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【論文の内容の要旨】

Although the global electrification has been progressing, 14% of the world's population is still living with no access to electricity, most of which are in underdeveloped nations in Asia and Saharan Africa. For instance, Mongolia is among the countries those still lack access to electricity and 43% of the overall population lives in depopulated areas. Thus, a small scale renewable energy system has been accepted as a promising method of providing access to electricity in Mongolia. Unfortunately, the initial investment cost of the renewable energy system is still high for most locals as the country's economy remains undeveloped. Besides, along with the electrification of transportation, the numbers of electric vehicles (EVs) have been increased rapidly not only in developed countries, but also in underdeveloped nations. Mongolia continuously imports a large quantity of secondhand hybrid electric vehicles (HEVs) from Japan. In detail, 42,439 HEVs were imported only within last year to Mongolia which owned more than 160,000 HEVs as of the end of 2019. The majority of these HEVs were early generation Toyota Prius models and were already considerably old. Due to a lack battery recycling facilities, a large number of nickel-metal hybrid (NiMH) batteries from these HEVs have caused hazardous chemical waste.

This dissertation proposes a single-phase power generation system for depopulated area that aims to efficiently reuse the recycling batteries as an energy storage device.

First, a typical single-phase power generation system with photovoltaic (PV)

modules and energy storage (ES) is developed, and its optimal structure and operational scenario are selected based on a comparison result of several different cases. Since a brand new battery is very costly, the effective reuse of the recycling batteries can be expected to present a significant reduction in the initial investment cost of the renewable energy system. Thus, a new power electronics circuit that enables the integration of multiple power electronics circuits required for the extension of battery lifecycle is developed. This circuit combines a generation control circuit (GCC) and an active power-decoupling circuit (APDC), and is capable of equalizing the state of charge (SOC) of each module in a battery pack while maintaining the input voltage of a single-phase inverter at a constant value.

Next, in order to accelerate battery equalization speed, a new SOC observation approach is introduced. In active battery balancing, many sensors are required to observe the SOC of each battery cell/module, regardless of which of the SOC observation techniques is considered. Therefore, a relative SOC estimation approach that uses only two sensors is developed.

By applying this approach to the GCC, the SOC of each battery module is adjusted to the same point and the rapid equalization performance could be realized through the experimental results.

Finally, in order to smoothen the discharging current when the battery system is in operation, a new power electronics circuit is developed. Conventional APDCs cannot sufficiently reduce a low-frequency ripple current because the internal impedance of the battery is very low. Moreover, the switching action of an APDC increases the amplitude of high-frequency ripples contained in a battery current. This is still detrimental to the lifecycle of batteries. Therefore, a novel APDC to reduce both high- and low-frequency ripple currents is introduced. An improved high-frequency ripple suppression performance was realized.

This dissertation is composed of 7 chapters. The outline of each chapter is provided as follows.

Chapter 1 describes the importance of the small scale renewable energy system and an urgent necessity of efficiently reusing the recycling batteries from HEVs.

Chapter 2 provides a literature review associated with this dissertation. First, a deterioration mechanism of the recycling batteries due to a long-aging is discussed and the existing battery SOC equalization techniques such as active equalizers, passive equalizers and hybrid equalizers are summarized. The feature of each type of equalizer is explained clearly. Moreover, the existing power-decoupling techniques historically developed for extending a service time of PV systems are analyzed. The challenges of applying a conventional power-decoupling circuit into the recycling batteries is mentioned.

Chapter 3 discusses the development of a small scale power generation system with PV and ES for local households. This system is composed of a unidirectional DC/DC converter for tracking a maximum power point of PV modules, a bidirectional DC/DC converter for battery charge/discharge operation and a utility-interactive inverter. The optimal operational scenario is selected from the three different algorithms based on experimental data. It was demonstrated that the use of nighttime electricity has a great effect on stabilizing a utility load and that the developed system can cover up to 90% of energy required for supplying a household load during summer season.

Chapter 4 proposes a new battery module equalizer equipped with GCC and APDC for ensuring safe operation of a battery pack. The APDC is connected to the most bottom battery module via a chopper circuit. It was verified that the excess energy of a high-SOC module can be successfully transferred to a low-SOC module and that the discharging time of the battery pack is prolonged by 12 min under the discharging condition of 1.65 A when the proposed equalizer is operated. Moreover, a low-frequency ripple contained in the input voltage of inverter was reduced from 0.92 V to 0.20 V when the APDC is operated. The capacitance required in APDC is 75 times smaller than that in a passive power-decoupling.

Chapter 5 introduces a new SOC observation approach. It was experimentally verified that the overall voltage variation was close 0 V under the balanced condition. By contrast, the variation reached its peak value of 0.6 V under the extremely unbalanced condition. Based on this, the relative SOC of each battery module can be observed. When the relative SOC observation method was applied to the GCC, SOC of each module (0.5, 1.0 and 0.7) was equalized after 135 min and the maximum capacity of the battery pack could be successfully extracted compared to the case with a conventional equalization control where the module with the lowest SOC depleted within 160 min prior to other and the unused capacity left after discharging. Thus, it was noted that the accelerated balancing was well executed using this SOC observation approach.

Chapter 6 proposes an APDC to reduce either the high- or low-frequency ripples contained in a battery current. Conventional APDCs cannot reduce the high-frequency ripples because of the low-internal impedance of the battery. Thus, a new circuit configuration and a new power-decoupling controller with a battery current feedback loop are introduced. The ripple current suppression capability of the proposed circuit was compared with that of the conventional circuit. As result, the proposed circuit could reduce the ripple current at 100 Hz to 2.5% of the battery nominal current (6.5 A, 1 C), whereas the conventional circuit reduced up to 5% of 1C. Moreover, the ripple current at the switching frequency is reduced by 35%.

Chapter 7 summarizes the results of this dissertation and discusses the future works need to be done.