Improved Commutation Control in Switching Regulators for Battery Equalizer Applications

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ABSTRACT

This paper presents an easy accessible method for improvement of the performance characteristics in some switching regulator toppologies, used for battery equalizer applications. Some strengths and weaknesses of the synchronous switching are shown. The authors propose solution for improvement of the performance characteristics in terms to avoid some of the main disadvantages in the battery equalizer system - active power losses in switching elements, reduced total efficiency and low quality waveforms caused by large transient time of commutation. The proposed solution is based on adaptive feedback adjusted dead-time commutation strategy. Test circuit and experimental results of dynamic non-overlap control with adaptive feedback are presented at the end of paper. Advanced driver circuit topology is developed and tested in DC-DC switching regulators for battery equalizer applications.

Keywords: synchronous switching, commutation control, adaptive feedback driver circuit.

1 INTRODUCTION

Batteries as energy storage elements in the electronic applications, are nearly always used in series combinations of multiple cells. When a series string of cells is charged as a group, a single current is imposed on all the cells. However, if their voltages begin to differ, the result is a charge imbalance that can lead ultimately to battery failure[5,6].

Most of the battery systems, used in present of the industrial electronic applications, are managed by charge distribution and balancing devices. Either passive or active, a perfect equalization process would ensure that a series string performs just like a single cell over time. That improves the performance, reduces the power losses and extends the battery life cycle.

In practical implementations different types of switching regulators are used for charge balancing[5]. The advances of the MOSFET and IGBT semiconductor switch technology provides high efficiency, low power losses, small or no cooling elements. However, their principle of operation demands particular control strategies that ensure the achievement of better efficiency parameters, independently from the load variations.

This paper considers one of the most common practical implementations of switching regulators that are used in battery management systems, and their performance. The authors propose a way to improve the efficiency and reduce the total power losses in the system using advanced driving circuit and buck/boost topology of DC-DC switching regulator.

2 BATTERY EQUALIZER APPLICATIONS – POWER LOSSES AND CONTROL FEATURES

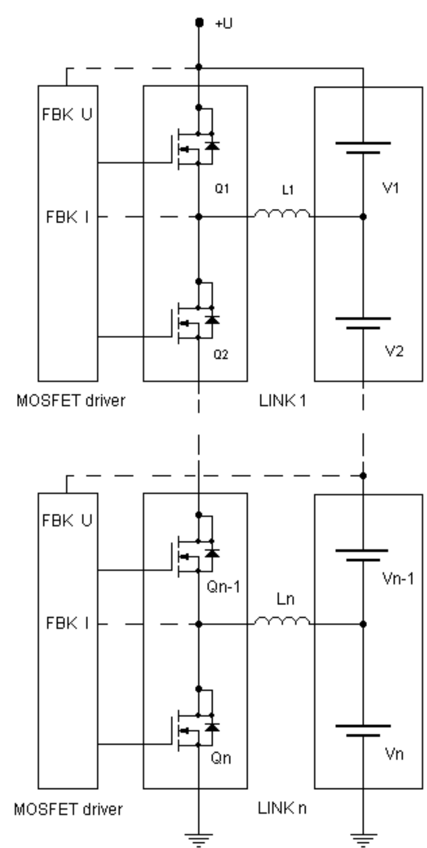

Figure 1: Battery charge equalization system

Figure 1 shows the topology used in the investigated charge equalization system – DC-DC buck/boost converter, connected between two cells of the battery string. It is capable to provide bi-directional energy transfer with proper control from the drive circuit. Most of the disadvantages in the battery management systems are related to low efficiency, increased value of the total power losses, large number of additional components etc. In this practical implementation the value of the power losses can be estimated for every link of the system – power losses in the switching stage, power losses in the connection wires (for large number of cells), power losses in the energy storage elements[1,2]. Every energy storage component could be presented by equivalent circuit of voltage source and some passive components, that forms its internal resistance, temperature dependent characteristics, self-discharge etc. and thus the active power losses in the battery during the charge/discharge process.

The proper coordination of the switching sequence for the power transistors is very important rule in all switching regulators[4]. One of their features is the presence of steady-state condition, when both transistors are closed. This minimum time, needed for full turn-off and reactive power dissipation and preparation for next cycle of operation is called "dead-time". For the switching stage (DC-DC buck/boost converter) the total power losses can be considered as number of switching losses and conduction losses[1]:

$$P_{MOSFET} = P_{SW} + P_{COND} \tag{1}$$

The power losses in the MOSFET Q1 are:

$$P_{COND} = I_L^{\ 2}.R_{DS(ON)}.V2/V1$$
$$P_{SW} = \frac{V1.I_L}{2}.(t_r + t_f).f_{SW} \tag{2}$$

where P_{COND} are conduction losses, P_{SW} - switching losses, I_L – output current, V1 and V2 - input and output voltage. $R_{DS(ON)}$ - Q1 active resistance, T_r and T_f are rise and fall switching times for the MOSFET component, f_{SW}-switcing frequency.

The power losses in Q2 are:

$$P_{COND} = (1-D).I_L^{\ 2}.R_{DS(ON)}$$
$$P_{SW} = \frac{t_r.V_F + t_f.V_F + I_L.1{,}1.R_{DS(ON)}}{2}.I_L.f_{SW} \tag{3}$$

where D is duty cycle ratio, Vf is body diode voltage drop.

The conduction losses, caused by the reverse body diodes conduction and recovery are:

$$P_{DIODE} = t_{DEADTIME}.f_{SW}.V_F.I_{OUT} \tag{4}$$

The power losses in the battery cell are calculated by the following equation:

$$P_{BAT} = I_0^{\ 2}.Rs.\gamma.(1-\gamma) = (I_{\max} - I_{\min})^2.Rs.\gamma.(1-\gamma) \tag{5}$$

where R_S is:

$$Rs = Ks.\exp.[K_1.(1-SOC)]\ /\ 1+\exp(K_2.I_0) \tag{6}$$

K_S is invariable of the resistance in Ω, K_1 and K_2 are invariables.

In the above equations state of charge coefficient (SOC) is presented:

$$SOC = 1 - Qe/C(0,\theta) \tag{7}$$

where Q_e is the battery charge in A/sec, C is the battery capacity, θ is temperature of the electrolyte.

3 DRIVER CIRCUIT WITH IMPROVED COMMUTATION CONTROL

The analysis of the reasons for active power losses in the battery power management systems and the calculations shows that with dead-time reduction the losses in the switching converters can be decreased. In some cases this affects the stability and increases the component overloads. Therefore an improved driver circuit with dynamic dead-time control is presented on Figure 2.

The proposed driver circuit has adaptive feedback, which monitors the state of power MOSFETs. It provides dynamic compensation of the dead-time in order to avoid short circuit and in the same time to keep it minimum. Therefore it does not affect the output waveforms. The presented driver with adaptive principle of commutation has application in DC-DC converters, inverters and other switching devices with fixed commutation that have two or more switching elements in synchronous sequence of operation. Other important advantage of the proposed circuit is the absence of additional reactive elements, compared to the applications with semi-soft and soft commutation, as way of switching loss reduction.

The simulation results show evaluation of the total power losses for DC-DC buck/boost switching regulator, used as charge equalizer device and driven by two different control circuits: with fixed dead-time and with dynamic regulated dead-time. The equivalent of lead-acid 12V/74Ah batteries is used in the examination. The diagrams of the currents and voltages in the regulator are shown on Figure. Calculated values of the total power losses and the efficiency of the battery management system for fixed and dynamic dead-time control is given in Table. Comparison between these two controls is shown on Figure.

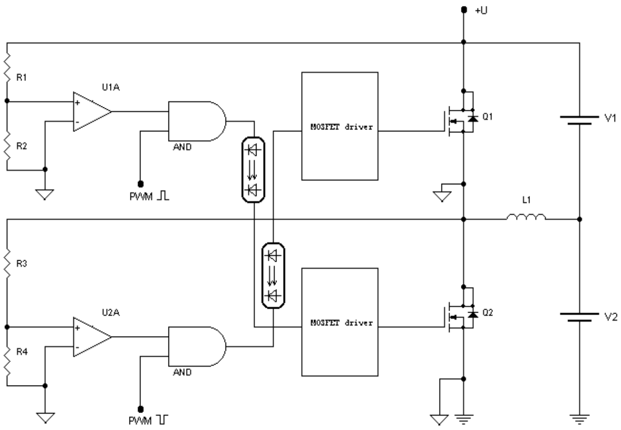

Figure 2 : Improved commutation control driver circuit

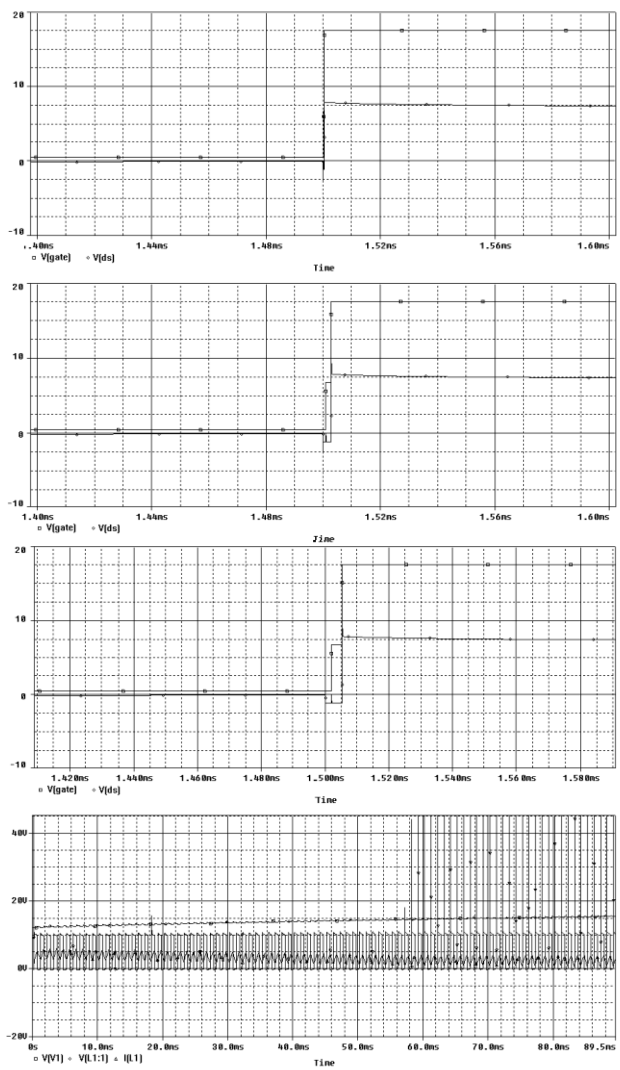

Figure 3 : Voltages and currents simulation results

The voltage diagrams on Figure 3 shows the operation principle of the proposed drive circuit with dynamic dead-time control for the MOSFET switching stage. Depending on the duty cycle ratio and therefore the load current variations, the increase of turn-off and turn-on edge times the drain voltage waveforms of the opposite transistors are shifted from the reference gate drive signals.

The output voltage and current waveforms of the equalizer circuits and the battery voltage are shown on the last diagram.

D	0,5	0,65	0,85
V(V1), V	12	12	12
I(L1), A	1,9	2,7	4,3
Total Power Losses, W	2,84	4,23	4,96
Efficiency, %	90,4	86,6	80,2

Table 1 : Calculated values at fixed control

D	0,5	0,65	0,85
V(V1), V	12	12	12
I(L1), A	1,9	2,7	4,3
Total Power Losses, W	2,36	3,83	4,12
Efficiency,%	91,2	88,2	84,2

Table 2 : Calculated values at dynamic control

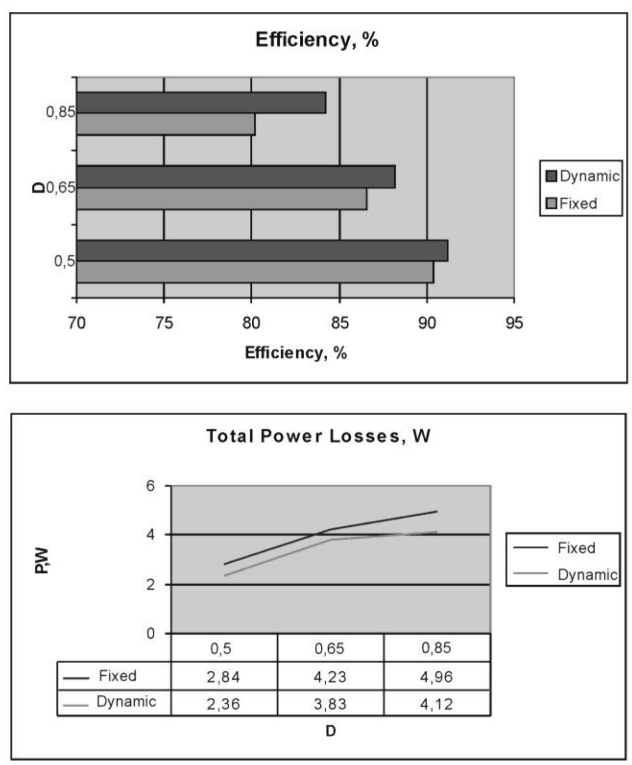

Figure 4 : Comparison of efficiency and total power losses

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The calculated and measured values of total power losses and efficiency for the considered battery equalizer circuit are given in Table 1 and Table 2. Table 1 shows the voltage and the current values for three different duty cicle ratios, and related values of total power losses and efficiency at fixed dead-time control. Table 2 shows the results for dynamic dead-time control.

Comparison of the researched control principles, according to the obtained results is given on the Figure 4.

4 CONCLUSION

The proposed control method in the researched battery equalizer circuit topology is useful and easy accesible way for improvement of the performance characteristics. The considered driver circuit improves the performance of the switching regulators by proper adjustment of the dead-time value. That allows to reduce the switching losses and dissipation of reactive power and increases the efficiency. In comaprison with fixed dead-time commutation control, the number of the total power losses can be reduced with 5-7% and the efficiency can be increased up to 10%. The proposed circuit topology can control the delay settings independently from the load variations. Therefore the presented control priciple can be used for most of the drivers in the switching power converter applications.

REFERENCES

[1] D.Finn, G.Walker, P.Sernia – "Method Of Extracting Switching Loss From High Efficiency MOSFET Based Half-bridge Converter". University Of Queensland, St.Lucia QLD4072 Australia.

[2] Osama Al-Naseem, Robert W. Erickson – "Prediction Of Switching Loss By Average Switch Modelling" Department Of Electrical And Computer Engineering, Univesity Of Colorado.

[3] Altowati A., K. Zenger, T. Suntio – "Improved DC-DC Switching Power Converter Design Through Modeling And Simulation". Control Engineering Laboratory, Helsinki University of Technology, Finland

[4] Divins D. – "Steady State, Stability and Transient Analysis of a Sync-Buck DC/DC Converter". Ansoft Converge, November 2005

[5] Hsieh M., S. Round, R. Duke – "An Investigation of Battery Voltage Equalization Topologies for Electric Vehicle". AUPEC 26-29 Sept. 2004

[6] Krein P., R. S. Balog – "Life extension through charge equalization of lead-acid batteries". INTELEC, 2002, pp. 516-523.