MYU Tokyo

S & M 3243

Design and Implementation of Charging and Discharging Management System for Two-set Lithium Ferrous Phosphate Batteries

Cheng-Tao Tsai* and Feng-Wei Peng

Department of Electrical Engineering, National Chin-Yi University of Technology, Taichung 41170, Taiwan

(Received September 12, 2022; accepted February 2, 2023)

Keywords: lithium ferrous phosphate batteries, exchanged control, PIC16F1824 controller

In this paper, a charging and discharging management system for two-set lithium ferrous phosphate (LFP) batteries is proposed. The charging and discharging management system uses a PIC16F1824 controller to control the charging and discharging of two-set LFP batteries by an exchanged control. When the two sets of lithium-iron phosphate batteries are sequentially and completely charged, the charging power can immediately be powered off via the PIC16F1824 controller. The advantage of this is that the LFP batteries can avoid continuous charging, which induces breakdown if charging continues beyond completion. Therefore, the life cycle of LFP batteries can effectively be increased and the probability of electrical accidents can be reduced. Additionally, the charging and discharging management system can also implement the exchanged discharging function of the two-set LFP batteries. When one of the LFP batteries is discharged below a safe voltage, the other can continuously be discharged via the PIC16F1824 controller. Therefore, the proposed charging and discharging management system can rapidly provide power to the LFP batteries. Finally, a prototype of the charging and discharging management system is built to verify its feasibility. Experimental results have confirmed that the proposed battery management system is suitable for applications to two-set LFP batteries with an exchanged charging and discharging management control.

1. Introduction

To solve the problems related to coal-fired power and vehicle emission pollution, the development of green energy and electric vehicle technologies, such as wind power, biomass power, photovoltaic power, and electric vehicles (EVs), has become important issues. According to data records, more than 24% of global carbon dioxide emissions come from fuel-powered vehicles.(1,2) To reduce the carbon dioxide emissions caused by fueled vehicles, leading to severe air pollution, EVs have been widely developed. Because EVs have advantages of being non-polluting and having high energy efficiency and low noise, they can contribute considerably to solving air pollution problems.(3,4)

*Corresponding author: e-mail: cttsai@ncut.edu.tw
https://doi.org/10.18494/SAM4119

ISSN 0914-4935

EVs include electric cars, electric scooters, and electric bicycles. They require high-performance batteries to provide the driving power of motors. High-performance batteries include lithium–ion and lithium ferrous phosphate (LFP) batteries. Of these two batteries, the LFP batteries are more widely used. They have advantages of lower charging and discharging temperatures, more high-performance discharging power, and longer cycle lives.(5–9) During the process of charging the LFP batteries, a violent chemical response is induced inside the batteries, causing a phenomenon that results in the terminal voltage of the LFP batteries to rise rapidly if charging continues even after the batteries are fully charged. If the LFP batteries are continuously charged, they will become overcharged and incur permanent damage.(10–12) Consequently, electrical accidents frequently occur. In Taiwan, electric scooters are popular, because they are more suitable for riding in the narrow streets and alleys of cities than cars. To provide sufficient power energy and increase endurance, the current electric scooters already use two-set LFP batteries that enable exchanged discharging. Therefore, the optimization of the processes of charging and discharging the two-set LFP batteries is an important researchable topic.

To overcome the above-mentioned charging problems, a charging and discharging management system for two-set LFP batteries is proposed, as shown in Fig. 1. The charging and discharging management system consists of an AC–DC half-bridge LLC resonant converter (composed of inductors, transformers, and capacitors), a PIC16F1824 controller, sensing components and power switches, and two-set LFP batteries. The main function of the AC–DC half-bridge LLC resonant converter is to provide the charging power of the two-set LFP batteries during charging. The exchanged charging and discharging control of the two-set LFP batteries is implemented via the PIC16F1824 controller, sensing components, and relay switches. Therefore, the proposed management system has the following advantages. (1) When the two sets of LFP batteries are sequentially and completely charged, the charging power can be immediately turned off. Therefore, overcharging can be effectively avoided, thereby reducing the probability of electrical accidents. (2) The exchanged charging and discharging control enables the two-set

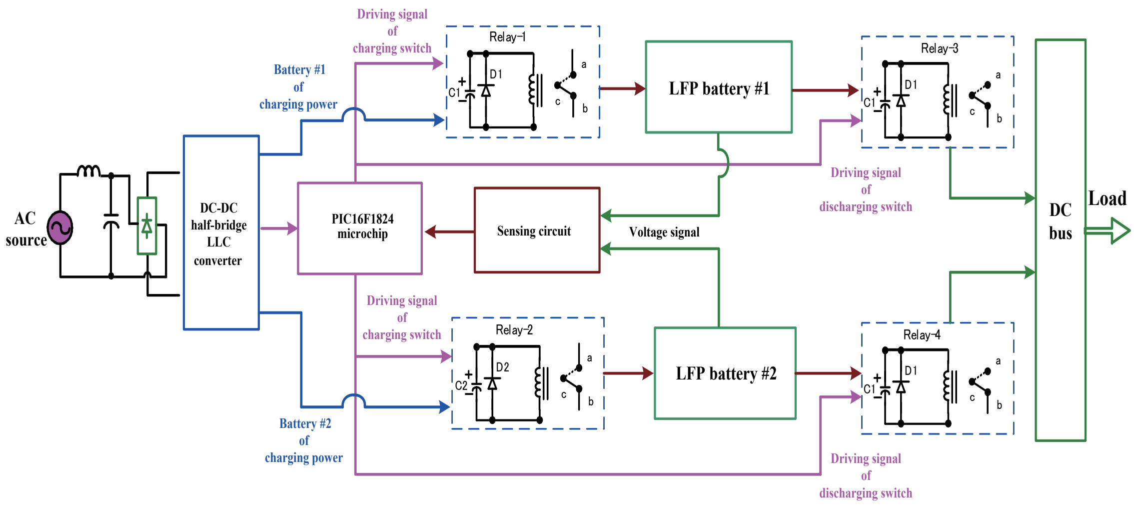

Fig. 1. (Color online) Structure of charging and discharging management system for two-set LFP batteries.

batteries to rapidly provide power and increase the endurance of electric scooters. The structures of the AC–DC half-bridge LLC resonant converter are described in Sect. 2. The control of the two-set LFP batteries with an exchanged charging and discharging control is analyzed in Sect. 3. The experimental results used to verify the feasibility of the proposed charging and discharging management system are shown in Sect. 4. Finally, conclusions are given in Sect. 5.

2. Structure of AC–DC Half-bridge LLC Resonant Converter

Figure 2 shows the structure of the AC–DC half-bridge LLC resonant converter. It consists of an AC filter, a full-wave rectifier, and a DC–DC half-bridge LLC resonant circuit. The operational principles of the half-bridge LLC resonant circuit are described below.

(a) Three reactive elements (C_r, L_r, and L_m) are used with an LLC resonant network. The input voltage (DC source) is converted into a square wave voltage by the half-bridge switch network. The square wave voltage via the LLC resonant network provides the output power.[13,14]

(b) In the half-bridge LLC resonant circuit, the power switches (M_{p1} and M_{p2}) are operated at zero-voltage switching (ZVS) during turn-on transition and zero-current switching (ZCS) during turn-off transition.[15–17]

(c) Therefore, the DC–DC half-bridge LLC resonant circuit has advantages of high efficiency and high power density.

3. Analysis of Two-set LFP Batteries with Exchanged Charging and Discharging Control

To effectively monitor the processes of charging and discharging the two-set LFP batteries, a battery management system (BMS) is necessarily equipped. The BMS is a real-time monitoring

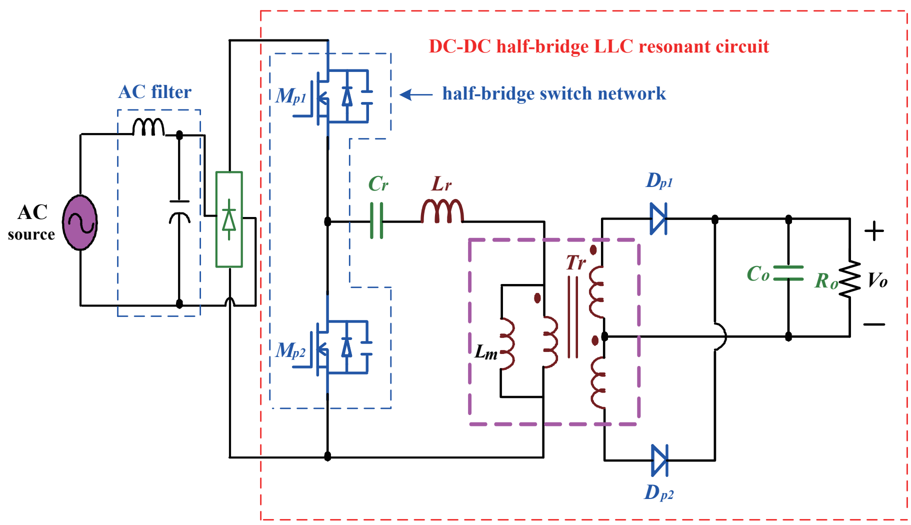

Fig. 2. (Color online) Structure of AC-DC half-bridge LLC resonant converter.

system that can effectively monitor real-time voltages, currents, and temperatures of the LFP batteries. When faults of the LFP batteries occur during charging and discharging processes, the BMS can perform optimal control and ensure safety. Therefore, stable and safe charging and discharging operations of the LFP batteries can be implemented.

In this section, a BMS comprising a PIC16F1824 microchip with an exchanged charging and discharging control is proposed to achieve the optimal control and safety of the two-set LFP batteries. The exchanged control methods of the proposed BMS can be divided into exchanged charging control and exchanged discharging control.

3.1 Analysis of BMS with exchanged charging control for two-set LFP batteries

Figure 3 shows the setup for charging the two-set LFP batteries. The operational principles of the BMS with an exchanged charging control are based on two conditions.

[Condition 1]: To detect two sets of LFP batteries, a low voltage signal is induced during charging.

To detect two sets of LFP batteries, a low-voltage signal is induced by the sensing circuit. The low-voltage signal via the PIC16F1824 controller induces a driving signal to turn on Relay-1. Thus, LFP battery #1 is charged first. The flowchart for charging LFP battery #1 is shown in Fig. 4. When LFP battery #1 becomes fully charged, Relay-1 is turned off and Relay-2 is turned on. LFP battery #1 is in an idle state and LFP battery #2 enters the charging state. The flowchart for charging LFP battery #2 is shown in Fig. 5.

[Condition 2]: One LFP battery induces a low voltage and another induces a high voltage during charging.

If LFP battery #1 induces a low voltage signal and LFP battery #2 induces a high voltage signal, as detected by the sensing circuit, the PIC16F1824 controller emits driving signals to turn on Relay-1 and turn off Relay-2, and vice versa.

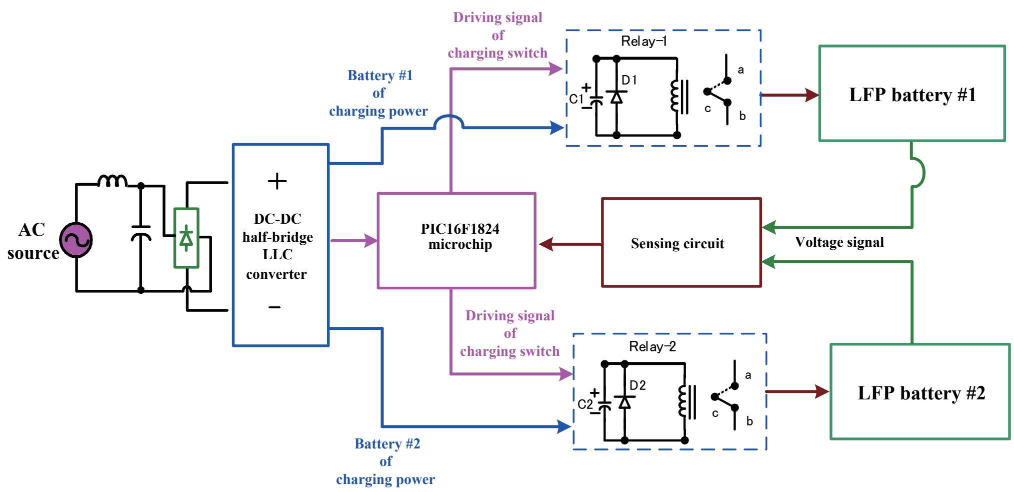

Fig. 3. (Color online) Setup for charging the two-set LFP batteries.

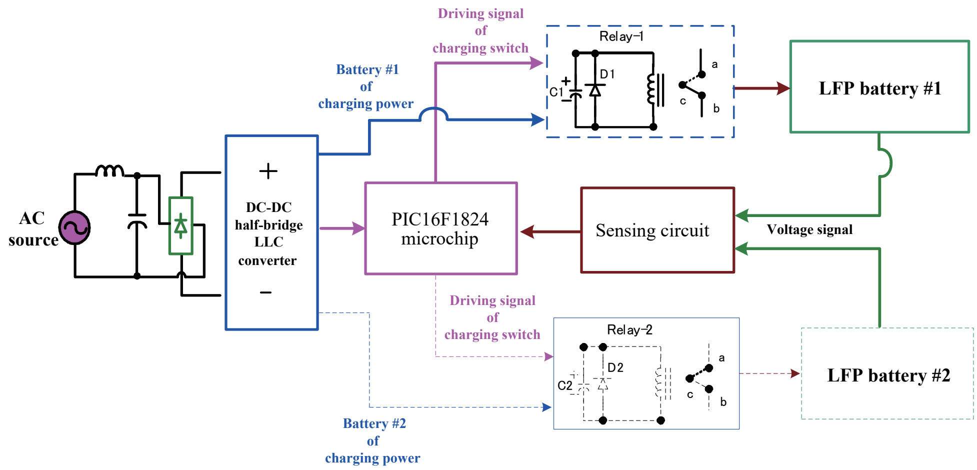

Fig. 4. (Color online) Flowchart for charging LFP battery #1.

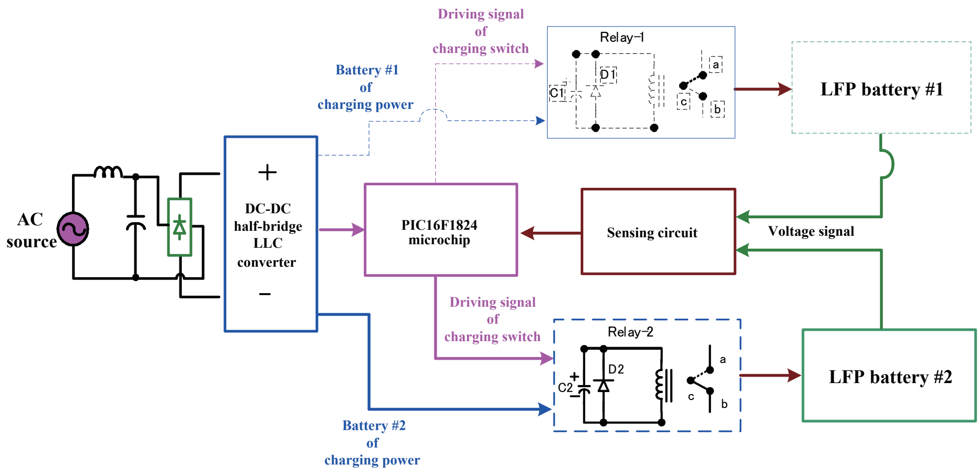

Fig. 5. (Color online) Flowchart for charging the LFP battery #2.

3.2 Analysis of BMS with exchanged discharging for two-set LFP batteries

Figure 6 shows the setup for discharging the two-set LFP batteries. The operational principles of the BMS with exchanged discharging are based on the following two conditions:

[Condition 1]: To detect two sets of LFP batteries, a low-voltage signal is induced during discharging.

To detect two sets of LFP batteries, a high-voltage signal is induced by the sensing circuit. When the high-voltage signal is input to the PIC16F1824 controller, a driving signal is induced to turn on Relay-3. Thus, LFP battery #1 will be discharged first. The flowchart for charging LFP battery #1 is shown in Fig. 7. When LFP battery #1 is fully discharged, Relay-3 is turned off and Relay-4 is turned on. LFP battery #1 becomes idle and the discharging of LFP battery #2 begins. The flowchart for discharging LFP battery #2 is shown in Fig. 8.

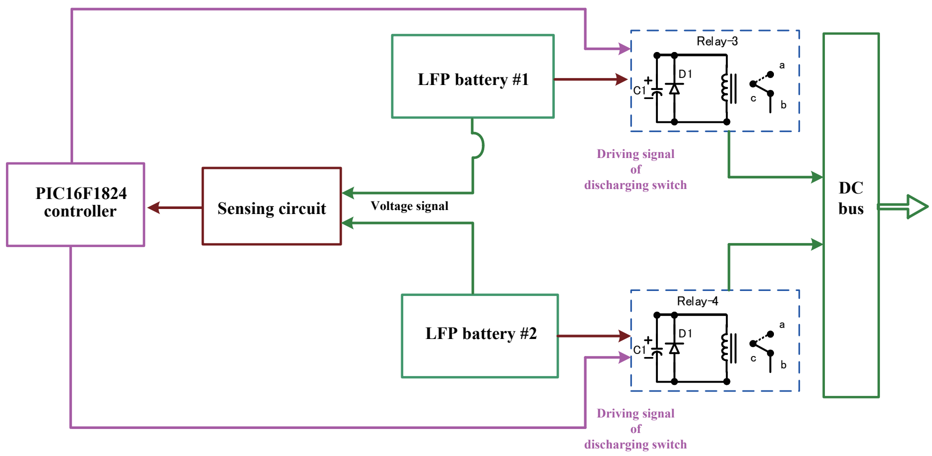

Fig. 6. (Color online) Setup for discharging the two-set LFP batteries.

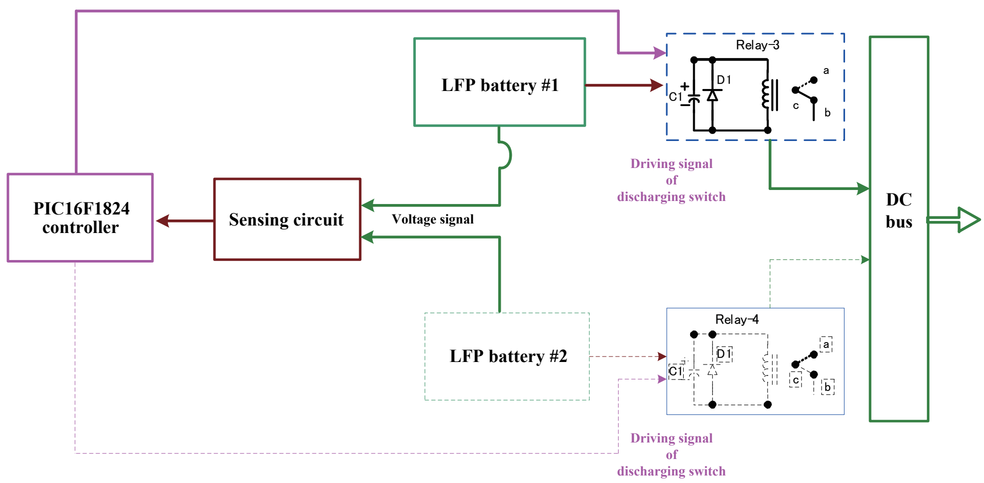

Fig. 7. (Color online) Flowchart for discharging LFP battery #1.

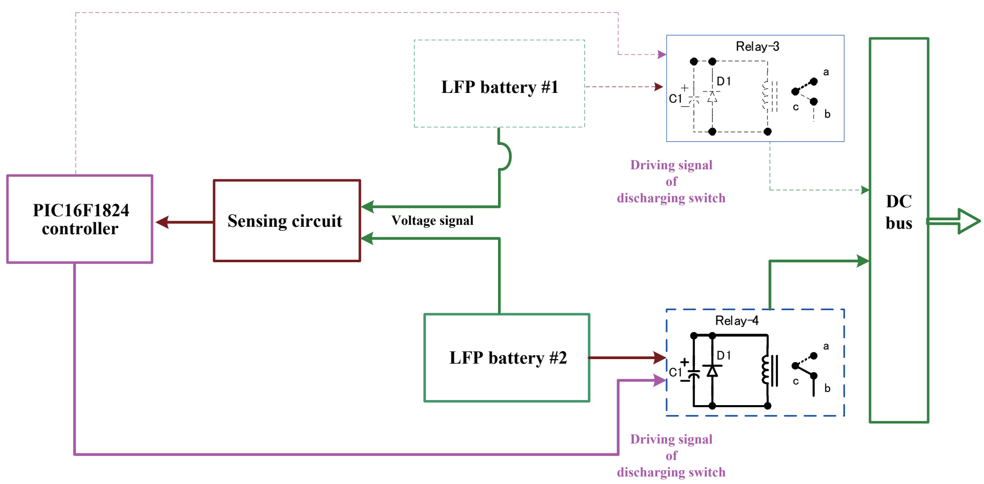

Fig. 8. (Color online) Flowchart for discharging LFP battery #2.

[Condition 2]: One LFP battery induces a low-voltage signal and the other induces a high-voltage signal during discharging.

If LFP battery #1 induces a low-voltage signal and LFP battery #2 induces a high-voltage signal, as detected by the sensing circuit, the PIC16F1824 controller emits driving signals to turn off Relay-3 and turn on Relay-4, and vice versa.

4. Experimental Results of Proposed Charging and Discharging Management System.

To verify the feasibility of the proposed BMS with the exchanged charging and discharging control for two-set LFP batteries, we built a test apparatus with an output voltage V_{DC} of 52 V, an output current A_{DC} of 4.8 A, and an output power of 250 W incorporating a control circuit with a PIC16F1824 controller, as shown in Fig. 9.

Figure 10 shows the measured driving voltage waveforms of the relay switches (Relay-1, Relay-2, Relay-3, and Relay-4). When the low-voltage signal of two-set LFP batteries is detected, Relay-1 is turned on, and LFP battery #1 is the first to be charged. Figure 11 shows the measured driving voltage waveforms of relay switches during the idle state of LFP battery #1 and the charging state of LFP battery #2. It can also be seen that when LFP battery #1 is fully charged, the charging of LFP battery #2 begins. Relay-1 is turned off and Relay-2 is turned on by the exchanged driving signals from the PIC16F 1824 controller. Figure 12 shows the measured driving voltage waveforms of the relay switches. When a high-voltage signal of the two-set LFP batteries is detected during discharging, Relay-1 is turned on and LFP battery #1 is the first to be discharged. Figure 13 shows the measured driving voltage waveforms of relay switches during the idle state of LFP battery #1 and the discharging state of LFP battery #2. It can also be seen that when LFP battery #1 is discharged to a low voltage, the discharging of LFP battery #2 begins. Relay-1 is turned off and Relay-2 is turned on by the exchanged driving signals from the PIC16F 1824 controller.

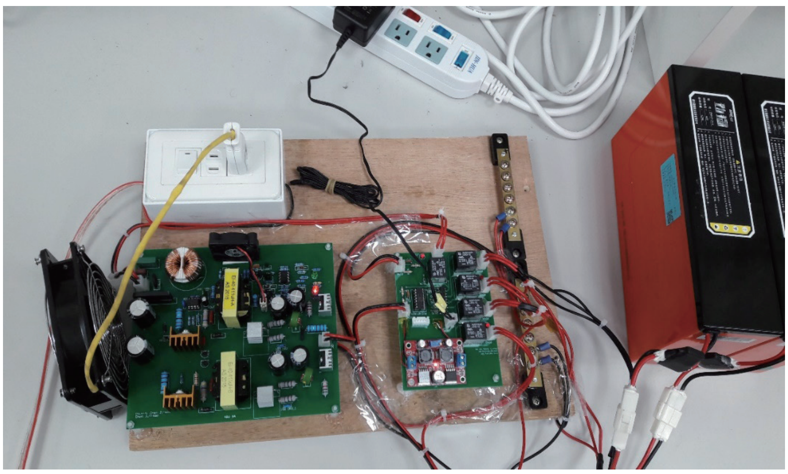

Fig. 9. (Color online) Test apparatus of charging and discharging management system for two-set LFP batteries.

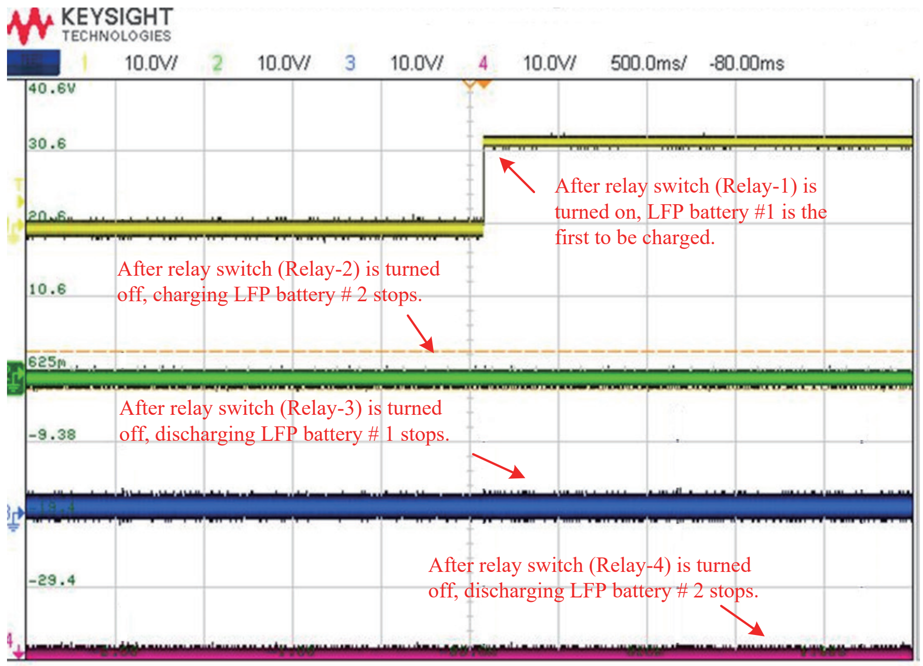

Fig. 10. (Color online) Measured driving voltage waveforms of relay switches when LFP battery #1 is charged first.

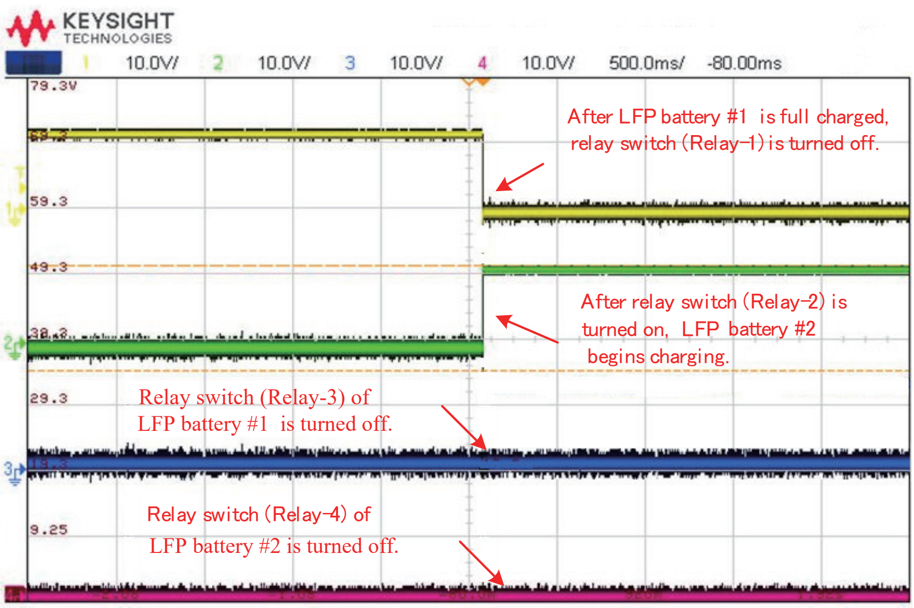

Fig. 11. (Color online) Measured driving voltage waveforms of relay switches during idle state of LFP battery #1 and charging state of LFP battery #2.

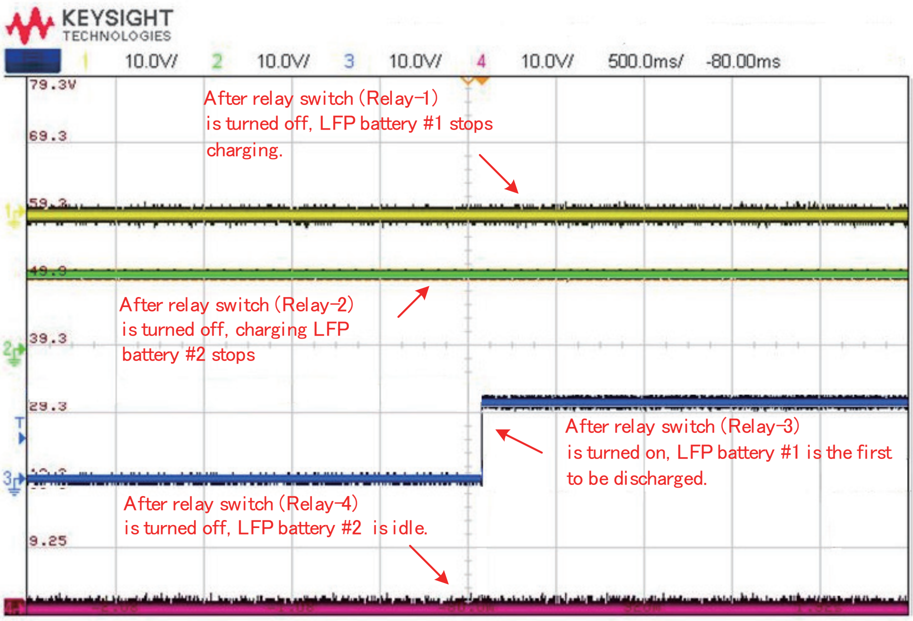

Fig. 12. (Color online) Measured driving voltage waveforms of relay switches when LFP battery #1 is discharged first.

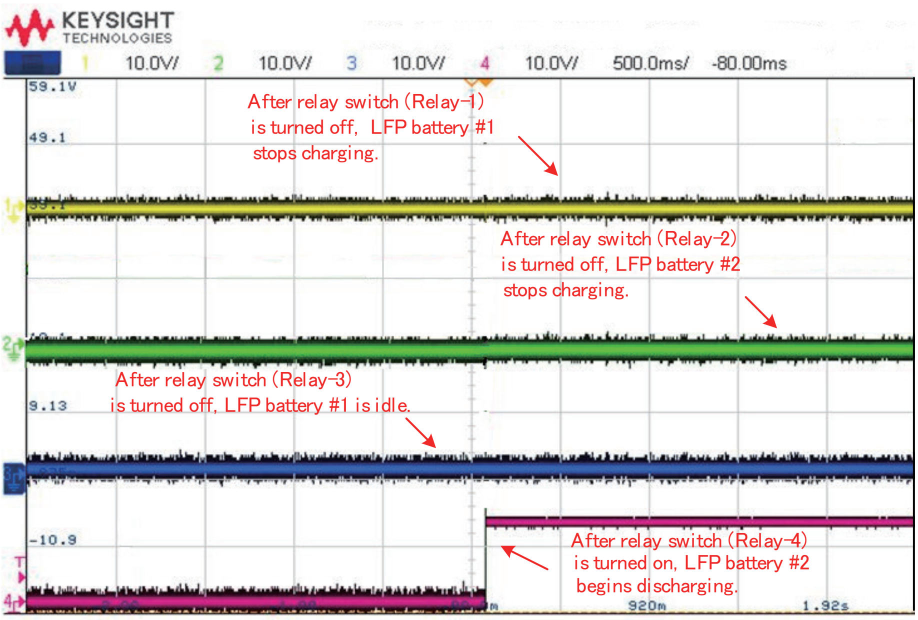

Fig. 13. (Color online) Measured driving voltage waveforms of relay switches during idle state of LFP battery #1 and discharging state of LFP battery #2.

5. Conclusions

We proposed, built, and implemented a charging and discharging management system for two-set LFP batteries. It uses a PIC16F1824 microchip with an exchanged control to implement the charging and discharging of the two-set LFP batteries. The proposed management system is a real-time monitoring system, and can effectively and instantly monitor the two-set LFP batteries during charging and discharging. Therefore, stable and safe charging and discharging operations of the two-set LFP batteries can be implemented. Experimental results have confirmed that the proposed management system with the exchanged charging and discharging control is suitable for two-set LFP batteries.

Acknowledgments

This work was supported by National Chin-Yi University of Technology, Taiwan

Author Contributions

All authors contributed to this paper. Cheng-Tao Tsai contributed to designing the circuit and writing this paper, and Feng-Wei Peng contributed to obtaining the experimental results of this paper.

Conflicts of Interests

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

1 K. Kobayashi, H. Matsuo, and Y. Sekine: IEEE Trans. Ind. Electron. **53** (2006) 281. https://doi.org/10.1109/TIE.2005.862250
2 C. Koroneos, T. Spachos, and N. Moussiopoulos: Renewable Energy **28** (2003) 295. https://doi.org/10.1016/S0960-1481(01)00125-2
3 B. T. Kuhn, G. E. Pitel, and P. T. Krein: Proc. Vehicle Power and Propulsion Conf. (IEEE, 2005) 55. https://doi.org/10.1109/VPPC.2005.1554532
4 K. Taesic and Q. Wei: IEEE Trans. Energy Convers. **26** (2011) 1172. https://doi.org/10.1109/TEC.2011.2167014
5 C. F. Chiasserini and R. R. Rao: IEEE Trans. Selected Areas Commun. **19** (2001) 1235. https://doi.org/10.1109/49.932692
6 K. W. E. Cheng, B. P. Divakar, H. Wu, K. Ding, and H. F. Ho: IEEE Trans. Vehicular Technol. **60** (2010) 76. https://doi.org/10.1109/TVT.2010.2089647
7 A. Szumanowski and Y. Chang: IEEE Trans. Vehicular Technol. **57** (2008) 1425. https://doi.org/10.1109/TVT.2007.912176
8 J. Zhang, D. D.-C. Lu, and T. Sun: IEEE Trans. Ind. Electron. **57** (2010) 1041. https://doi.org/10.1109/TIE.2009.2028336
9 S. M. Chen, T. J. Liang, L. S. Yang, and J. F. Chen: IEEE Trans. Power Electron. **26** (2011) 1146. https://doi.org/10.1109/TPEL.2010.2090362
10 M. Ceraolo and G. Pede: IEEE Trans. Vehicular Technol. **50** (2001) 109. https://doi.org/10.1109/25.917893
11 S. Pang, J. Farrell, J. Du, and M. Barth: Proc. American Control Conf. (IEEE, 2001) 4435. https://doi.org/10.1109/ACC.2001.945964

12 J. Cao, N. Schofield, and A. Emadi: Proc. IEEE Vehicle Power and Propulsion Conf. (IEEE, 2008) 11058. https://doi.org/10.1109/VPPC.2008.4677669
13 I. Batarseh: IEEE Trans. Power Electron. **9** (1994) 64. https://doi.org/10.1109/63.285495
14 R.L. Steigerwald: IEEE Trans. Power Electron. **3** (1988) 174. https://doi.org/10.1109/63.4347
15 H. P. Park and J. H. Jung: Ind. Electron. **64** (2016) 253. https://doi.org/10.1109/TIE.2016.2599138
16 W. Hao, J. Gong, X. Zhao, C. S. Yeh, and J. S. Lai: IEEJ Trans. Power Electron. **34** (2019) 11952. https://doi.org/10.1109/TPEL.2019.2909426
17 U. Kundu, K. Yenduri, and P. Sensarma: IEEJ Trans. Power Electron. **32** (20169) 1703. https://doi.org/10.1109/TPEL.2016.2604118