IMPLEMENTATION OF AN ACTIVE BATTERY BALANCER USING FLY-BACK TRANSFORMER

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ABSTRACT

This paper presents an implementation of an active battery balancing method using fly-back transformer. The need for balancing the batteries in series is to reduce damage to the battery string and to increase its life span. The proposed charge equalization method utilizes active switches and a multi-input single output fly-back transformer to transfer energy between the batteries. The equalizer achieves voltage and State of Charge (SoC) balance of batteries with same ratings. The method utilizes excess energy from charged cell to charge the other cells making it more efficient and use of single DC-DC boost converter with a fly-back transformer makes it compact and cheaper to implement. The method is proved by MatLab simulation and validated by hardware implementation.

Keywords: state of charge (SoC), battery capacity, battery balancing methods, DC-DC boost converter, fly-back transformer.

INTRODUCTION

Rechargeable batteries are now common sources of power in many applications ranging from electric vehicles, portable devices to energy storage systems. The terminal voltage of a single battery is low and hence these batteries are usually connected in series to meet the load voltage requirement. The high manufacturing costs prevent the use of a single high voltage battery to meet the load demand. This is overcome by using batteries of lower voltage connected in series. Such series connected batteries pose severe problems of imbalance amongst themselves caused due to some internal/external factors.

The state of imbalance refers to a condition where the series connected batteries are unequally charged / discharged at the end of a charging/discharging cycle (Sihua Wen, 2009). The batteries are said to be balanced when all of them in the pack poses the same SoC %, which defines the present battery capacity as a percentage of maximum capacity, as they charge and discharge. An imbalance of batteries cause their voltages to drift apart from each other overtime and thus decreasing the capacity that can drawn from the whole battery pack. Due to these reasons a balancing system is required to protect the battery from damage. This increases battery life and maintains the system in a reliable and accurate manner.

This paper presents a battery balancing method for series connected batteries using fly-back transformer. The following sections explain the implementation of the proposed method.

BALANCING CIRCUIT

Basic block diagram

The basic block diagram of the balancing circuit is shown in Figure-1.

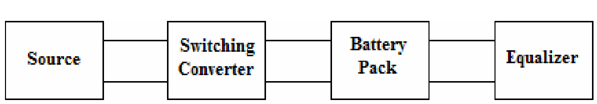

Figure-1. Block diagram of the battery equalizer.

- Source - It provides a constant DC voltage and current supply for the DC-DC boost converter.
- DC-DC Boost Converter - It steps up the input DC voltage provided by the DC source and it provides a constant output current.
- Battery pack - It comprises of series-connected batteries. The battery pack is charged using the constant current supplied by the boost converter.
- Equalizer - It comprises of a fly-back multi input transformer and a controller circuit. It makes use of the battery module active balancing topology (Yi-Hsun Hsieh *et al.*, 2013) which controls the charging/discharging current for balancing the battery pack.

Operating principle

A schematic of the balancing circuit is shown in Figure-2.

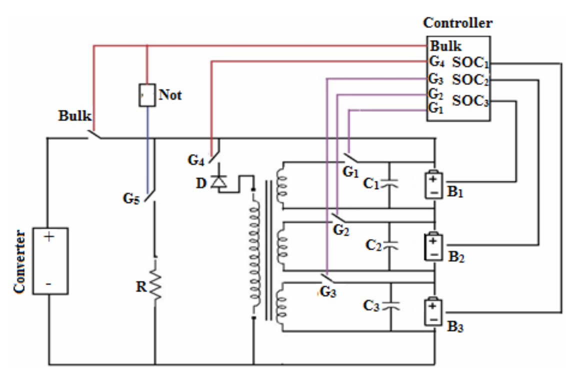

Figure-2. Schematic diagram.

The schematic gives a complete picture of the battery balancing circuit. Three lead acid batteries of 12 V each, connected in series are charged continuously by DC-DC boost converter. A fly-back transformer is implemented as the equalizer for the system battery balancing (Werner Robler, 2008). It is used as a multi-input and single-output transformer. The primary side

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carries three windings, each of which is connected to a corresponding battery in the pack, respectively in series with a diode and a switch (Chol-Ho Kim *et al.*, 2009; Kutkut N.H *et al*., 1995). The secondary winding carries a single winding connected to the battery pack in series with a diode and a switch. Both the primary and the secondary windings of the transformer are winded on a single core. Every switch in the balancing circuit is controlled by a controller block which provides pulsing operation for their switching.

The batteries are initially at different SoC levels. Due to such an initial state, the battery with the highest initial SoC level charges faster compared to the other batteries in the pack and hence tends to overcharge until the other batteries reach the required SoC level (Yevgen Barsukov). This, being an imbalance state, is overcome using the equalizer working.

As the batteries charge, their SoC levels are continuously monitored and given as input to the controller block. When the SoC level of any battery goes above 60% (20% - 60% SoC level considered as the safe operating limit for a lead-acid battery), the controller gives a pulsing wave to close the primary winding switch corresponding to that battery. The battery starts discharging its energy and stores it in the transformer core which is coupled with the secondary side, making a current flow from the secondary to charge the battery pack. This operation is carried on until all the batteries attain the 60% charge level. On reaching this condition, the controller block opens all the switches in the circuit. Using this principle of charge transfer from highly charged batteries to lower charged batteries, all the batteries in the pack are maintained at a safe SoC limit and prevented from going into the imbalance condition.

SIMULATION

The battery equalizer is simulated using MatLab Simulink tool (www.mathworks.com, Mohamed Daowd *et al*, 2011). The single battery characteristics have been discussed in a paper by Ramaprabha *et al*., 2014. The characteristics of series connected batteries with and without equalizer are presented in the following sections.

Battery characteristics without equalizer

Three batteries of 1.2 Ah, 12 V rating are charged serially using 1 A current. The batteries have different initial SoC of 0%, 10% and 20%. The SoC and voltage characteristics of the batteries while charging are shown in Figure-3 and Figure-4, respectively.

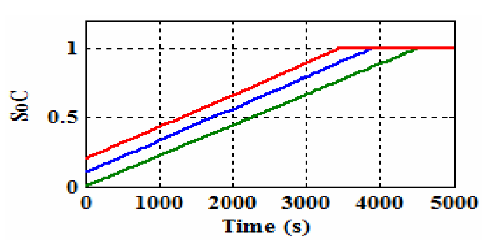

Figure-3. SoC characteristics.

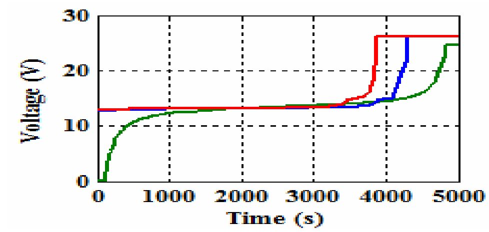

Figure-4. Voltage characteristics.

It can be inferred from the graphs that the batteries with high initial SoC get overcharged.

Battery characteristics with equalizer

The SoC and voltage characteristics of the batteries with equalizer are shown in Figure-5 and Figure-6, respectively. The controller of the battery equalizer has been coded such that all the batteries settle at a SoC of 60%. By balancing SoC, the voltage is also balanced.

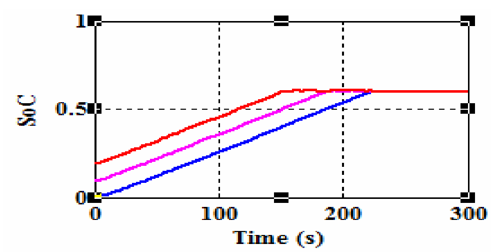

Figure-5. SoC characteristics.

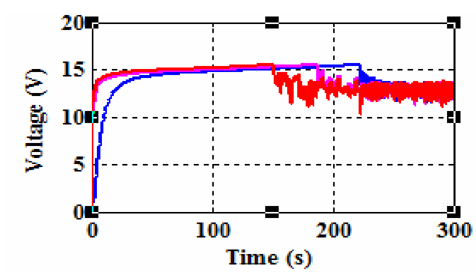

Figure-6. Voltage characteristics.

HARDWARE IMPLEMENTATION

The battery specifications used for this work are shown in Table-1.

Table-1. Battery specifications.

Parameters	Specifications/Ratings
Battery type	Sealed lead acid battery
Nominal voltage	12 V
Nominal capacity	1.2 Ah
Cycle use	14.5 V - 14.9 V
Stand-by use	13.6 V - 13.8 V
Maximum charging current	0.36 A

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HARDWARE RESULTS

The hardware implementation is explained as various sub blocks.

Boost converter

Figure-7 shows the boost converter circuit. An output current of 0.56 A and a boosted voltage of 31.4 V was obtained from an input of 12 V.

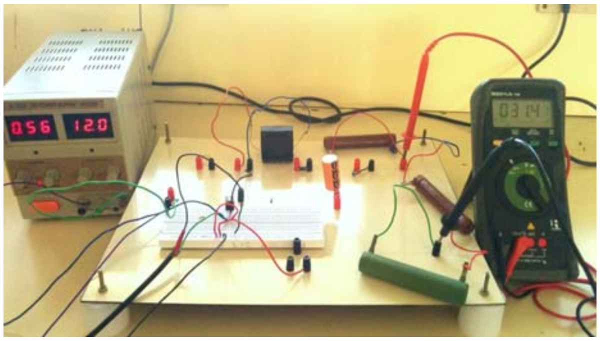


Figure-7. Boost converter.

The gating circuit for boost converter is designed using a 555 timer in astable mode to obtain pulses of frequency 30 kHz and a duty cycle of 75%. Figure-8 and Figure-9 show the timer circuit and the gating pulses, respectively.

Figure-8. 555 Timer circuit.

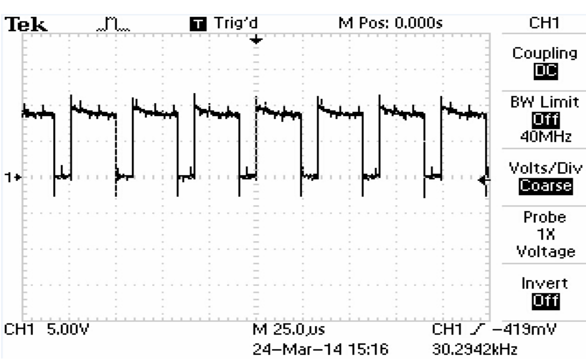


Figure-9. Timer output - gating pulse.

Battery charging without equalizer

Figure-10 shows the charger circuit in which two batteries are connected and charged in series with a current of 0.45 A.

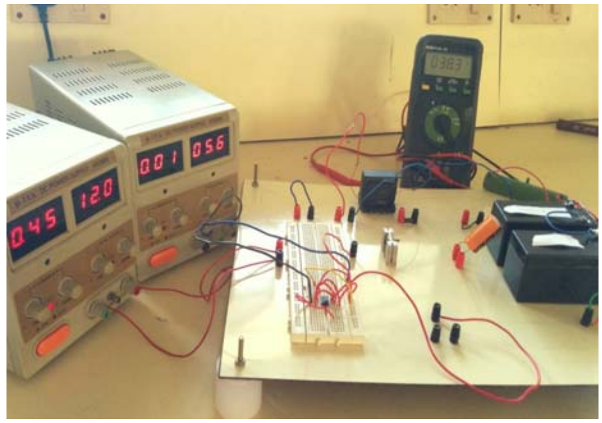


Figure-10. Battery charging circuit (Without equalizer).

The terminal voltage of each battery is recorded for every one hour while charging and the readings are tabulated as shown in Table-2.

Table-2. Terminal voltages of batteries without equalizer.

	11:00 a.m.	12:00 p.m.	1:00 p.m.	2:00 p.m.
Battery 1	12.96 V	13.04 V	13.20 V	13.32 V
Battery 2	12.87 V	13.00 V	13.13 V	13.25 V

Battery charging with equalizer

Figure-11 shows the complete charger circuit with equalizer. The circuit comprises of a boost converter, a fly-back transformer, a controller circuit and a voltage sensor.

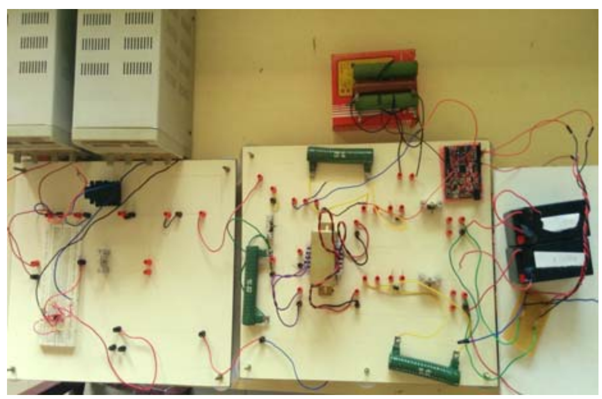
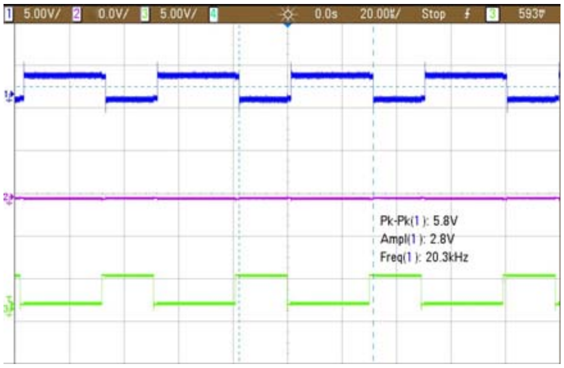
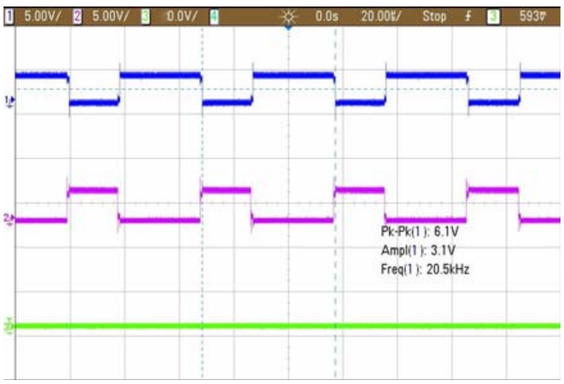


Figure-11. Battery balancing circuit.

The controller circuit is realized using Arduino kit uC32. The waveforms for different conditions of battery voltages are shown in Figure-12(a) and Figure-12(b). Scope 1 and Scope 2 show the fly-back transformer primary side switching and Scope 3 shows the switching at the secondary side of the fly-back transformer.



(a)



(b)

Figure-12. Waveforms of controller gating pulses.

The terminal voltage of each battery is recorded and the readings are tabulated as shown in Table-3.

Table-3. Terminal voltages of batteries with equalizer.

	11:00 a.m.	**12:00 p.m.**	**1:00 p.m.**	**2:00 p.m.**
Battery 1	13.56 V	13.61 V	13.63 V	13.64 V
Battery 2	13.47 V	13.59 V	13.62 V	13.65 V

It is observed from the Table that the battery voltages after balancing are maintained around 13.6 V which corresponds to a SoC level of 60%. The SoC-Voltage co-relation is determined by graphical method (Richard Perez, 1993).

CONCLUSIONS

This paper presents an equalizer for balancing series connected battery modules. The equalizer achieves the State of Charge (SoC) and voltage balance of the batteries. This balancing method provides a low cost and high efficiency solution for balancing the batteries and improving their life span. The charging of the series connected batteries with and without equalizer has been simulated and the feasibility of the balancing method has been verified by practical experimentation in charging two series connected 12 V, 1.2 Ah lead-acid batteries with different initial SoC levels. The results clearly depict that the problem of reduced usable capacity in these series connected batteries can be overcome by using the equalizer. This principle is also applicable for discharging mode and can be extended for any converter/battery type.

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