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Voltage Equalizer for Two Batteries with Buck/ Boost Converters

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ABSTRACT

In this article is presented a complete schematic circuit of the power section and the control system for a voltage equalizer of two batteries. The equalizer consists of two buck/boost inverting DC-DC converters with common inductance. The operation of the circuit is described, and the computer investigation results, and practical use are presented. The shown and implemented device can find application in systems with energy conversion from renewable sources and in electric vehicles.
Keywords: voltage equalizer, battery, buck-boost converter, supercapcharge.

INTRODUCTION

Often in practice, the connection of several batteries in series is used to increase the total voltage. For example, such applications can be found in photovoltaic and wind generator systems, in electric vehicles supply systems, etc [1 - 5]. Due to the difference in the parameters of individual batteries, the voltages on them in charge and discharge modes will be different, resulting in different load and different lifetime. For voltage equalization are applied different methods, as the main ones are systematized in [6 - 10]. These methods are divided into passive and active, with the latter being rapidly developed based on various circuits of power electronic converters. The half-bridge converter described by Uno et al. is using hard switching of devices [11]. To increase the efficiency factor, resonance principles and soft switching of devices are used [12 - 14]. Some of the equalizers use specially designed magnetic elements [15, 16]. An integrated system for equalizing battery voltages and charging ultracapacitors in hybrid vehicles is described in [17].

One of the most used power circuit for equalizing the voltages of two series-connected energy storage elements is that of two buck/ boost converters with common inductance [1, 10]. Two circuits of this kind are used to equalize the voltages of four series-connected batteries [5]. Additionally, a third converter of this type is included as an equalizer of the pairs of series connected batteries. Antchev described an examination of a voltage equalizer consisting of two buck/boost converters [18]. This operation is also the basis of the present article, the aim of which is to show the new additional computer investigation results and practical implementation of the examined equalizer. Part II contains computer investigation results. Part III contains

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complete principle scheme of the power part of the equalizer and its control system as well as a description of the operation. This part describes the results of the study in practical implementation.

EXPERIMENTAL

Initially, before the practical implementation, a study of the work of the equalizer was done using the PSIM program. Fig.1 shows the computer simulation scheme when the voltage of the lower storage battery is initially higher than that of the upper battery - V2>V1. Both batteries are presented with high capacity capacitors. The two MOSFETs and the inductance L1 form the two DC - to - DC converters. Their frequency of operation is determined by the VSQ1 generator, which in this case is equal to 20 kHz. The duty factor is equal to 0.6, where the converters work as boosts. The voltages of the two batteries are compared in value by means of the block designated as adder and, depending on the sign of the difference, the operation of one of the two transistors is enabled. By means of the operational amplifier, a comparator with hysteresis is implemented, the value of which is determined by the resistors R1 and R2. The operation of one of the two converters is allowed until the difference in the voltages of the two batteries is greater than the hysteresis. When this difference is less than the hysteresis, the two converters do not work.

Fig. 2 shows the simulation results. Initially the lower converter works, then the upper one is switched on and again the lower one, and after about 5 ms the two converters stop working, i.e. the two voltages equalize with the set hysteresis. From the measurement results shown below right, the equalization is accurate to about 10 mV.

Fig. 3 shows the computer simulation scheme when the voltage of the upper storage battery is initially higher than that of the lower battery - V2<V1.

Fig. 4 shows the simulation results. Initially the upper converter works, then the lower one and again the upper one and lower one, and after about 5 ms the two converters stop working, i.e. the two voltages equalize with the set hysteresis. From the measurement results shown below right, the equalization is accurate to about 10 mV. Equalization in both cases takes place in a short time, because the value of the capacitance of both capacitors is 1 F. As it increases, the equalization time increases, but the computer simulation time also increases.

The computer simulation results were used in the practical implementation of the equalizer described in the next part.

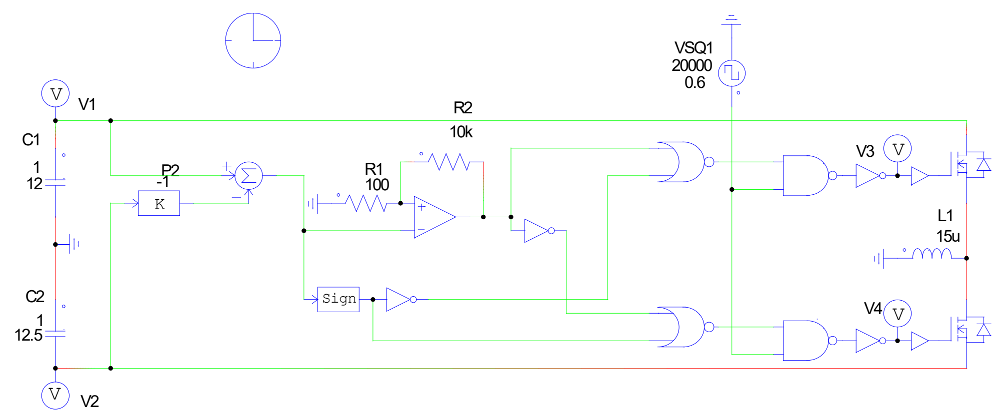

Fig. 1. Computer simulation scheme - V2>V1.

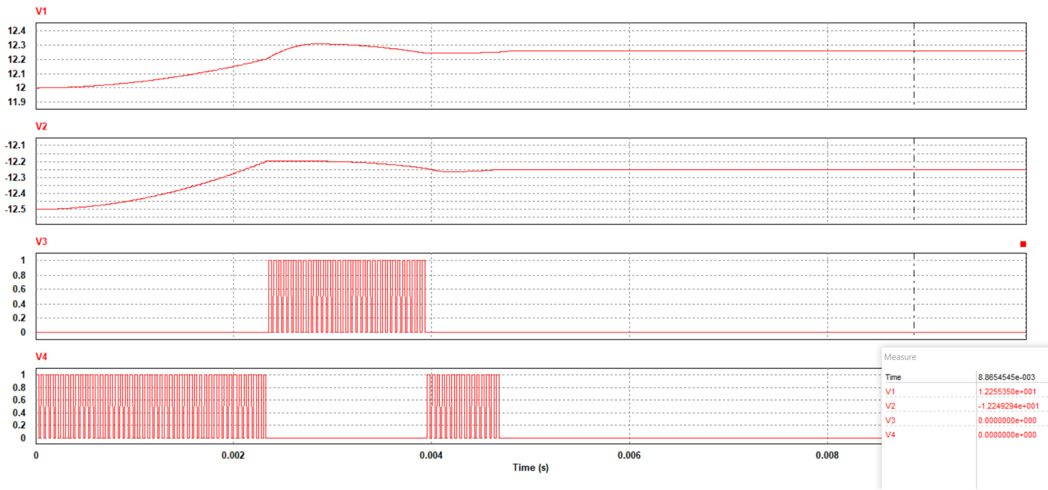

Fig. 2. Simulation results of the scheme of Fig.1. V1 - the voltage of the upper battery; V2 - the voltage of the lower battery; V3 - the control pulses of the upper transistor; V4 - the control pulses of the lower transistor.

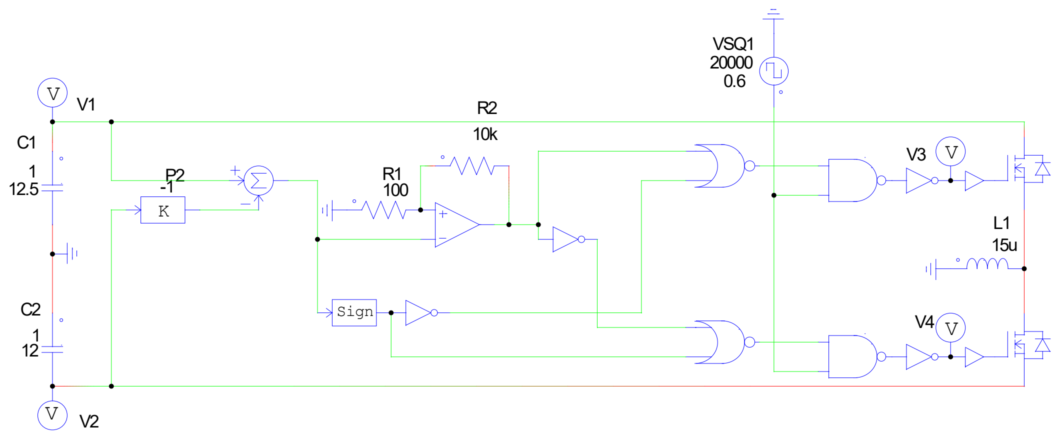

Fig. 3. Computer simulation scheme - V2<V1.

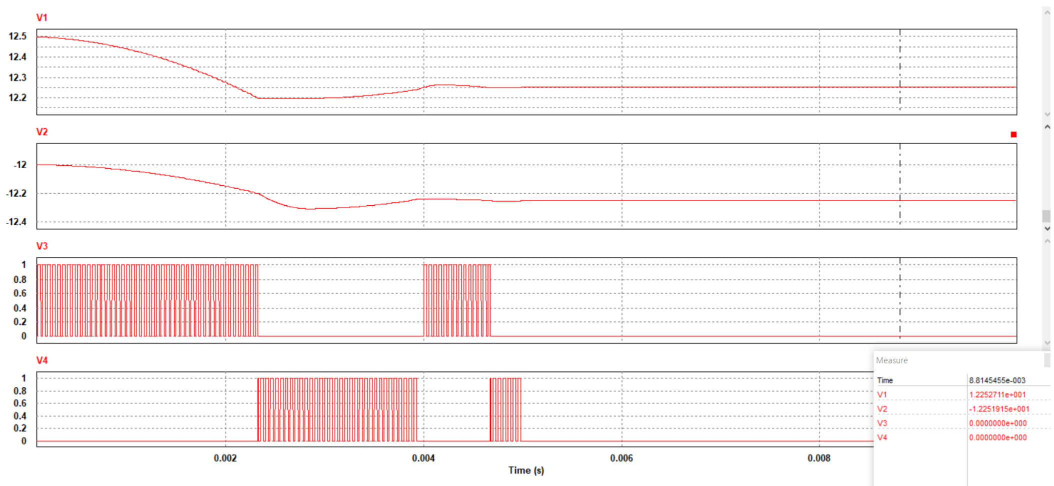

Fig. 4. Simulation results of the scheme of Fig.3. V1 - the voltage of the upper battery; V2 - the voltage of the lower battery; V3 - the control pulses of the upper transistor; V4 - the control pulses of the lower transistor.

RESULTS AND DISCISSION

Fig. 5 shows the complete principle scheme of the equalizer.

The two batteries are connected in series, with the positive terminal of the upper one connected to “Battery Plus” and the negative one - to “Battery Middle”. The positive terminal of the lower battery is connected to “Battery Middle” and the negative terminal to “Battery Minus”. The power part consists of the transistors Q1 and Q3 and the inductance L3. Each of the transistors, together with the reverse diode of the other and the inductance form a circuit of DC-to-DC voltage buck/boost inverting converter. When the voltage of the upper battery is higher than that of the lower battery, the received control pulses turn transistor Q1 on and off. It operates along with the inductance and the reverse diode of Q3 and energy is transferred from the upper to the lower battery. When the lower battery voltage is higher than that of the upper one, the input control pulses turn transistor Q3 on and off. It operates along with the inductance and the reverse diode of Q1 and energy is transferred from the lower to the upper battery. The remaining elements of the circuit in Fig. 5 form the control part of the two DC-DC voltage converters.

The control pulses are transmitted with galvanic isolation to the two transistors Q1 and Q3 through optocouplers ISO1 and ISO2 respectively. The supply voltage to the secondary side of ISO1 is result from the upper battery voltage via R23, D5 and C14, with the voltage limited via D6. The supply voltage on the secondary side of ISO2 is result from the lower battery voltage by R27, D7 and C15, the voltage being limited by D8. Charging of the gate-source input capacitance for switching on transistors Q1 and Q3 is done through transistors Q2 and Q4, respectively, at conducting diode of the corresponding optocoupler. The discharge of the gate-source input capacitance for switching off transistors Q1 and Q3 is done through resistors R22 and R24, respectively, at a non-conducting diode of the respective optocoupler. To protect against inadmissible overvoltage of the gate relative to the source of transistors Q1 and Q3, diodes D3 and D4 are included.

The supply voltages for the control part (positive +8 V and negative -8 V) are obtained from the upper and lower batteries via voltage regulators U1 and U3 respectively.

The pulses from the output of the multivibrator U1 are used to switch the transistors Q1 or Q3. Their frequency determines the frequency of operation of one of the two DC-DC converters. In this case it is approximately 50 kHz. The duty cycle (the ratio of the switch-on time of Q1 or Q3 to the period of operation) is determined by resistors R18 and R19 and in this case is equal to 2/3. At this duty cycle, the converters operate as boost converters.

The voltage values of the upper and lower batteries are monitored by the control system via the voltage drops across resistors R2 and R3 respectively. Since the voltage on R3 is negative with respect to ground (the common pole of both batteries), it is inverted with a coefficient -1 by means of the operational amplifier U2C. The voltage values of the two batteries are compared by the differential amplifier U2A, the instantaneous value of its output voltage depends on the difference of the two voltages. The polarity of the output voltage of the U2D comparator gives information about which of the battery voltages is greater, regardless of how much greater. For example, if the upper battery voltage is greater, the output voltage of the U2D will be negative. There will be a logic 1 at the output of U4B, a logic 0 at the output of U4D, a logic 1 at the output of U5B, and a logic 0 at the output of U5D. Therefore, there will be no control pulses to transistor Q3 and it will not switch (transistor Q1 is working since the upper battery voltage is higher). Conversely, if the lower battery voltage is greater, the output voltage of U2D will be positive, the output of U5C will have a logic 0 and transistor Q1 will not switch.

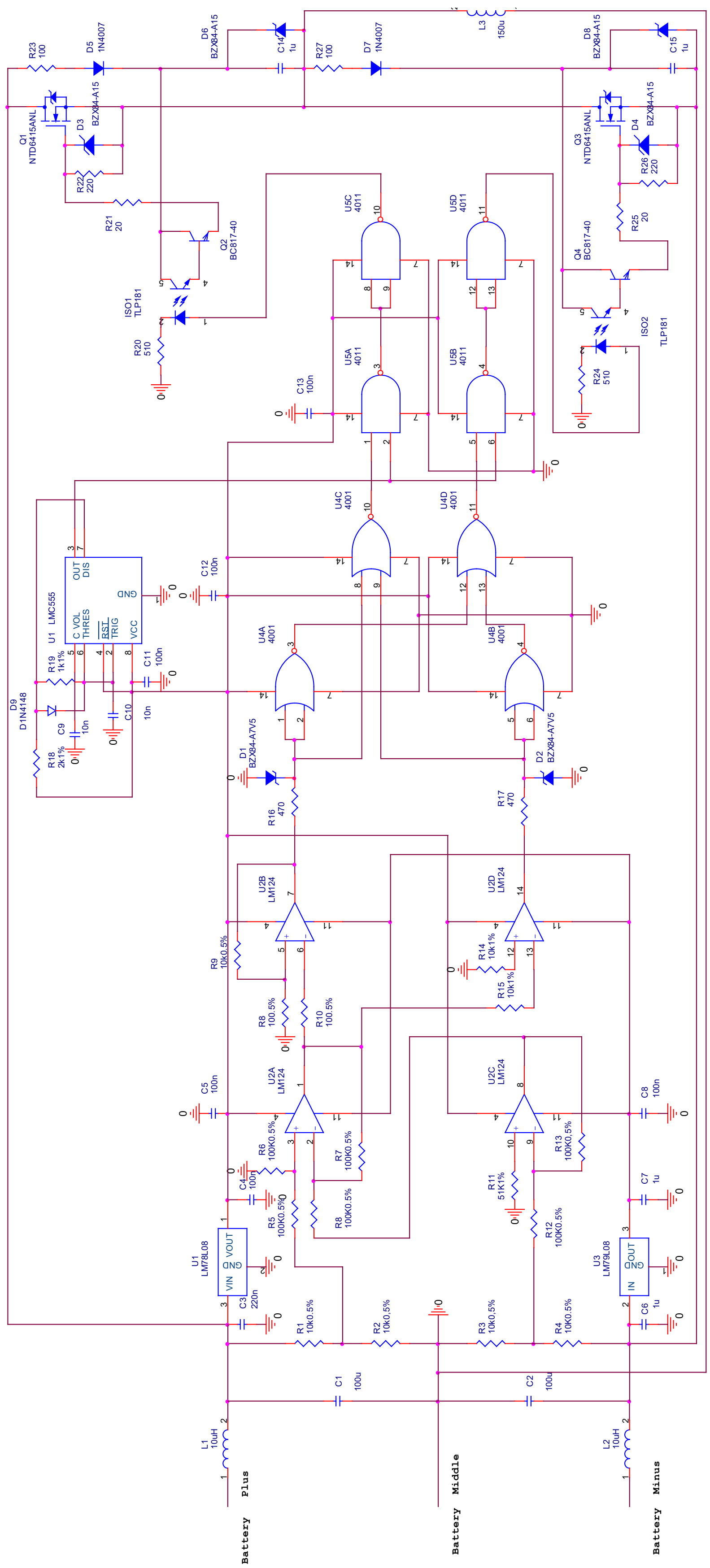

Fig. 5. Principle scheme of the equalizer.

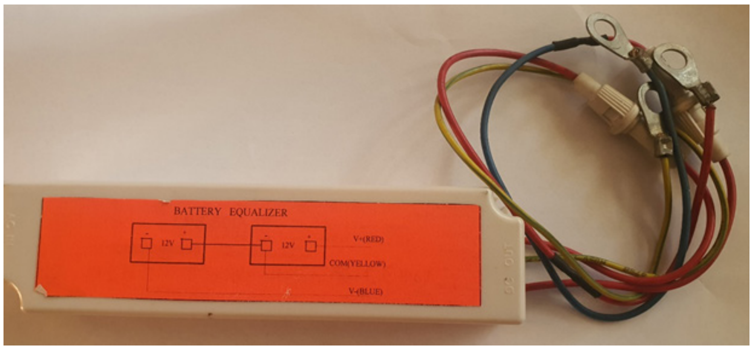

Fig. 6. Practical implementation of the equalizer.

Enabling the operation of the two DC-DC converters is done with a hysteresis whose value is determined by the comparator U2B. In this case it is about 8 mV. So, for example, if the upper battery voltage is greater, and greater by more than the hysteresis value, the voltage across the output of U2B will be negative, there will be logic 0 at the upper input of U4C, and the control pulses for switching transistor Q1 will be enabled. If the upper battery voltage is greater, but less than the hysteresis value, the voltage across the output of U2B will be positive and both DC-DC converters will not operate. The hysteresis value can be adjusted by resistors R8 and R9.

There are anti-interference filters - L1, C1 and L2, C2 to prevent the penetration of high frequency interferences to the batteries provided at the input of the circuit of Fig.5. The resonance frequency of the filters is chosen to be about 5 kHz - 10 times smaller than the operating frequency of the two converters.

Based on the principle scheme described in Part III, an equalizer which appearance is shown in Fig. 6 is implemented. Since the circuit board with the elements is hermetically sealed, fuse sockets to each of the batteries are provided externally to the cables. The equalizer is permanently connected to the batteries.

It is examined at operation in a photovoltaic system including two batteries with a nominal voltage of 12 V and a capacity of 110 Ah each.

Although the hysteresis of the U2B comparator is theoretically 8 mV, voltage equalization occurs with an accuracy of about ±10 mV because of non-ideality and tolerance of the elements. Of interest is the value of the consumed by the batteries current in a mode when both converters are not operating (the difference in voltage values is less than the hysteresis value). In this mode, the consumed by each battery current does not exceed 10 mA.

CONCLUSIONS

The two-battery voltage equalizer presented in this article contains a minimal number of elements. At implementation it shows reliable operation and very good accuracy. It could also be applied in voltage equalization of series connected ultracapacitors. An advantage of the article is the presentation and description of the computer simulation results and complete principle scheme of the equalizer.

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REFERENCES

1. A. Alvarez-Diazcomas, A.A. Estévez-Bén, J. Rodríguez-Reséndiz, M.A. Martínez-Prado,

R.V. Carrillo-Serrano, S.A. Thenozhi, A Review of Battery Equalizer Circuits for Electric Vehicle Applications, Energies, 13, 2020, 5688. https://doi.org/10.3390/en13215688

2. O. Egbue, S. Long , S.D. Kim, Resource Availability and Implications for the Development of Plug-In Electric Vehicles, Sustainability, 14, 2022, 1665. https://doi.org/10.3390/ su14031665
3. Y. Liu, C. Xia, M. Gu, W. Xin, X. Men, A novel active equalizer for Li-ion battery pack in electric vehicles, 10th International Conference on Applied Energy (ICAE2018), 22-25 August 2018, Hong Kong, China, Energy Procedia, 158, 2019, 2649-2654.
4. H. Yao, A. Thinzar, Litium-ion battery equalization circuit and control strategy for photovoltaic energy storage application, International Journal of Low-Carbon Technologies, 18, 2023, 341-347.
5. S. Zeng1, X. Ma, L. Hu1, H. Su, Q. Yu, L. Li, Y. Chen, Electric vehicle battery equalization technology applied to vehicle-to-grid, International Journal of Low-Carbon Technologies, 19, 2024, 1397-1402.
6. Y. Izadi, R. Beiranvand, A Comprehensive Review of Battery and Super-Capacitor Cells Voltage Equalizer Circuits, IEEE Transactions on Power Electronics, 2023, 15671-15692.
7. N. Ghaeminezhad, Q. Ouyang, X. Hu, G. Xu, Z. Wang, Active Cell Equalization Topologies Analysis for Battery Packs: A Systematic Review, IEEE Transactions on Power Electronics, 36, 8, 2021, 9119-9135. doi: 10.1109/TPEL.2021.3052163
8. F. Liu, J. Dai, Equalization circuit topologies of lithium battery strings: a brief review, Physics, 2020, Conf. Ser. 1633, 012141.
9. Z.B. Omariba, L. Zhang, D. Sun, Review of Battery Cell Balancing Methodologies for Optimizing Battery Pack Performance in Electric Vehicles, IEEE Access, 7, 2019, 129335-129352. doi: 10.1109/ACCESS.2019.2940090
10. R. Yang, L. Gao, T. Wu, Comparative study on Equalization Technology of Lithium Battery packs for Electric vehicle, IOP Conference Series Earth and Environmental Science, 461, 2020, 012030. doi:10.1088/1755-1315/461/1/012030
11. M. Uno, A. Kukita, String-to-Battery Voltage Equalizer Based on a Half-Bridge Converter With Multistacked Current Doublers for Series-Connected Batteries, IEEE Transactions on Power Electronics, 34, 2, 2019, 1286-1298. doi: 10.1109/TPEL.2018.2829664
12. L. Zeyuan, Y. Shang, D. Bin, C. Zhang, A pack-to-cell-to-pack battery equalizer with soft-switching based on buck-boost and bidirectional LC resonant converters, 2016 IEEE Energy Conversion Congress and Exposition (ECCE), 2016, 1-7. doi: 10.1109/ECCE.2016.7854753
13. P. Xu, L. Kang, D. Xie, X. Luo, H. Lin, A Switch-Reduced Multicell-to-Multicell Battery Equalizer Based on Full-Bridge Bipolar-Resonant LC Converter, Batteries, 8, 2022, 53. https://doi.org/10.3390/batteries8060053
14. Y. Shang, C. Zhang, N. Cui, J. M. Guerrero, A Cell-to-Cell Battery Equalizer With Zero-Current Switching and Zero-Voltage Gap Based on Quasi-Resonant LC Converter and Boost Converter, IEEE Transactions on Power Electronics, 30, 7, 2015, 3731-3747. doi: 10.1109/TPEL.2014.2345672
15. F. Shi, D. Song, A Novel High-Efficiency Double-Input Bidirectional DC/DC Converter for Battery Cell-Voltage Equalizer with Flyback Transformer, Electronics, 8, 2019, 1426. https://doi.org/10.3390/electronics8121426
16. A. Farzan Moghaddam, A.Van den Bossche, An Efficient Equalizing Method for Lithium-Ion Batteries Based on Coupled Inductor Balancing. Electronics, 8, 2019, 136. https://doi.org/10.3390/electronics8020136

17. X. Tan, Y. Chen, J. Zeng, W. Liao, J. Liu, An Integrated Self-Modularized Battery Equalizer and Supercapacitor Charger for Hybrid Electric Vehicle Energy Storage System, IEEE Transactions on Vehicular Technology, 73, 7, 2024, 9865-9877. doi: 10.1109/TVT.2024.3376711
18. H. Antchev, Voltage Equalizer for Two Batteries/ Ultracapacitors - Cotrol System and Practicsal Realization, Proceedings of 7th Junior Conference of Lighting 2022, Bulgaria, 2022.