optimal match of different energy storage devices, the sizing study is very essential. A new sizing method used for the HESS is, therefore, also introduced in this paper.

2. System Description

As shown in Fig. 1, a test system based on the real time digital simulator is established in the study, which consists of the RTDS embed with the ODAC and GTDI cards [13], the analogue and the digital interfacing module and the DSP (TMS320F28335). A microgrid system with the renewable generation is established and simulated in the RTDS. The analogue output is achieved through the on-board RTDS ODAC cards, which is responsible for converting the digital values from the RTDS to the analogue outputs. The analogue and the digital interfaces are used to connect the two hardware systems (the RTDS and the DSP). The function of the interfacing module is to process the output signals of the RTDS and the DSP and to make sure the input signals to each system are at the desired levels. The power management strategy and the HESS controller are implemented in the DSP. The DSP captures the analogue output signals from the ODAC card in RTDS and converts them to the digital signal by using the embedded ADC module. Then, based on the measurement data from the RTDS, the DSP generates the control signals. The control algorithms are also debugged in the DSP board. The PWM pulses generated by the DSP are read by the RTDS through its GTDI card.

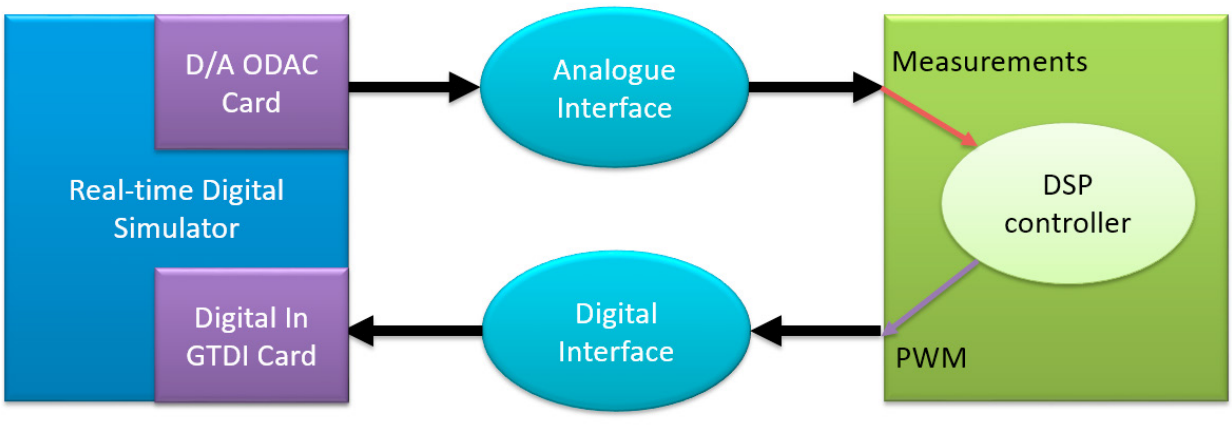

Fig. 1. The principle of the real-time test system.

3. Power management strategy

To fulfil the active combination of the different kinds of the energy storage systems, a power management which is designed based on the different characteristics of the supercapacitor and the battery, is significantly essential. The hybrid control for the SMES and battery is also developed based on the power management introduction. In this previous method, the battery and the SC are in parallel position and the power disturbances are seen at the same time by the SC and the battery. The advantage of this design is that the battery could be protected from the short-term power flotations. However, in this method, the SC is controlled only to deal with the high-frequency components, which cannot fully take advantage of the benefit of SC. Therefore, this paper proposes a new design of overall power management strategy as shown in Fig. 2, that the SC responds to the power surplus/deficiency directly and the battery works as the energy supply to the SC.

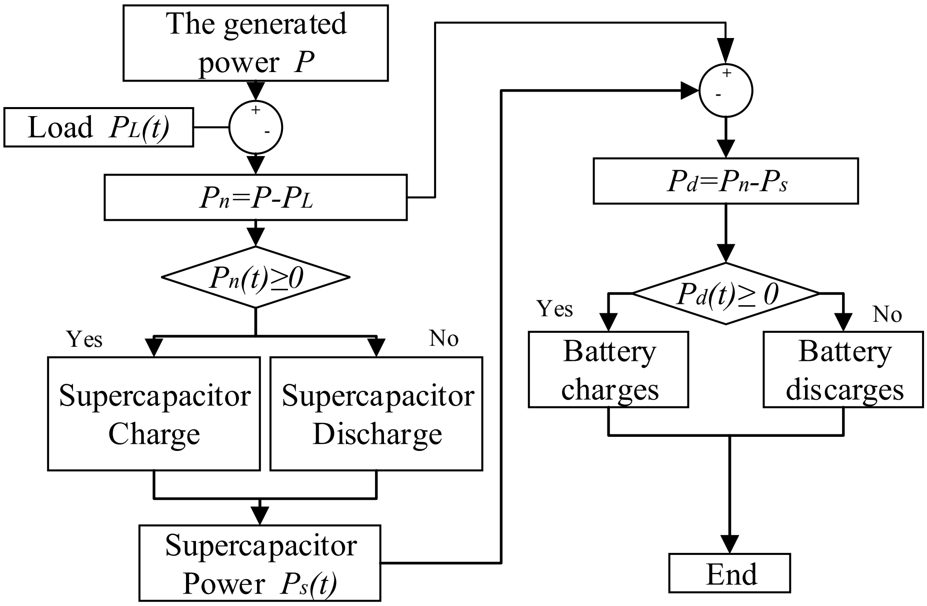

Fig. 2 The power management strategy.

As shown in Fig. 2, the SC will come into action firstly. For example, if $P_n > 0$, the supercapacitor, otherwise the SMES discharges. The power dealt by the supercapacitor is defined as P_s, then obtain the power deficiency $P_d = P_{net} - P_s$. The P_d is dealt by the battery. As a result, the supercapacitor is fully active to the power disturbance, and the energy of the SMES is provided by the battery.

4. Sizing Study

The main function of the proposed hybrid energy storage system is to compensate the unbalanced power between the generation and the load demand. Therefore, aiming to obtain an optimal capacity of energy storage devices the sizing study is very essential. The optimisation study for the single energy storage is not very challenging and many published works have introduced various kinds of sizing methods. However, the sizing study of the SC and battery hybrid energy storage is very complicated. Not only the essential functions of the ESSs need to be considered in the sizing method but the functional complementation between the energy storage systems also has a significant impact on the sizing results. To the best knowledge of the author, it can hardly find published works that give a cooperative sizing design to effectively combine the battery and the SC based their different characteristics. Therefore, the sizing strategy for both the battery and the SMES in the HESS is studied in this paper. Basically, in an electrical energy storage project, the energy storage devices need to achieve the following two objectives:

- Meet the power requirement
- Meet the energy requirement

Therefore, the sizing method is carried out by two steps:

Regarding energy dispatching requirement, size battery to make sure that the load energy demand is always met.

In view of the short-term power fluctuation mitigation function, determine the size of SC.

One of the advantages of the HESS over the signal energy storage system can be figured out from the two-step sizing strategy that the energy/power requirements for the signal ESS are more flexible. The SC and the battery can be designed according to their own merits rather than restricted by the system constraints. The HESS should be designed to satisfy all constraints whereas, the SC or the battery does not need to meet both the power/energy requirements.

5. Results and discussions

Based on the real-time test system as shown in Fig.1, a simplified microgrid is established in the real time digital simulator as shown in Fig. 3.

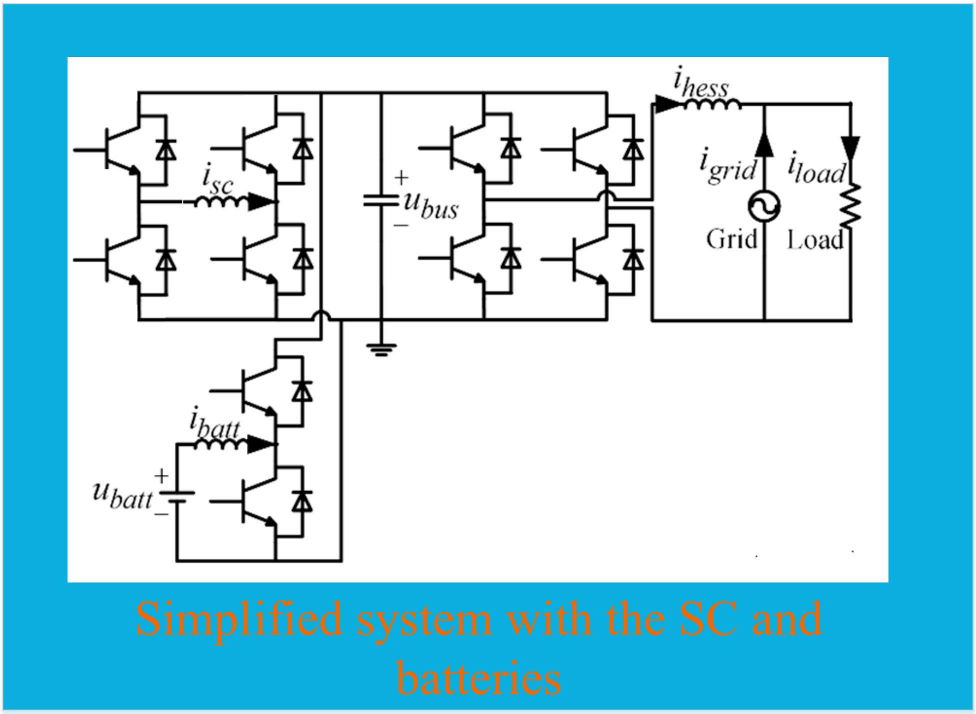

Fig. 3 The test system in the real time digital simulator.

The step power changes as shown in Fig. 4 are used to test the performance of the two systems: the system with the SC and the battery and the system with only the battery. The results are shown in Fig. 4.

It is very obvious in the Fig. 4 that the hybrid energy storage system has a much better performance than that of the system with only the batteries. The working condition of the battery is improved with the help of the supercapacitor. The improvement can be summarized in the hybrid energy storage that:

- The battery in the HESS does not charge or discharge according to the net power.
- The supercapacitor deal with the immediate power change.
- The battery is controlled charge/discharge according to the SC.
- The battery undergoes no power nor current abrupt changes
- The SC is controlled to deal with the immediate power change.

As a result, the advantages that high power capacity and high cycling life of the supercapacitor have been fully exploited in the hybrid energy storage design. In addition, the battery has a relatively larger energy density that could store more energy than the SC so that it works as an energy source to the supercapacitor. One of the mort essential advantages of this design, which could be observed from the Fig. 4 is that the battery has much lower charge/discharge currents in the HESS than that in the battery only system under the same situation. This results in a lower depth of discharge of the battery which will save the battery lifetime.

The battery lifetime extension is one of the most important advantages of the hybrid energy storage system. As can be seen from the Fig. 4 that in this study the battery lifetime can be improved in two ways:

- The lower depth of discharge in the same power situations
- The mitigative charge/discharge operation of the battery.

A battery lifetime prediction model is very necessary for the quantitative analysis of the improvement of the lifetime, which highlights the future work of this study.

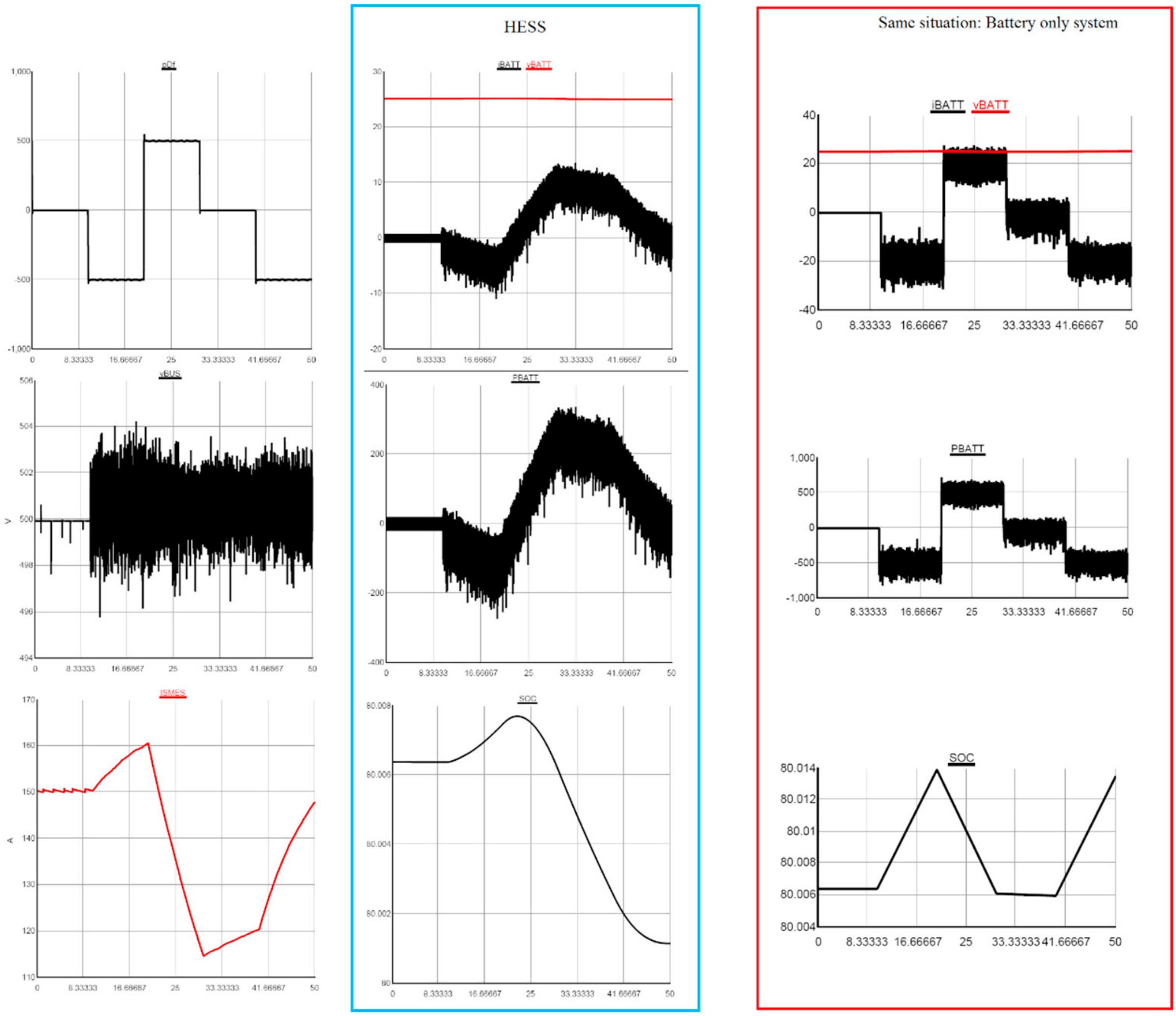

Fig. 4 Results from the RTDS

6. Concussions

This study introduces a kind of hybrid energy storage system using the battery and the supercapacitors. A case study based on a simplified microgrid is carried out to test the performance of the hybrid energy storage system and the power management method. In order to obtain a more accurate simulation, the real time digital simulator is used to give the real time operation of the proposed system. The results show that the supercapacitor is able to protect the battery from drastic power changes and relieve battery charge/discharge intensity. In addition, the battery lifetime can be improved by the SC and the quantitative analysis of the improvement is very necessary, which is the future work of this study.

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