CHARGE EQUALIZING SYSTEM FOR TWO UNITS OF A SERIALLY CONNECTED LEAD-ACID BATTERY STRING USING A BUCK-BOOST CONVERTER TOPOLOGY

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Abstract

This article presents a charge equalizing system for two units of a serially connected lead-acid battery string using buck-boost converter topology. Serially connected two unit lead-acid battery strings are popular as a main power source in modern electric vehicles. The main problem of serially connecting a lead-acid battery string is the unbalanced energy levels in the battery units. To manage the problem, a charge equalizing system is introduced. A converter is part of the system. The operation of the converter can be buck and boost mode. In the buck mode the converter steps down the output voltage to be equal or lower than the input voltage. Conversely in the boost mode the converter steps up the output voltage to be equal or greater than the input voltage. Both of these modes allow the converter to drain excessive energy from batteries or supply additional current to batteries to manage the unbalanced energy level problem. Computer CAD simulation results consolidate the proposed technique.

Keywords: charge equalizing system, buck-boost converter, lead-acid battery

Introduction

Nowadays many modern electrical vehicles use serially connected lead-acid battery strings as a power source. The electric vehicle market is growing rapidly to meet the demand of customers. As a result, the demand of lead-acid battery strings for this electric vehicle is also growing hand-in-hand. The main maintenance expense of this electric vehicle is the cost to replace the lead-acid battery strings every two years at the end of the service life time of the batteries. Some electric vehicles require a serially connected battery string with two or more battery units to provide a large enough power source. There are many reasons that shorten the service life time of a lead-acid battery string. One is an unbalance energy problem between serially connected battery units. A charge equalization system is one of the solution methods for the unbalance problem. A charge equalization system acts as an electrical bridge that allows energy to transfer forward and backward between battery units for balancing their energy level. Balancing the energy level of a serially connected battery string keeps service life time to its maximum capability.

Literature Review and Proposed Technique

Previous research (Uno et al. 2011; Uno et al. 2011) proposed a charge equalization system using a power electronic converter with a single switch. It had problems because it was complicated to adjust and balance the current between batteries in the string. To overcome this obstacle, this paper proposes a charge equalizing system for two serially connected lead-acid battery strings using a buck-boost converter topology. The mode of operation of the proposed converter can be buck mode and boost mode. The buck mode is a mode where the converter steps down the output voltage to be equal or lower than the input voltage. The boost mode is a mode where the converter steps up the output voltage to be equal or greater than the input voltage. The proposed changes in the equalizing system topology are shown in Figure 1.

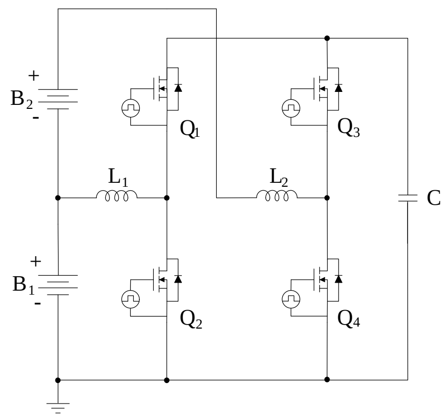


Figure 1 Proposed change in the equalizing system topology

For a serially connected battery string with a two battery unit, the charge equalization system consisted of four main switches, two inductors and one capacitor. Switches Q_1, Q_2 and L_1 were the component parts of the buck/boost converter's first charge equalization module. Switches Q_3, Q_4 and L_2 were the component parts of the buck/boost converter's second charge equalization module. These two charge equalization modules were tied together with one DC-linked capacitor C.

Principle of Operation of the Proposed Technique

The principle of operation of the proposed technique could be derived in eight operating modes. as shown in figure 2.

mode 1: Switches, Q_1 was turned on, Q_2, Q_3 and Q_4 were turned off. Energy from DC-linked capacitor flowed to charging battery B_1 and some energy was stored in inductor L_1.

mode 2: Switches, Q_2 was turned on, Q_1, Q_3 and Q_4 were turned off. Energy from inductor L_1 continues flowed to charging battery B_1 until energy from inductor L_1 dropped to zero.

mode 3: Switches, Q_2 was turned on, Q_1, Q_3 and Q_4 were turned off. Energy from battery B_1 flowed to storage at inductor L_1.

mode 4: Switches, Q_1 was turned on, Q_2, Q_3 and Q_4 were turned off. Energy from inductor L_1 flowed to storage at capacitor C.

mode 5: Switches, Q_3 was turned on, Q_1, Q_2 and Q_4 were turned off. Energy from the DC-linked capacitor flowed to charging batteries B_1 and B_2, some energy was stored in inductor L_2.

mode 6: Switches, Q_4 was turned on, Q_1, Q_2 and Q_3 were turned off. Energy from inductor L_2 flowed to charging batteries B_1 and B_2 until the energy from inductor L_2 dropped to zero.

mode 7: Switches Q_4 was turn on, Q_1, Q_2 and Q_3 were turn off. Energy from battery B_1 and B_2 flowed to storage at inductor L_2.

mode 8: Switches, Q_3 was turn on, Q_1, Q_2 and Q_4 were turn off. Energy from inductor L_2 flowed to storage at capacitor C.

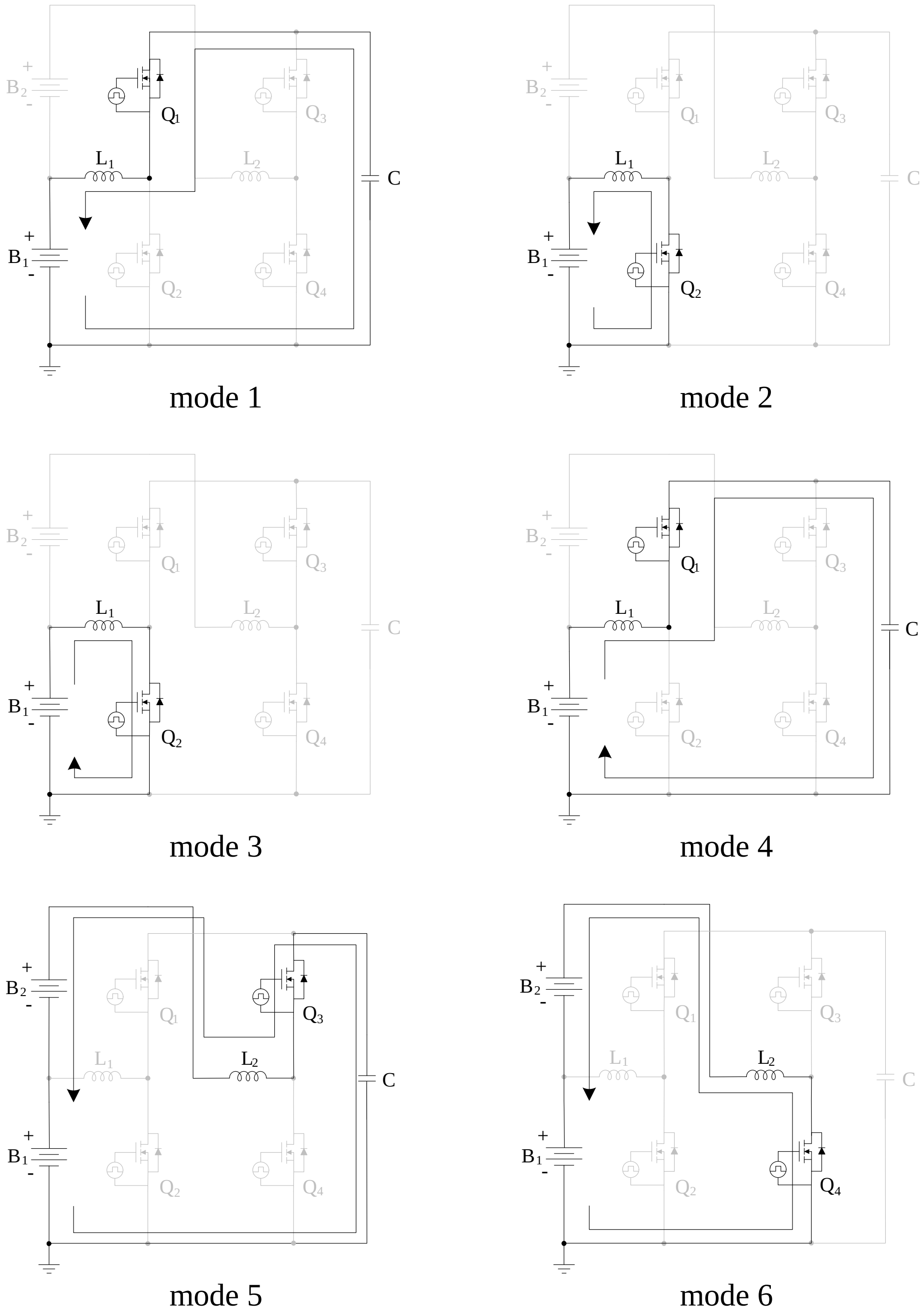
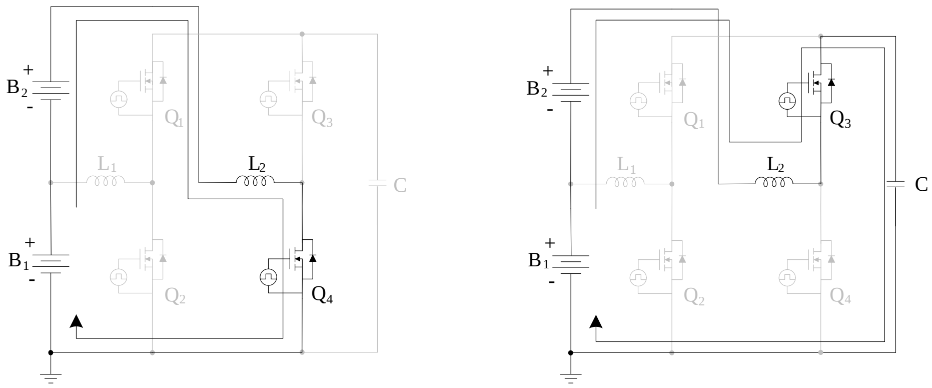


Figure 2 Principle of operation of the proposed technique



mode 7 mode 8

Figure 2 Principle of operation of the proposed technique (cont'd)

Simulation Results

For setting up the computer CAD simulations, the pre-defined variables of the proposed charge equalization technique are shown in Table 1.

Table 1 Pre-defined variables of proposed charge equalize technique

Input variable	Value
Number of Battery	2 Units
Battery Voltage	12 V
MOSFET	IRFZ44
Switching frequency	20 kHz
Inductor Value L_1 and L_2	100 µH
Capacitor Value C	1,000 µF

The computer CAD simulation results I_{L1} I_{L2} and V_C are shown in Figure 3. The operation of the proposed technique in modes 1, 2, 5 and 6 was to transfer energy from capacitor C to batteries B_n. In contrast, the operation of this technique in modes 3, 4, 7 and 8 was to transfer energy from batteries B_n to capacitor C. The slew rate of inductor current can be calculated from:

$$\Delta i_L = \frac{V_L \Delta t}{L} \qquad (1)$$

Where

- Δi_L is a small change of inductor current
- V_L is the voltage drop across inductor
- Δt is a small change of time
- L is the inductance

The maximum Δi_L occurs at Δt = DT (2)

Where

- D is a duty cycle of the power switch
- T is the switching period that can be calculated from T=1/f
- f is the switching frequency

From the simulation results, the average current in modes 1 and 2 was greater than the average current in modes 3 and 4 because the inductor voltage of modes 1 and 2 was equal to the sum of the two battery voltages V_{B1} and V_{B2}. In contrast, the inductor voltage of modes 3 and 4 was equal to the sum of only one battery voltage V_{B1}. This problem of an unequal current waveform can be solved by compensating with a switching duty cycle command for each power switch, thereby decreasing the duty cycle for modes 1 and 7, and increasing the duty cycle for modes 3 and 5. This compensation of the duty cycle command made the average inductor current to be equal. To perform intelligent control of all system operation, the duty control signal could be generated from a small microcomputer such as microcontroller dsPIC30f4011. In addition, the advantages of using a microcontroller were their ease of use, simple circuit configuration and reprogrammable firmware.

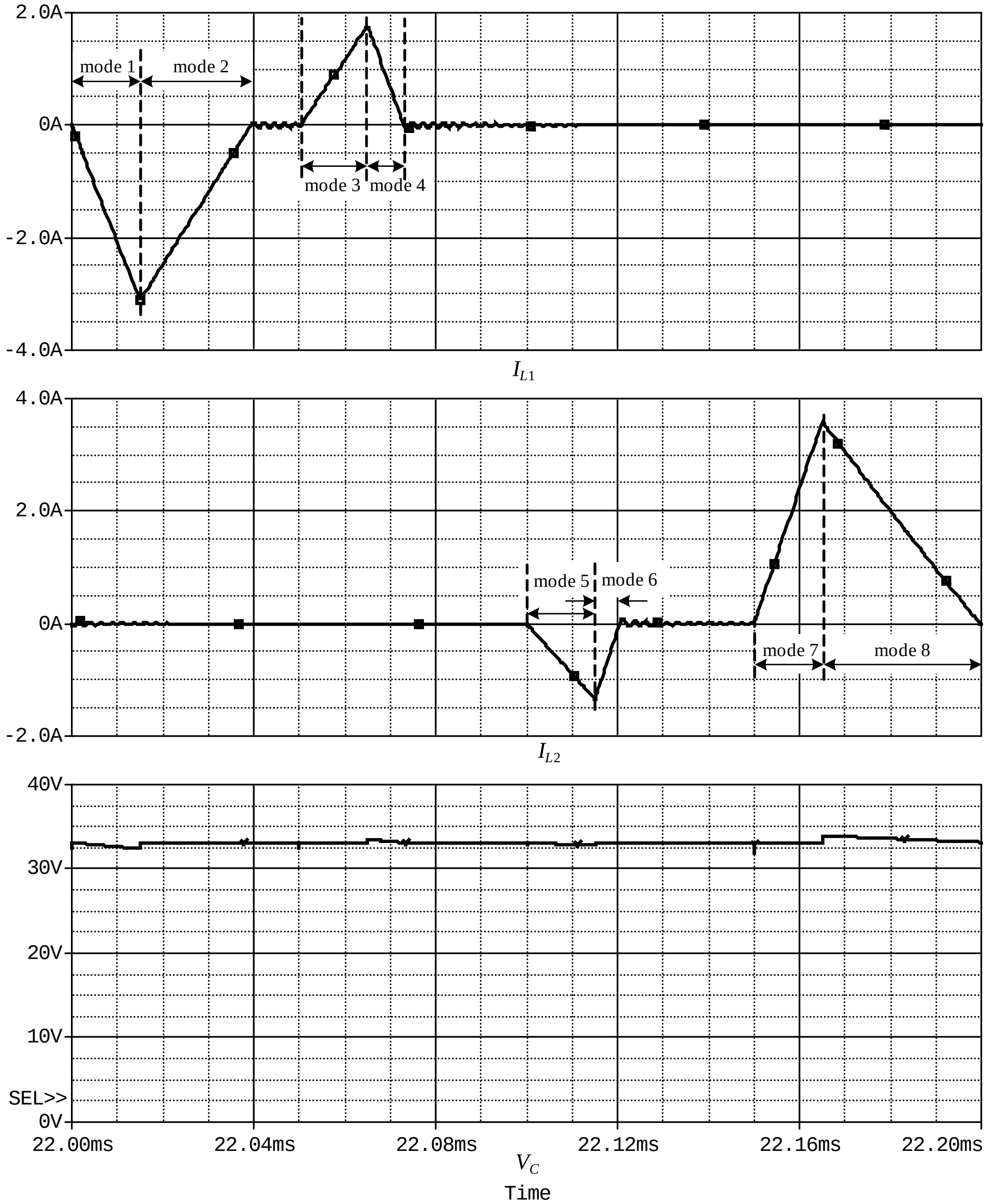


Figure 3 The computer CAD simulation results of proposed charge equalization technique.

Discussion and Conclusion

This proposed charge equalizing system for two units serially connected lead-acid battery string using buck-boost converter topology is a selective choice for balancing an unbalance energy problem for extends battery service life time. The main advantage of this proposed circuit is not required auxiliary power supply to support high side gate driving signal leading to simple circuit configuration. However, this article proposes only a computer CAD simulation. It is better to verify this simulation results by setting up an experimental prototype charge equalization system.

Acknowledgements

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