International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

Buck Boost Based Battery Charge Equalization Controller for an Electrical Vehicle

K.Jamuna, R.Vignesh, K.Usha

Abstract: ***The conventional automobiles are the major source for the air pollution in the world. By the deficit of the fuels and the environmental point of view, many researches focused on the electric vehicle. Electricity can be stored in economically with the help of batteries. In order to meet the demand of the vehicles, the batteries are connected in series. These series connected batteries supply higher voltage and consequently reduces I^2R losses. The battery string with imbalance voltage condition causes the potential damage to the battery and its life diminishes. Hence, the battery charging system is required to improve the life of batteries and it is necessary for equal charging and discharging of the batteries. Buck boost based charge equalizer topology is proposed to reduce voltage imbalance in the battery string. The control algorithm for that equalizer is formulated and it has been verified with the developed prototype model. Both the simulation and hardware results obtained are discussed in detail.***

***Index Terms*: Charge Equalizer, Energy Storage Systems, PI Controller, Lead Acid Battery.**

I. INTRODUCTION

World's power demand is increasing progressively. Hence, the existing methods of power generation using fossil fuels are not sufficient. Renewable energy sources are naturally available which are replenishing over a period of time, such as solar energy, wind energy, hydroelectric energy, and biomass. But these generated powers are intermittent in nature. Hence, renewable power generation need power converters and energy storage system where the battery plays a very important role. Batteries of most applications are connected in series to meet the required voltage. When batteries are connected in series as a string, the battery voltage has to be maintained as constant. But batteries voltage could not be same due to the many factors. Batteries' chemical and electrical characteristics from manufacturing, they experience the temperature mismatch which leads to the asymmetrical degradation with aging. The imbalanced batteries kept in use without control that decreases the usable storage capacity and the battery with higher State of Charge (SOC) would suffer overcharging and may be exploded on fire. Similarly, the battery with lower SOC would suffer over discharging and it cause full drain out. This condition leads to separation of battery from the string and that has to be replaced with the new battery which reduces the overall life of the battery string. Generally, battery performance is based on environmental temperature, charging /discharging profile, the state of charge. But it is complicated to maintain the identical conditions for all batteries. Due to the imbalance among the batteries, the charging /discharging process become difficult. Efficient charging reduces the charging time, increase battery life and less operating cost. In order to avoid the above conditions, the charge equalizers are used. Charge equalizers are connected across the battery string which are operated based on the SOC level of the individual battery in the string. Charge equalizer is necessary for equal charging /discharging of series connected batteries. The equalizer can be classified into two categories namely dissipative and non-dissipative. The dissipative method used the shunt resistors that are connected across the battery string in order dissipate the excess voltage [1]. In dissipative shunting method [2], the dissipative resistors are used for equalizing which are connected across the batteries using switches or relays. Switches connected with higher voltage will be switched on that connects the resistor into the circuit. When this resistor is connected, then the battery with higher voltage has less charging current. So the remaining batteries have high charging current compared to the battery having higher voltage. The method is simple in structure but the power loss is high. The non-dissipative methods are capacitor based, inductor based and the transformer-based methods. Switched capacitor circuit [2-7] is used for equal charging of series connected batteries. A capacitor is connected across each battery and that capacitor is charged or discharged till the voltage became same as the battery's voltage. The process is repeated for all batteries get to be equally charged. There is no control required in this method. The similar operation is performed in single switched capacitor method [3], [8]. Based on the voltage level of batteries, the capacitor is connected across batteries. But it needs a separate control algorithm for performing the capacitor switching operation. Switched transformer [3] is used for equalizer, which is functioned as a selectable energy converter. In this method, the input of the switched transformer is connected with the total battery bank and the output is connected with series of switches. These switches are connected with each battery in a bank. Hence the respective switch will be switched ON based on the voltage level of the battery. The switching sequence should have a control algorithm and the battery voltage has to be sensed separately that makes the circuit complex. There is no feedback control available in the non-dissipative methods. Hence dc-dc converters are used for equalizer circuits.

Revised Manuscript Received on 30 July 2019.

***** Correspondence Author

Vignesh R, Jamuna K*, School of Electrical Engineering, VIT, Chennai,Tamilnadu, India.

K.Usha, Department of Electrical and Electronics Engineering, SSN College of Engineering, Chennai, Tamilnadu, India.

In PWM controlled shunting [4] method, the battery voltage is sensed and the PWM signals are generated based on the voltage, that is given to the MOSFETs. PWM signals are varied based on the current difference between two batteries. By this method the current flows through the higher voltage battery is less than the current flowing through the normal cell. This method needs accurate voltage sensing and it is relatively complex. In boost shunting method [9-10], the boost converter is connected across each battery. Converter which is connected across the higher voltage battery will be activated. The switching pulses for the switch are generated depends on the battery voltage. Too many converters increase the cost of the setup. Converter based equalizer circuits have been proposed in the literature [11-21]. In [11, 16 -17], the detailed literature of the various equalization methods has been discussed. In this paper, the charge equalizer based on buck boost configuration is used which works in buck or boost mode depends on the SOC of the battery. The number of components required for a battery is very minimal that reduces the cost. The battery voltages have been measured at regular intervals. The error value is obtained by calculating the difference between the battery voltage and their average value. This error value is used for generating the switching pulses to maintain the equal voltages among the batteries. The duty ratio for the pulses is calculated using PI controller based on the error value. With this duty ratio, the pulses are generated with Audino uno. The PI controller is implemented using ATMEGA microcontroller in the hardware environment. This paper is constructed as follows: the section 2 describes the concepts, analysis of the charge equalizer and its controller. Section 3 explains both the simulation and experimental results. Finally, the conclusion is discussed in section 5.

II. CHARGE EQUALIZER

Fig. 1 shows the charge equalizer circuit for series connected batteries. Charge equalization sub circuit is connected across each battery that utilizes the buck –boost configuration. In order to increase the efficiency, the charge equalizer must be lossless circuit. The major components of the sub circuit are a diode, a switch and an inductor. Depends on number of batteries, equalization sub circuits is added in shunt configuration. Sub circuit connected across the battery with higher voltage is activated by giving gate pulse to the switch. Duty ratio of the gate pulse is decided based on error value which will be discussed later. When switch is ON, Inductor connected across the battery is charged and it is discharged to the other battery.

A. *Operating Modes of Charge Equalizer*

When the two batteries are charging in parallel and its equivalent circuit is shown in Fig 2. Hence two charge equalizer circuits has been build that utilizes two switches. The modes of operation are explained and its pictorial representation is shown in Fig.3.

MODE 1: If the battery B1 have is higher voltage than battery B2 then switch s1 is switched ON. When switch s1 is ON then the inductor L1 is charged. The current flows from source, battery B1 then to battery B2 and also source to inductor L1 to battery B2. In this mode the diode D1 is in blocking state.

MODE 2: When switch S1 is OFF then the inductor L1 start to discharge and diode D1 is in conducting mode. The discharging inductor current is passing through diode D1 and to the battery B2. Again when switch S1 is ON then the inductor L1 is charged by the source current.

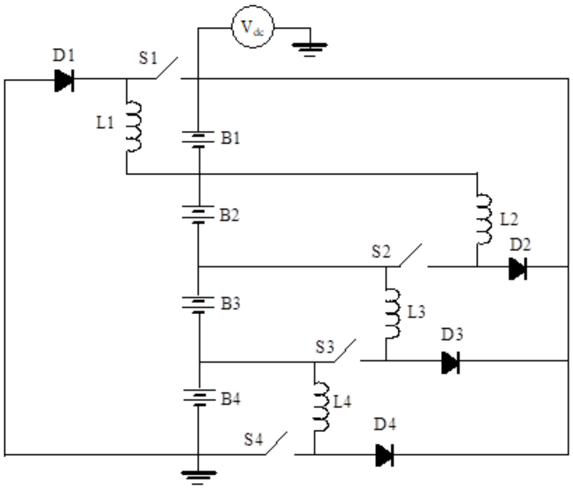


Fig. 1. Buck boost-based charge equalizer circuit for series connected batteries

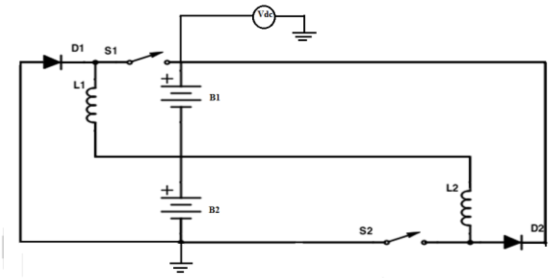


Fig. 2. Simplified Buck boost-based charge equalizer circuit for series connected batteries

MODE 3: If the battery B2 voltage is higher than battery B1then switch S2 is switched ON. When switch S2 is ON then the inductor L2 is charged. The current flows from the source to battery B1 then to battery and also source to battery B1 then to inductor L2. In this B2 mode the diode D2 is in blocking state.

MODE 4: When switch S2 is OFF then the inductor L2 starts to discharge as diode D2 is in conducting mode. The inductor is discharged through diode D2 and to the battery B1. Again when switch S2 is ON then the inductor is charged by the source current.

B. *Analysis of Charge Equalizer*

The design of inductor plays a major role in the charge equalizer circuit. The stored energy in the inductor supplies energy to the batteries. The net energy in the inductor should be zero at the end of each cycle that is energy stored in inductor should be discharged within a cycle. Otherwise the excess energy will be increasing progressively as the number of cycle increases which saturates the inductor. Therefore, the energy stored in the inductor must be utilized during the discharge period which is formulated as eqn. (1).

$$i_L(T_s) - i_L(0) = \frac{1}{L}\int_0^{T_s} V_L(t)\,dt \quad (1)$$

where i_L is the inductor current, V_L is the voltage across the inductor and T_s is the switching period. The inductor voltage over one switching cycle is expressed in eqn. (2).

$$V_B \times (DT_S) - (NV_B) \times T_D = 0 \qquad (2)$$

V_B is the battery voltage which connected across inductor. The sub circuit is activated for a duty ratio (D) of switching period (T_S). N is the number of batteries charged due to the stored energy of the inductor that are connected between the battery has higher voltage. When the sub circuit is switched off, then the energy stored in the inductor will be discharged to the batteries connected in downstream. This process is continued until the inductor current becomes zero. T_D is the time required for the inductor current to become zero, can be obtained by rearranging (2) as

$$T_D = \frac{DT_S}{N} \qquad (3)$$

The equalization inductor diverts the charging current and also draws the current from the battery. So the energy stored in the inductor should be discharged properly, else excess energy in the inductor after every cycle leads to saturation of the inductor. To avoid the saturation, the charging and discharging time of inductor should be constrained within a switching period, that is

$$DT_S + \frac{DT_S}{N} \le T_S \qquad (4)$$

The maximum duty ratio for the equalizer sub circuit can be be derived from (4) and is expressed in (5)

$$D_{max} \le \frac{N}{N+1} \qquad (5)$$

The inductor value is calculated by considering the maximum duty cycle (D_{max}) for equalizer sub circuit (6)

$$L_i \ge \frac{V_B}{I_i \times f_s} \times D_{max} \qquad (6)$$

Where f_s is the switching frequency, I_i the maximum equalization current and L_i is the equalization inductor.

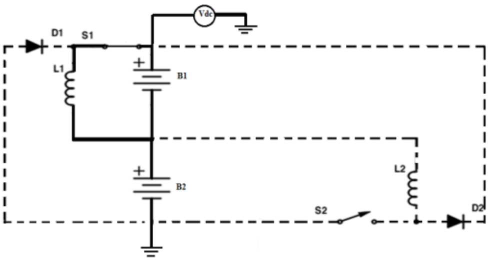
C. *Control of Charge Equalizer*

Generally the PID controller is given by the relation,

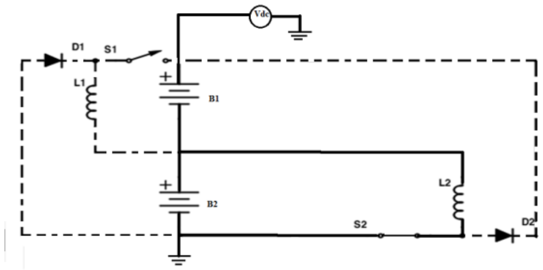
$$u(t) = K_p e(t) + K_i \int_0^t e(t)\,dt + K_d \frac{de(t)}{dt} \qquad (7)$$

This controller calculates the error value that is the difference between the set point and the actual value. It is used to minimize the error time by adjusting the damper. The term K_p, K_i, K_d are the gain of the proportional, integral and derivative terms of the controller respectively. The proportional is used to determine the present values of the error. The term integral is used to represent the past values of the error so that in case of weak control outputs, the controller will respond by applying some action. The derivate term is used to represent the future of the error values. An error signal $e(t)$ is created by the difference between the set point and actual point. This error signals are sent to PID controller where the controller computes the integral, derivative and proportional error signals. The output from this controller will be equal to the proportional gain time's magnitude plus the integral gain time's magnitude plus the derivative gain time's magnitude of the respective errors. The error signal is sent to the plant from where final output is obtained. This output is again sent to a sensor to produce the new error value which is sent to the controller and the process continues.

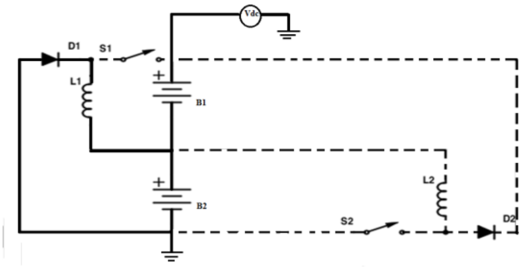
PID controller has the properties of zero steady state error, high stability, fast response and zero oscillations. The reason for including derivative component in the PID controller is used to eliminate the overshoot and output oscillations in the controller's output response. The advantage of using PID controller is that can be used even in higher order circuit having more than one storage elements.



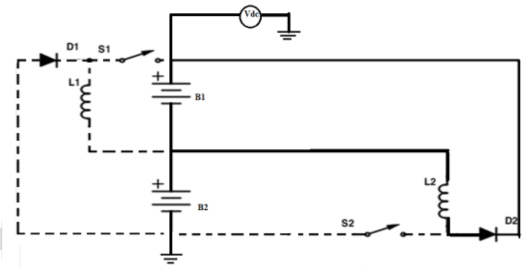
a. Mode 1: Switch S1 is ON



c. Mode 3: Switch S2 is ON



b. Mode 2: Switch S1 is OFF



d. Mode 4 Switch S2 is OFF

Fig 3. Modes of operation of the buck boost-based charge equalizer circuit

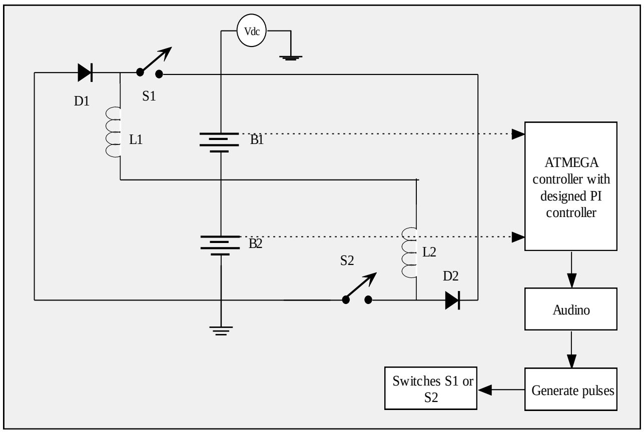


Fig 4 Charge equalizer controller

Charge equalizer operation basically depends on the gate pulse given to the switches in the circuit. The working of the controller is explained in Fig. 4. The battery voltages are measured at the regular intervals using the voltage sensors. The measured values are transmitted to the Atmega controller. The designed PI controller calculates the duty ratio of the pulses. These gate pulses are generated using Arduino Uno with the available duty ratio. These pulses used to operate the switches according to the battery voltage and maintain the string voltage constant.

D. *Algorithm for Charge Equalizer*

The triggering gate pulses for the charge equalizer circuit is generated using ATMEGA controller. These pulses are controlled based on the battery voltages. The arduino uno is used as controller; the coding for pulse generation is done in arduino software.

Step 1- Read the voltage of all series connected batteries.

Step 2- Check whether all batteries are fully charged if it is fully charged then terminate charging process else go to step 3.

Step 3- Evaluate the highest voltage of the batteries by comparing with each other.

Step 4- Calculate the average battery voltages from the measured value.

Step 5- Find an error by comparing highest voltage with average battery voltage.

Step 6- Generate pulse based on the error value using PI controller.

Step 7- Wait for delay, after delay go to step 2

Using this algorithm, the proper pulses for the switches can be generated. The proposed algorithm uses the battery voltages, based on that the error is calculated. The pulses are generated based on the error value using PI controller. Both the simulation and experimental results of charge equalizer are discussed in the next section.

III. RESULTS AND DISCUSSION

The charge equalizer circuit is designed and implemented in MATLAB/Simulink environment and that has been verified with experimental results. Battery model available in Simulink library is used for simulation and the inductor values are designed based on the eqn. (6). In simulation study, the three batteries are connected in series and the works has been carried out. The circuit specifications for simulation are input voltage 26V, battery 12V, 35Ah, switching frequency 15 kHz, Inductor L1 and L2 105µH, K_p and K_i 1.3 and 5 respectively. Only two batteries are taken for experimental setup to validate the results.

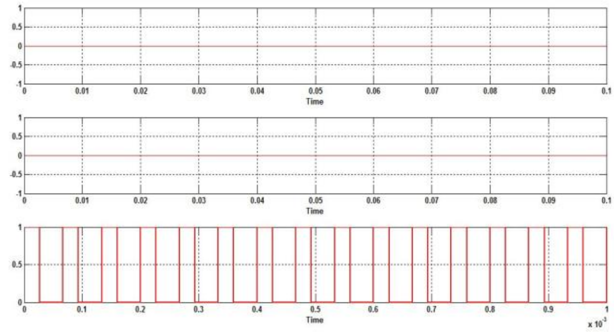


Fig 5 Switching Pulses of the series connected batteries B1, B2 and B3 respectively

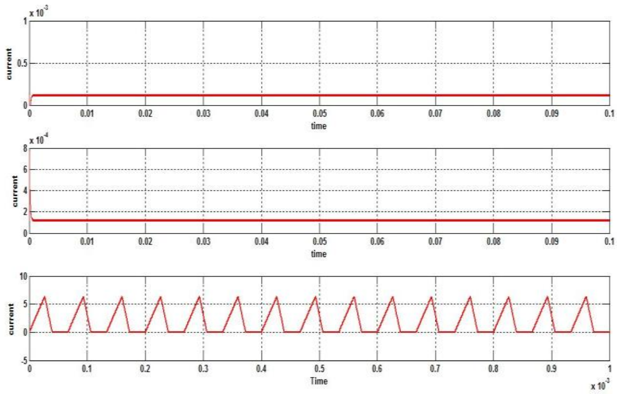


Fig 6 Inductor current waveform of three battery B1,B2 and B3 respectively

Simulation Study: The battery voltages are measured and according to that the results obtained after running the simulation for 0.1s is shown in Fig 5. In which, last figure shows the pulse generated for the third battery from the controller. Since the third battery's voltage is higher than other two batteries, the pulse is generated in the third system only. The duty ratio of pulse depends on the error value which is calculated by comparing high voltage of battery's with average voltage of the batteries. Fig 6 shows the current waveform of inductors. As third battery voltage is high compared to other batteries, the respective switch is turned ON. Hence the inductor connected across third battery is charged. When the switch is OFF, the inductor starts to discharge to other batteries In Fig 7, the battery voltage variation is only 0.02 V for simulation time of 0.1s. Hence the total time required for charging the battery on its full capacity takes around 1000s. But the charging process takes more than 40 minutes for 1V to complete the simulation. For study purpose, the circuit is simulated only for 0.1s. Since it is simulated for 0.1s, the voltage variation is not visible in the simulation. But the working of circuit and controller is verified with inductor current waveforms. In Fig 7, it is observed that third battery had higher voltage than the other two batteries.

Hence the inductor connected across third battery has to be charged and it is verified in Fig 6. The variation in the inductor current in 3rd waveform shows that the third battery having high voltage as compared to the two batteries.

Experimental Results: The charge equalizer circuit is fabricated and it is tested with two batteries connected in series. Arduino Uno is the microcontroller used in the control unit for the charge equalization circuit. The inductors used in the circuit are designed based on the design parameter discussed in section 2. The required components are listed in Table I. The component analysis has been performed with the equalizer incorporated with the switched capacitor (SC) [12] and the selective buck boost equalizer circuit [11] that have been listed in Table II. It is observed that the present work requires the fewer components and reduces the cost of the entire structure in order to meet the common goal. In the charge equalizer circuit, the voltage across each battery has to be measured and that is given as the input to the controller. Voltage sensors are used to measure the voltage across each battery. In arduino, the input analog voltage has equal to 5V or less than 5V. But the battery voltage is around 12V that has to be reduced proportionally. The voltage sensor is nothing but voltage divider circuit that is used to reduce the voltage which consists of two resistors R1 and R2. In this work, resistor R1 and R2 values are 30KΩ and 7.5KΩ respectively.

Fig. 8 shows the hardware setup of charge equalizer. The equalizer circuit is connected across two series connected batteries. The voltage of each battery is measured with help of voltage sensor and it is given as input to arduino. The pulses from arduino are given to the driver circuit and the output of the driver circuit is given to the switches. The experimental setup should remain kept under charging for a particular time period. Here the batteries are kept charging and four readings have been taken for an hour interval. The first set of wave forms and the last set of waveforms are shown in Fig 9 & Fig 10 and Fig 11 & Fig 12 respectively. The results are obtained immediately after the battery started to charge at 11.33am. Same parameters are measured for each interval which is shown in Fig 9-12. In Fig 9 and Fig 10, channel 1 and channel 2 are the voltages of first battery and second battery respectively. Third channel and forth channel show the charging current of first battery and second battery respectively. In Fig 9, the input of the batteries B1 and B2 are 12.4V and 12.9V. Comparing both the battery voltages, the battery B2 has more voltage and its current is 1.94A which is less than the current in the battery B1 that is 2.52 A. The switching pulses are generated for battery B2 because the voltage of battery B2 is higher than the battery B1 by observing the voltage waveforms as shown in Fig 9 and Fig 10. Hence the inductor across the battery B2 is charging and discharging which is shown in Fig 9. At the end of four hours, the battery voltages, battery currents of both batteries B1 and B2 are shown in Fig 12 at channel 1, 2 and 3,4 respectively . While comparing voltage magnitude of both batteries, battery B2 has more voltage than battery B1. Hence the respective switch is turned ON and thus second inductor gets charged. By comparing the inductor currents in Fig 11 and Fig 12, it can be observed that the current is reduced in Fig 12. The battery B2 is found to be charged at a higher rate than that of battery B1 which indicates that the error gets reduced and simultaneously the second battery is charged to the higher voltage than the previous condition. Hence the duty ratio also reduces that decreases the inductor current. Fig 9 shows the input current for batteries of 1.98A in channel 3. Fig 12 shows the input current for batteries of 309mA in channel 3. The value of input current is reduced by the process of charging the battery. The results obtained from the equalizer circuit are formulated in Table III. Initially the voltage difference between the batteries is 0.5V. It observed that the battery 2 has higher voltage than the battery 1. Hence the charge equalizer charges the battery 1 and boosted up to 13.2V which is almost equal to battery 2 voltage which shows that the control algorithm is working well practically. From the Table III, the input current flow in the circuit is more when the difference between batteries are

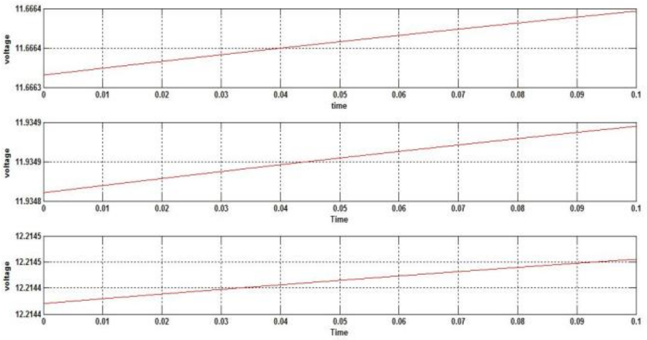


Fig 7 Series connected battery voltages of battery B1, B2 and B3 respectively

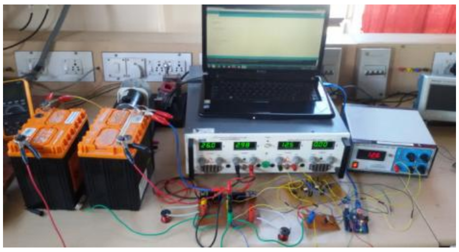


Fig 8 Hardware prototype of the buck boost based battery charge equalizer circuit

Table I: Components for charge equalizer

S.no	Component	Device /Rating	Specification
1	Battery (lead acid)	--	12V, 35AH
2	MOSFET	IRFP250	200V,30A
3	Driver	TLP250	15V,0.1A
4	Diode	MOSPEC2020	20A
5	Inductor	105 μH	10A

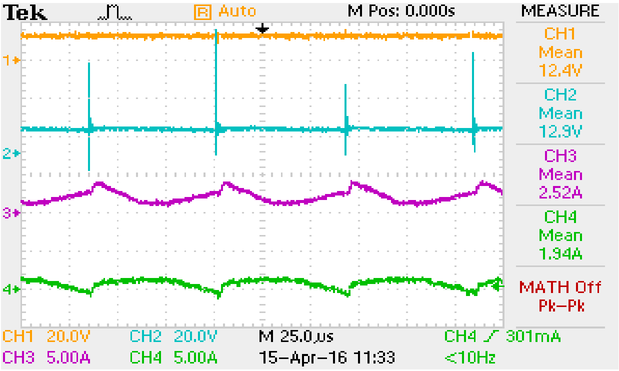


Fig 9 Battery voltages and inductor current at 11.33am (1st hour reading)

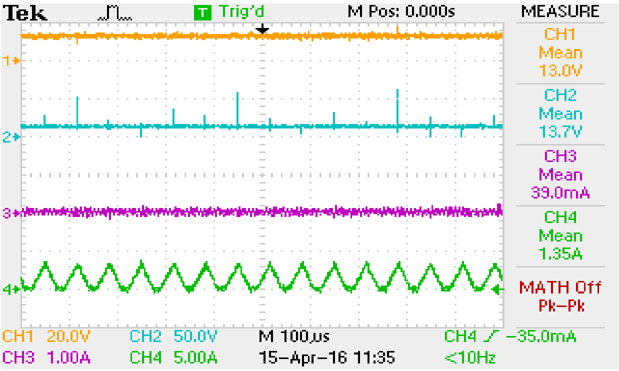


Fig 10 Battery voltages and inductor current at 11.35am (1st hour reading)

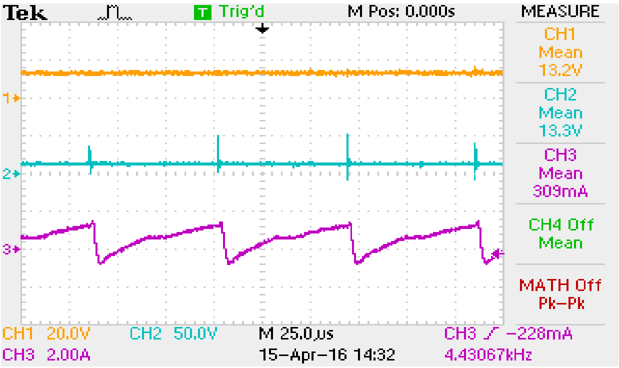


Fig 11 Battery voltage and input current at 14.32am (4th hour reading)

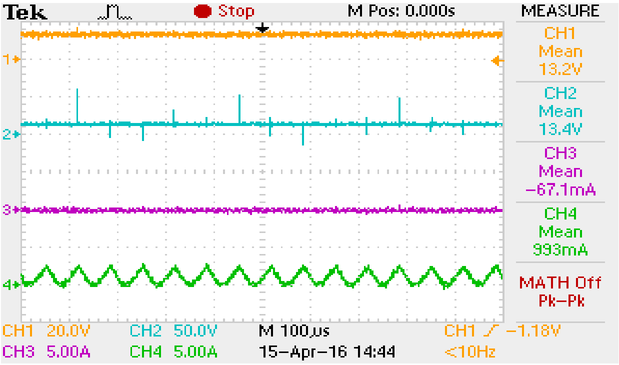


Fig 12 Battery voltages and inductor current at 14.44am (4th hour reading)

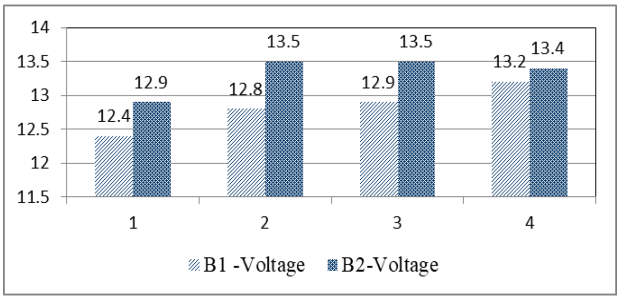


Fig 13 Battery voltages after an hour interval (In the last hour, they almost are equal in voltages)

Table II. Components Analysis with [11] and [12]

Equalizer circuit	No. of Switches	No. of Capacitors	No. of Inductors	Diodes/resistors/transistors	Cost
The classical SC	2n	n-1	NIL	NIL	Low
Switched coupling capacitor equalizer [12]	2n	n*	NIL	NIL	Slightly High
Selective buck boost equalizer [11]	2n	n	n	3n/2n/2n	NA
Proposed equalizer	2n	NIL	n	n/0/0	Low

Table III. Battery voltage and inductor currents of charge equalizer

Time period/parameter	0 (11.33am)	60 (12.33pm)	120 (13.33pm)	180 (14.35pm)
1st Battery voltage V_1, V	12.4	12.8	12.9	13.2
2nd Battery voltage V_2, V	12.9	13.5	13.5	13.4
Input current, A	1.98	0.7	0.5	0.3
1st Battery current, A	2.52	1.01	1.34	1.13
2nd Battery current, A	1.94	0.82	0.136	0.513
Inductor (L_1) current, mA	39	45.8	52.5	67
Inductor (L_1) current, mA	1.35	1.15	1.33	0.93

high and it gradually decreases when the difference in battery voltages gets reduced. The battery voltages are measured after an interval and compared each other, which are shown in Fig.13. The bar chart indicates that batteries are getting charged until the string voltages become equal. It shows that the controller is effectively maintaining the string voltage as constant by properly tuning the switches in the circuit.

IV. CONCLUSION

In this paper, the control algorithm for the series connected batteries are discussed and implemented in the simulation and the hardware. Algorithm has been explained with three batteries and has been implemented with two batteries for the electric vehicle applications. It is concluded that battery with lower voltage is charged faster than the battery with higher voltage. Since the fast charging of the lower voltage battery, the average error value reduces gradually. Hence the inductor current also reduced gradually and both batteries maintain the same voltage level. In future, the equalizer can be designed and tested with batteries string without reducing their charging efficiency. This work is well suitable for electric vehicles where solar energy is used as one source of energy.

REFERENCES

1. Chih-Chiang Hua, Yi-Hsiung Fang and Pei-Hong Li, "Charge equalisation for series-connected $LiFePO_4$ battery strings", IET transactions on Power Electronics, vol. 8, no.6, Jan. 2015, pp.1017-1025.
2. S. W. Moore and P. J. Schneider "A review of cell equalization methods for lithium ion and lithium polymer battery systems," in *Proc. SAE 2001 World Congress,* Detroit, MI, Mar. 2001.
3. Woei Luen Chen and Shin Rung Chang, "Optimal charge equalisation control for series connected batteries", IET transactions on Generation, Transmission and Distribution, vol. 7, no.8, April 2013, pp.843-854.
4. K. Nishijima, H. Sakamoto and K. Harada, "A PWM controlled simple and high performance battery balancing system," in *Proc. IEEE 31st Annual Power Electronics Specialists Conference,* vol. 1, Galway, Ireland, Jan. 2000, pp. 517-520.
5. C. Pascual and P. T. Krein, "Switched capacitor system for automatic series battery equalization," in *Proc. 12th Annual Applied Power Electronics Conference and Exposition,* vol. 2, Atlanta, GA, Feb. 1997, pp. 848-854.
6. S. West and P. T. Krein, "Equalization of valve-regulated lead acid batteries: issues and life test results," in *Proc. 22nd International Telecommunications Energy Conference,* Dresden, Germany, Sept. 2000, pp. 439-446.
7. J. W. Kimball and P. T. Krein, "Analysis and design of switched capacitor converters," in Proc. *20th Annual IEEE Applied Power Electronics Conference and Exposition,* vol. 3, Mar. 2005, pp. 1473-1477.
8. M. J. Isaacson, R. P. Hoolandsworth and P. J. Giampaoli, "Advanced lithium ion battery charger," in *Proc. 25th Annual Battery Conference on Applications and Advances,* Jan. 2000, pp. 193-198.
9. C. S. Moo, Y. C. Hsieh and I. S. Tsai "Charge equalization for series-connected batteries," in *Proc. Power Conversion Conference,* vol. 3, 2002, pp. 1138-1143.
10. C. S. Moo, Y. C. Hsieh and I. S. Tsai "Charge equalization for series-connected batteries," *IEEE Transactions on Aerospace and Electronic Systems,* vol. 39, no. 2, pp. 704-710, Apr. 2003.
11. Ming Tang and Thomas Stuart, "Selective buck boost equalizer for series battery packs", IEEE transactions on Aerospace and electronic systems, vol.36, no.1, Jan 2000, pp.201-211.
12. Yunlong Shang, Bing Xia, Fei Lu, Zhang C, N Cui and C Chris Mi, "A switched-coupling capacitor equalizer for series connected battery strings", IEEE transaction on power electronics, vol. 32, no.10, Oct. 2017, pp. 7694-7706.
13. Moo, C.S., Hsieh, Y.C., Tsai, I.S.: 'Charge equalization for series-connected batteries', IEEE Trans. Aerosp. Electron. Syst., 2003, 39, (2), pp. 704–710.
14. Koutroulis, E., Kalaitzakis, K.: 'Novel battery charging regulation system for photovoltaic applications', IEE Proc. Electr. Power Appl., 2004, 151, (2), pp. 191–197.
15. Nelson, J.P., Bolin,W.D.: 'Basic and advances in battery systems', IEEE Trans. Ind. Appl., 1995, 31, (2), pp. 419–428.
16. Cao, J., Schofield, N., Emadi, A.: 'Battery balancing methods: a comprehensive review'. Proc. IEEE Vehicle Power and Propulsion Conf., 2008, pp. 1–6.
17. Moore, S.W., Schneider, P.J.: 'A review of cell equalization methods for lithium ion and lithium polymer battery systems'. Proc. SAE World Congress, 2001, Paper 2001-01-0959.
18. Baughman, A.C., Ferdowsi, M.: 'Double-tiered switched-capacitor battery charge equalization technique', IEEE Trans. Ind. Electron., 2008, 55, (6), pp. 2227–2285.
19. Chen, W.-L., Li, J.-F., Huang, B.-X.: 'Design of an energy-saving charge equalization system', Electr. Power Compon. Syst., 2011, 39, (15), pp. 1632–1646.
20. Li, J.F., Chen, Y. H., Chen, W.L 'Research of a charge equalization strategy for series-connected batteries'. Proc. 30th Power Engineering Conf., 2009, pp. 1–5
21. Moo, C.S., Hsieh, Y.C., Tsai, I.S., Cheng, J.C.: 'Dynamic charge equalization for series-connected batteries', IEE Proc. Electr. Power Appl., 2003, 150, (5), pp. 501–505.

AUTHORS PROFILE

R.Vignesh is currently working as TCS, Chennai. He studied M.Tech (Power Electronics and Drives) in school of Electrical Engineering, VIT Chennai. He received his Bachelor's Degree in Electrical and Electronics Engineering from Anna University, Chennai.

K.Jamuna is an associate professor in school of Electrical Engineering, VIT Chennai. She has 15+ years of teaching experience in various engineering colleges. She received her PhD in IIT Madras in the area of Power system, Masters in Power Systems Engineering from College of Engineering Trivandrum, India and Bachelor's Degree in Electrical and Electronics Engineering from Thiagarajar College of Engineering, Madurai, India. Her research interests are smart grid, power system state estimation, wide area measurement systems and control. She has published many international journals and conferences.

K.Usha is an associate professor in the Department of Electrical and Electronics Engineering, SSN College of Engineering, Chennai, Tamilnadu, India. She has 15+ years of teaching experience. She received her PhD and M.Tech from College of Engineering, Guindy in the area of High Voltage Engineering. Her research interests are power electronics and high voltage. She has published many international journals and conferences.