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Characteristics of high efficiency current charging system for HTS magnet with solar energy

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Abstract

In terms of electrical energy, the technical fusion with solar energy system is promisingly applied in order to improve the efficiency in the power applications, since the solar energy system can convert an eternal electric energy in all-year-around. As one of such power applications, we proposed a current charging system for HTS magnet combined with solar energy (CHS). As this system can operate without external utility power to charge the HTS load magnet due to the solar energy, the operating efficiency is practically improved. The power converter, which is interfaced with solar energy and HTS magnet systems, plays an important role to transfer the stable electric energy and thus, the stabilized performance of the converter with solar energy system is one of essential factors. In this study, we investigated various charging performances under different operating conditions of the converter. In addition, operating characteristics have been analyzed by solving solar cell equivalent equations based on circuit simulation program.

Keywords: current charging; HTS magnet; power converter; solar energy system

1. Introduction

Technological applications in the high temperature superconducting (HTS) wires benefit from both the higher critical temperature being above the boiling point of liquid nitrogen and also the higher critical magnetic field compared with low temperature superconducting (LTS) applications. The GHz-scale hybrid nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI) magnet systems are one of successfully superconducting applications using HTS magnet [1]-[2]. However, even though there are mentioned merits of the HTS coils, the drawback of the HTS wires are difficult to realize the persistent current mode up to now because of an intrinsically low n-value and a difficulty of superconducting joint of HTS wires [3]-[4]. In order to overcome such problems, various types of a current charging system, i.e. current compensator, have been developed [5]-[7]. Generally, it is not easy to improve the efficiency since an ordinary power system was used. As one of practical options, a solar energy system has been promisingly expected to improve the efficiency in the power applications.

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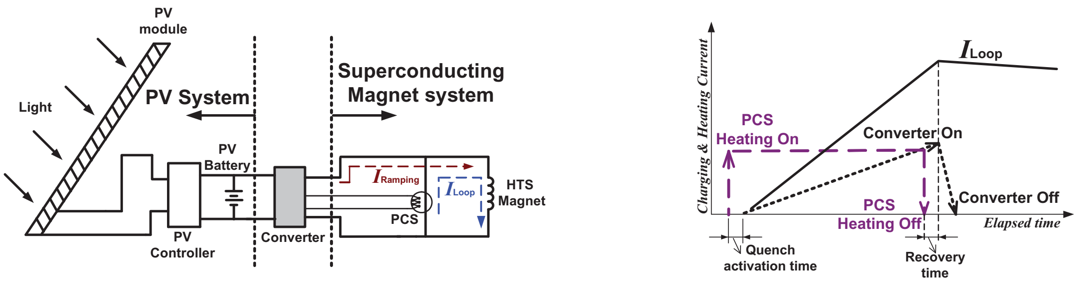
Recently, the vast quantity of non-polluting energy from renewable energy such as solar energy has received a great deal of attention since solar energy directly converts into electric energy. In terms of electrical energy, the solar energy system produces eternal electrical energy in all-year-round [8]-[9]. From this reason, the necessity of applications for the solar energy has been increased in the industries. Especially, the fusion technology of solar energy system for electric power applications has been promisingly expected as one of noble solutions to improve the operating efficiency.

From this point of view, we have been achieved a current charging system for HTS magnet utilized a solar energy (CHS) system. Since the CHS system including the power converter can operate without external utility power to charge the HTS load magnet due to the solar energy, the operating efficiency is effectively improved compared with developed others. In this paper, we carried out operating characteristics of the CHS system under different operating conditions of the power converter. In addition, it has been analyzed by solving solar cell equivalent equations based on circuit simulation program.

2. Structure and operating sequence

The CHS system is mainly consists of HTS magnet system with a persistent current switch (PCS), photovoltaic (PV) energy system and power converter system. Fig. 1 (a) shows the schematic diagram of CHS system, which is composed of 6 components as follows; (1) PV module, (2) PV controller, (3) PV battery, (4) converter, (5) One heater trigger type PCS, (6) HTS magnet. In order to use electric source from the PV module, the PV controller and PV battery are required. The DC converter, which is supplied constant voltage from the PV battery, provides heating current for PCS and generates ramping current for HTS magnet. From the operating sequences, the converted electric energy is transferred into the HTS magnet. Since the CHS system can operate without external utility power, its operating efficiency can be improved. This is the sequences of charging current in the HTS magnet as shown in Fig. 1 (b).



(a) structure of the current charging system. (b) operation sequences

Fig. 1. Schematic diagrams of structure and operating sequence of charging current.

3. Simulation analysis

We designed an equivalent circuit of CHS system based on the circuit analysis program. The profiles from solar energy to HTS magnet were investigated by the equivalent circuit analysis. The analysis results are referred to model the design and fabrication of the CHS system. The analysis is carried out by the commercial simulation program: PSIM®. Fig. 2 shows the equivalent circuit of HTS charging system with solar energy. The solar cell array is designed by DLL (Dynamic Link Library) model that is considered by solar energy density and temperature. The power

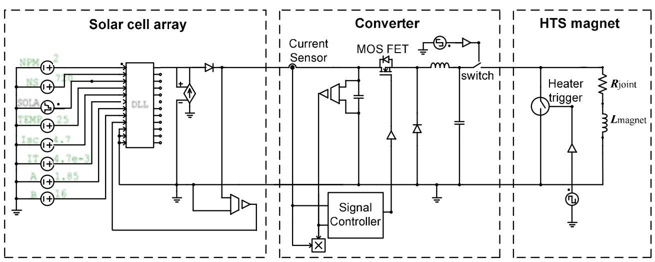


Fig. 2. Equivalent circuit of CHS system.

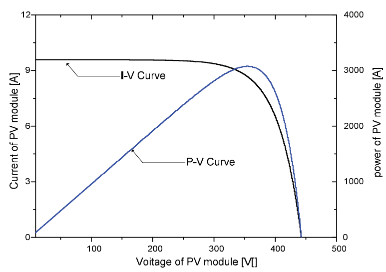


Fig. 3. I-V and P-V profiles of solar cell array.

converter that is designed with Buck converter, and the HTS magnet that is equalized by inductance of 9 mH, joint resistance of 10 nΩ and trigger switch are respectively modeled as shown in Fig. 2. The (photo voltaic) PV array consists of solar cells that convert photo energy into electric energy. Fig. 3 shows the simulation results I-V and P-V characteristics for solar energy density of 1000 W/m^2 of PV module. The simulation for charging current is carried out based on the equivalent circuit of Fig.2 and the results will be compared with experimental results in the next.

4. Fabrication

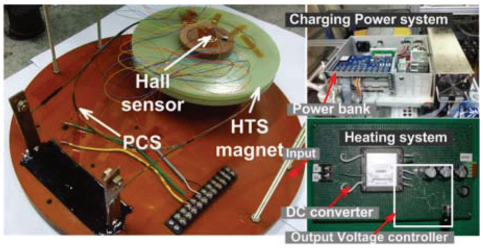


Fig. 4. Photograph of fabricated HTS magnet and power converter systems.

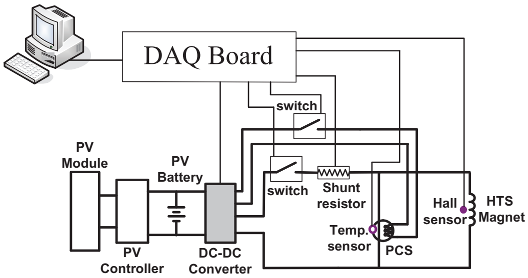


Fig. 5. Connection diagram of experimental setup.

We assembled the fabricated CHS system and installed measurements as shown in Fig. 4. The inductance of HTS magnet with Bi-2223 is 9.1 mH and the n value of the coil is 6. The resistance of heating wire for PCS is 37 Ω. The PV system is composed of the PV module, PV controller, PV battery and DC converter. The module has a 170 W (24 V×7 A) peak capability. The capacity of PV battery is 14 A × 15 V for 12 hours. In this system, a couple of PV modules were installed in parallel to add current for voltage with the gradient of 30^0. The DC converter supplies charging current for the HTS magnet and heating current of the PCS. The converter is designed to connect to one unit with 8-module. Since the converter combined with 3 units with 24-module is designed and the total capacity of the converter is easily available to extend until 100 A and minimum charging rate per second is 1 mA/s. The control range current of the converter is -6000 ~ 6000 mA. Fig. 5 shows the experimental set-up of the CHS system. One hall sensor in the magnet and a shunt resistor are installed, respectively. All measured signals are amplified and recorded into main computer through the DAQ board.

5. Experimental results

Fig. 6 shows the experimental and simulation results of conditions of ramping current in the converter and charging current of HTS magnet. The converter generated stably ramping currents such as case 1, 2 and 3. These rates for case 1, 2 and 3 are 80, 64 and 48mA/s, respectively. The heating current of heat trigger switch is 1 A. The converter produces charging current until 40 A in this experiment. Since the converter is designed to combine with 3 units with 24-module, the total capacity of the converter is easily available to extend over 40 A. Fig. (b) shows stable charging actions in the HTS magnet under different conditions of the converter. As the n-value of the HTS wire is low, the decay rates in the persistent current (PC) mode are unstably caused. From this reason, charging results agreed with simulation ones, on the other hands, the simulation results draw some intervals from experimental ones at PC mode. The conditions of ramping rate of the converter are shown in Fig. (a). Fig. (c) shows the experimental results of charging current and decay of the persistent current mode at 40, 30 and 20 A, respectively. As shown in the results, the charging current is saved in the HTS magnet from PV system under different operation current. The condition of the ramping current of

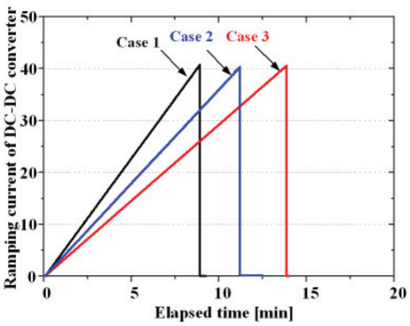


Fig. 6 (a) Converter currents

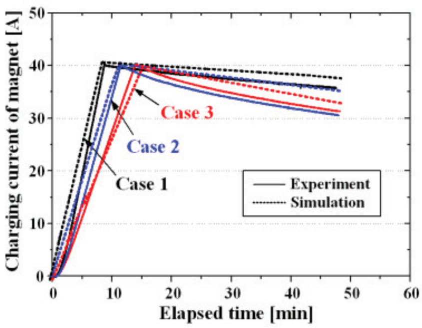


Fig. 6 (b) charging current of HTS magnet

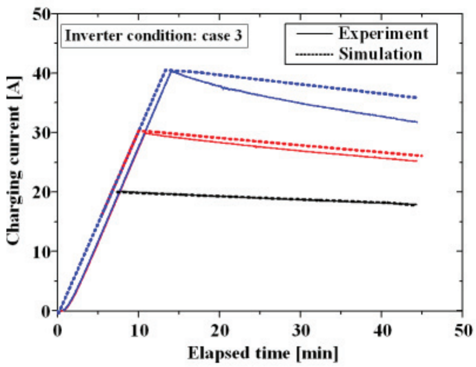


Fig. 6 (c) charging currents; case 3 of inverter

converter is case 3 in Fig. 6. The different decay of persistent current is caused due to flux creep of the HTS wire. The decay rates of the persistent current at 40, 30 and 20 A are 4.10, 2.05, 0.89 mA/s. Consequently, since the capacity of two PV batteries in parallel, 420 W (28 A × 15 V), which is produced from PV modules, supplies for DC converter and PCS switch without any external utility power, compared with developed power charging systems, the operating efficiency of CHS system is practically improved.

6. Conclusions

This work presented the o sequence of CHS system, also its operating characteristics as an HTS superconducting power supply. As well as, since the solar energy system have some merits to supply a mount of electric power, we combined to superconducting power applications as an electric power source. In terms of electric power energy, since this system can be handled without conventional electric power, compared with developed HTS charging system, the operating efficiency of CHS is remarkably improved. As a fundamental investigation, we carried out the charging actions under different ramping conditions of DC converter. In addition, we obtained the equivalent model for charging performances of the CHS system based on the circuit simulation. In the next study, based on the obtained results, we will design to develop a prototype current compensator for high field HTS magnet for NMR, MRI magnetic levitation (MAGLEV), superconducting fault current limiter (SFCL) systems.

Acknowledgements

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