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Development of a DC-DC Converter for Active Battery Balancing Systems in a Format of Student Competition

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***Abstract*—The article presents the development of a DC-DC converter for active battery balancing systems in the format of student competition. Active balancing, which ensures stable energy transfer between battery cells, is critically important for optimizing their operation and extending their service life. Various topologies of DC-DC converters, in particular SEPIC, Push-Pull and DAB, are analyzed, their advantages and disadvantages are shown. The results of the work contribute to increasing the efficiency of battery balancing systems, extending their service life and developing students' technical skills.**

Keywords* — *DC-DC converter; active balancer; storage battery; balancing system; power converter.

I. Introduction

In the modern world, there are many applications for battery packs, such as portable devices, electric vehicles, micro-transport, spacecrafts, stationary energy storage, and others [1]. A battery pack is a complex system consisting of smaller elements – modules, which, in turn, consist of identical individual elements – cells. For any application, a long service life of the battery pack is important, and extending this life is a very important and relevant task [2].

Many methods for extending the life of battery packs are known. One of them is balancing the cells of the battery pack. During the operation of a battery pack, an imbalance in charge levels may occur between the cells. To counteract this effect, battery management systems (BMS) are used, one of the functions of which is to balance the energy between the buttery cells. Depending on the type of balancing, BMS are divided into two main types: passive and active. The passive balancing method consists in discharging the more charged cells by shunting the cell with a resistor. This method cannot be considered as effective one because the excess energy of cells is dissipated on resistors as heat. The active balancing method consists in exchanging energy between a cell with a higher charge level and a cell with a lower charge level. This method is more efficient, but less common due to more complex technical implementation [3].

According to the sources [3], [4], the studies in the field of active balancing systems are quite promising and relevant now. In the course of such studies, the authors faced the task of developing a DC-DC (Direct current) converter for the active balancing system. It is known, that one of the effective tools for solving technical issues is to conduct professional competitions (hereinafter referred to as hackathons), since many involved and motivated participants must solve the task during a limited time.

The task of the authors was to choose the optimal topology of the DC-DC converter as a part of the battery balancing system and to develop a prototype of this converter, holding a student hackathon.

II. Hackathon conditions

The hackathon was held at the Igor Sikorsky Kyiv Polytechnic Institute on the technical base of Department of Electronic Devices and Systems and Noosphere Engineering School KPI. It was dedicated to the development of DC-DC converters for the battery active balancing system, which is structurally shown in Fig. 1.

The presented circuit has significant potential as a modern solution to replace existing modular BMS with passive balancing used in electric vehicles now. If implementing in new BMS with active balancing the same form factor, connection method, and the data exchange interface, they can be used in electrical vehicles instead of passive BMS, which are currently common. [5]. Such modernization will significantly extend the service life of battery packs of existing electric vehicles and energy storage systems.

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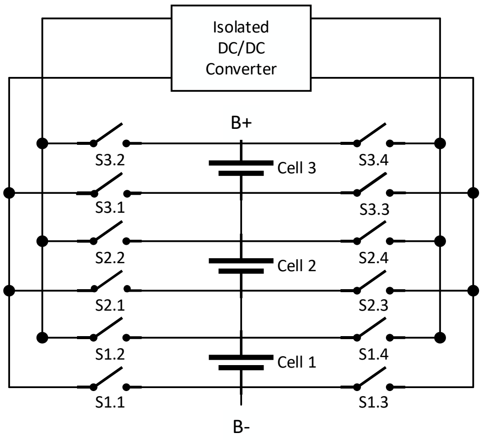

Fig. 1 Active Balancer Structure

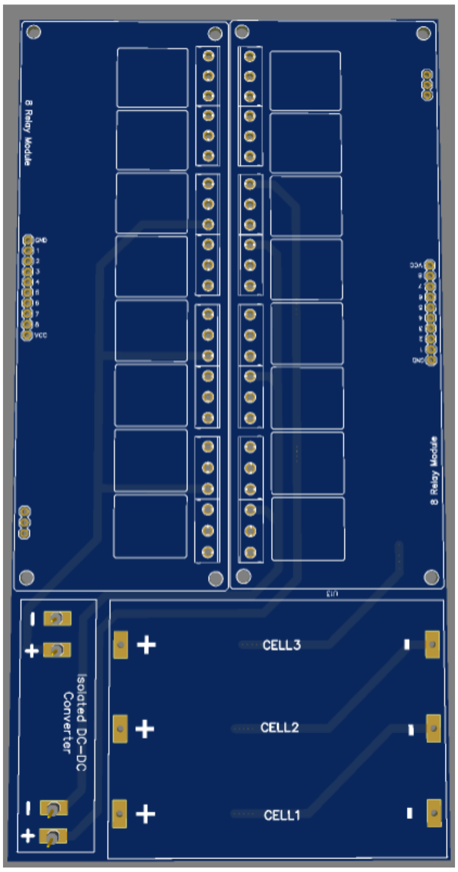

Fig. 2 Active Balancer PCB for Test Bench

This topology of the active balancer supports several modes of operation, in particular cell-to-cell balancing, cell-to-module balancing and vice versa. The basic structure of the system uses a module consisting of serially connected Li-Ion cells with a voltage of one cell in the range from 3.2 to 4.2 V. According to the hackathon conditions, the minimum number of the cells in the balancer is three, but the system is designed in such a way that its topology can be easily scaled to work with a larger number of cells, which is an important aspect for participants in the competitions.

The authors carried out a preliminary analysis and narrowed the choice of DC-DC converter topologies to all those with galvanic isolation. In addition, the following topologies of such converters were considered: Flyback Converter, Forward Converter, Push-Pull Converter, Half-Bridge Converter, Full-Bridge Converter. For the task-at-hand, the authors concluded that the Full-Bridge topology in the modification of a converter with two active bridges (Dual Active Bridge, abbreviated as DAB) is the most suitable, since this topology has the greatest functionality.

Based on the preliminary analysis of possible options for completing the task, the organizers allocated an initial set of components, with the help of which it was possible to implement any topology of the DC-DC converter. Also, teams were allocated an additional financial fund for the purchase of components that were not in the initial set. To speed up the development and to ease the testing, participants were provided with a printed circuit board of the active balancer for the test bench, which is shown in Fig. 2. It contains a holder for three 18650 form-factor lithium-ion cells, a relay-based switch system, and terminals for disconnecting an external DC-DC converter. The switches are controlled using 5 V logic voltage levels. The switch control board and the type of DC-DC converter should be chosen by the teams independently in order to determine the optimal configuration of the system.

The criteria for evaluating the work results were as follows:

- Workability of the prototype.
- Possibility of working in all balancing modes.
- Converter efficiency.
- Bidirectional energy transfer.
- Simplicity of the converter design (number of components, dimensions).
- Ability to work with a larger number of cells.
- User interface quality.
- Balancing speed.
- Balances of the additional fund.

The value of these criteria was arranged so that the 1st criterion was the most significant, and the 9th was the least significant.

III. *Overview of Presented Converters at the Hackathon*

Twenty students took part in the hackathon. They were divided into five teams, 3 of which coped with the task and took prize places, demonstrating the practical implementation of a DC-DC converter for operation in an active battery balancing system. According to

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the evaluation criteria, the results were distributed as follows: the third place was taken by the team that used the SEPIC topology, the second place – Push-Pull, and the first place – DAB. Let's consider the topologies of DC-DC converters that were used by the members within the hackathon.

A. SEPIC topology

SEPIC (Single-Ended Primary Inductor Converter) is a single-ended DC-DC converter that can provide both an increase and decrease in output voltage. This makes SEPIC especially useful in active battery balancing systems with large variability of charge between individual cells [6]. The main advantage of SEPIC is its ability to maintain stable operation with fluctuations in input voltage. This is important for battery systems, as operating conditions can change and the voltage in the system can fluctuate [7]. A model of the SEPIC converter can be seen in Fig. 3.

The converter has two operating phases, the first phase the switch Q1 is on-state, and the second phase the switch Q1 is off-state.

When the switch Q1 is on-state, the current passes through the inductor L1, accumulating energy in the magnetic field, the primary winding of the transformer accumulates energy, creating a variable magnetic flux that induces a voltage in the secondary winding, diode D1 is closed, and capacitor C2 powers the load R.

When the switch Q1 is off-state, the energy which accumulated in the magnetic field of inductor L1 begins to be transferred to the output through the transformer, diode D1 opens, the current passes through it and charges the output capacitor C2, as well as powers the load R. The operation of the converter in time intervals can be seen in Fig. 4.

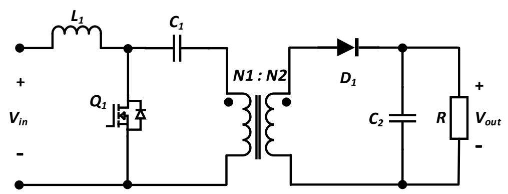

Fig. 3 SEPIC DC-DC Converter with Galvanic Isolation [8]

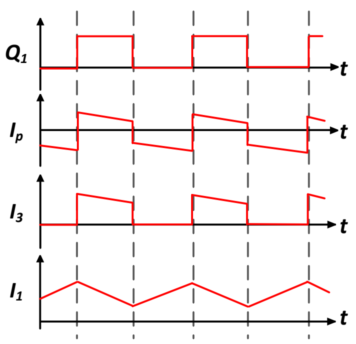

Fig. 4 Diagrams of the SEPIC DC-DC converter [9]

To calculate the dependence of the input and output voltage on the duty cycle of the SEPIC converter, it is necessary to know the duty cycle D, which is determined by:

$$D = \frac{t_{\text{on}}}{T}, \tag{1}$$

t_{on} – the switch on-state time; T – full switching period.

It is also necessary to know the transformation ratio N, which is determined by the formula:

$$N = \frac{N_2}{N_1}, \tag{2}$$

where N_1 – the number of turns of the primary winding of the transformer; N_2 – the number of turns of the secondary winding of the transformer.

The output voltage V_{out} of the converter is calculated as follows [6]:

$$V_{\text{out}} = \frac{D \cdot N \cdot V_{\text{in}}}{1-D}, \tag{3}$$

where V_{in} – the input voltage.

This formula shows that the output voltage can be regulated both by changing the duty cycle D and the transformation ratio N, and therefore they determine the converter operating mode, increasing (Boost) or decreasing the voltage (Buck).

When D increases, the output voltage V_{out} increases too. The closer D to 1, the more the voltage increases. However, some negative effects, such as oversaturation of the inductor, arise as well, that causes a drop in efficiency.

When D decreases, the output voltage V_{out} decreases too, which allows it to work as a buck converter. For stable operation, D should be in the range: $0.2 \le D \le 0.8$. This minimizes losses and ensures stable operation of switches and inductors. The transformation ratio N makes it possible to change the output voltage even with a fixed D, at $N>1$ the transformer increases the voltage, at $N<1$ the transformer decreases the voltage, at $N=1$ the transformer only provides isolation without changing the voltage. The choice of optimal values of the coefficients D and N affects not only the output voltage of the converter, but also its stability and efficiency [10]. The SEPIC converter can be adapted for two-way power transfer by making modifications to the original circuit. The advantage of this topology is the small number of components, but this converter has difficulties in matching the component base for stable operation.

B. Push-Pull topology

The Push-Pull converter (Fig. 5) uses a transformer with a center tap on the primary winding, which allows two switches (transistors) to work alternately to transfer energy from the input source to the transformer. Diodes are used on the output side to rectify the alternating current that is transferred from the secondary winding of the transformer [11].

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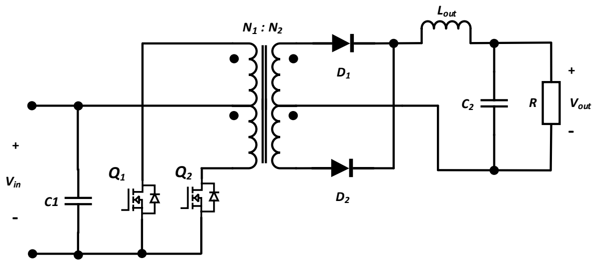

Fig. 5 Push-Pull DC-DC Converter

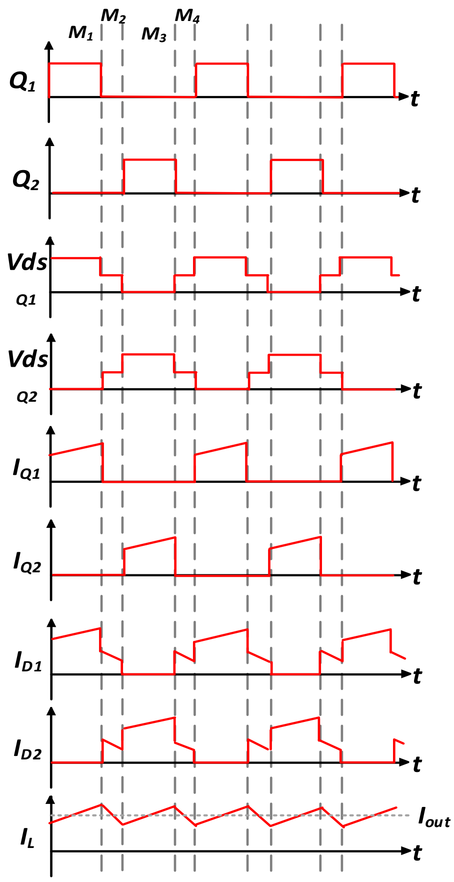

Fig. 6 Diagrams of the Push-Pull DC-DC converter

The primary winding of the transformer is divided into two equal parts with a center tap. When one of the switches (transistors) is on-state, current passes through the half of the primary winding of the transformer, generating a magnetic flux in the core. During the operation of the first switch, one part of the transformer is magnetized, and this ensures an increase in the magnetic flux in the core. Then the first switch is off-state, and the second switch is on-state, and the current passes through the other half of the primary winding, generating a flux in the opposite direction. This ensures symmetrical use of the magnetic material of the core, which makes the transformer more efficient. The secondary winding of the transformer receives energy both during the operation of the first switch and the second, and thus, a continuous supply of energy to the output occurs [12].

The following formula is used [12] to calculate the output voltage in Push-Pull:

$$V_{out} = 2 \cdot N \cdot D \cdot V_{in}, \tag{4}$$

The control is carried out by switches *Q1* and *Q2*. They provide four modes of the circuit operation (M 1-4), which include alternating operation of the switches and rectification of the voltage on the secondary side. When one transistor opens, the energy is transferred through the transformer to the corresponding diode (*D1* or *D2*) on the secondary side. These processes are shown in Fig. 6.

The transformer provides isolation between the primary and secondary sides, and changes the voltage level according to the transformation ratio. The output inductor and capacitor form a filter that provides ripple smoothing and output voltage stability.

C. DAB topology

A DC-DC converter based on the DAB topology consists of two full-bridge inverters separated by a high-frequency transformer. Fig. 7 shows the diagram of this converter.

Two active bridge inverters are placed on the primary and the secondary side of the transformer. Each of them consists of four switches that allow controlling the direction and the level of energy flow. The primary inverter converts the DC voltage into a high-frequency alternating voltage, which is supplied to the primary winding of the transformer. The secondary inverter restores the DC voltage at the output of the converter, which may be higher or lower than the input voltage [14] [15].

There are several modes of DAB control. The participants of the hackathon chose to implement the Single-Phase Shift (SPS) mode. It is based on regulating the phase shift between the signals of the inverter's switches on the primary and secondary sides of the transformer to control the energy transfer [16] [17].

In this mode, the output voltage is determined as:

$$V_{\text{out}} = N \cdot \left(V_{\text{in}} - \frac{L \cdot P}{f \cdot \phi \cdot (1-\phi)}\right), \tag{5}$$

where L – leakage inductance of the transformer; P – power of energy transfer; f – switching frequency; ϕ – phase shift between the signals of the primary and secondary inverter.

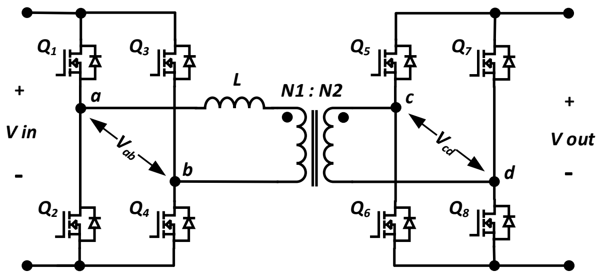

Fig. 7 DAB DC-DC converter [13]

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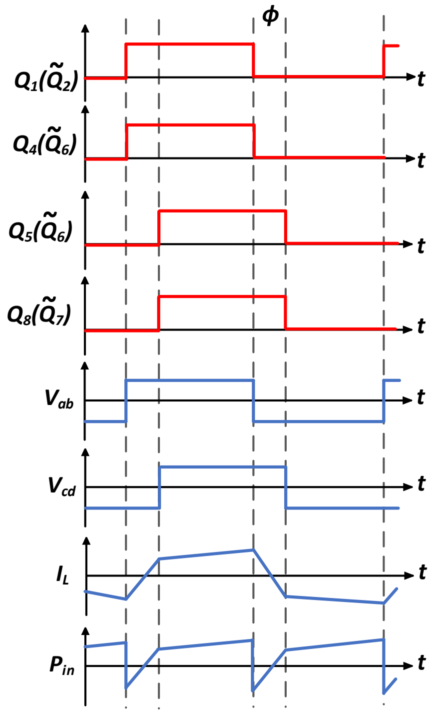


Fig. 8 Diagrams of DAB DC-DC converter in SPS modulation mode [19] [13]

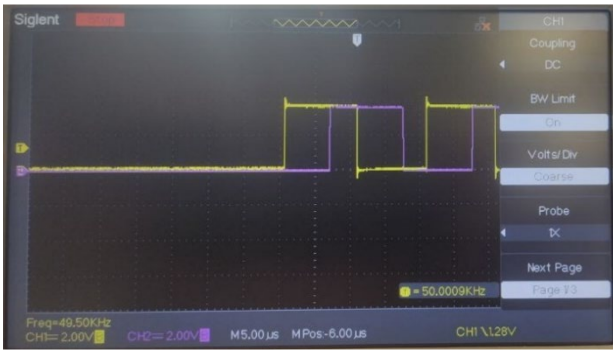
Based on the previous simulations in the MATLAB Simulink environment, the team of participants chose a fixed switching frequency of 50 kHz for controlling the switches. Phase shift between the control signals of the inverters – controlling the phase shift between the primary and secondary inverters regulates the amount of energy transferred from the primary to the secondary side of the transformer. The operating mode of the converter depends on the phase shift, including bidirectional energy transfer. When $\phi < 0.5$, the energy is transferred partially. At the optimal value of $\phi = 0.5$, maximum power is transferred, and the maximum efficiency mode is achieved. At $\phi > 0.5$, the reverse energy transfer occurs [18]. The converter operation process is shown in time in Fig. 8.

A two-channel oscilloscope was connected to the working prototype of the DAB converter, the results of the measurements during testing are shown in Fig. 9. The image contains four oscillograms, which illustrate different aspects of the converter's operation.

In Fig. 9a, two signals, the control of the switches, are shown. Channel 1 (CH1) with an amplitude of 2 V/div shows the signal on switches *Q1* and *Q4*. The signal voltage is 3.8 V, and the frequency is 50 kHz. Channel 2 (CH2) with an amplitude of 2 V/div shows the signal on switches *Q2* and *Q3*. The signal is the same as on switches *Q1* and *Q4*, 3.8 V frequency 50 kHz, but has a shift of $\phi \approx 0.25$. This shows that the converter is working in the direct mode, transferring energy from the input to the output.

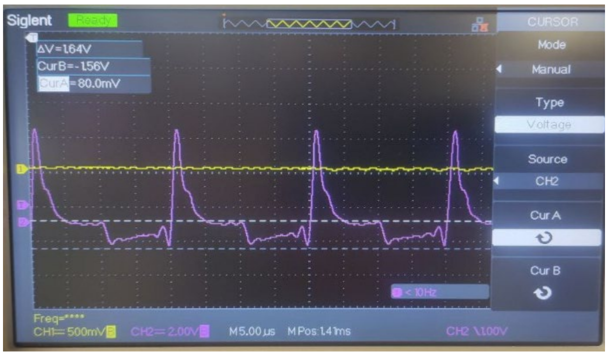
In Fig. 9b, two control signals are shown, similar to the previous Fig. 9a, but there is a difference, the phase shift $\phi \approx 0.75$, which indicates the operation of the converter in reverse mode, energy is transferred from the output to the input.

In Fig. 9c, channel 2 shows the current of the secondary winding of the transformer in the direct mode of energy transfer. This oscillogram shows that the current of the secondary winding of the transformer is different from the idealized one, which means that the converter is working in the wrong mode of operation. This worsens the characteristics of the converter, which can affect its overall efficiency.



a)

b)



c)

Fig. 9 Diagrams obtained during testing, a) Control of switches during direct energy transfer, b) Control of switches during reverse energy transfer, c) Current on the secondary side of the transformer.

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The scope measurements confirm the correctness of the converter control system settings, but the output current has a form different from the correct one, which means that the prototype converter is not operating in the most efficient mode. This may be explained by the incorrect choice of the component base, and some faults in making the transformer. In the future, it is necessary to select the component base more correctly to achieve greater converter efficiency.

When one cell with a voltage of 4.1 V was connected to the input of the converter and a second cell with a voltage of 3.6 V was connected to the output of the converter, the process of energy transfer from the input to the output of the converter took place, thus the charging current of the cell at the output was 750 mA, which means the conversion power is ~ 3 Watts. The phase shift was also implemented, due to which the mode of reverse energy transfer was achieved.

Despite the complexity of the circuitry and the time constraints, the participants of the hackathon were able to implement a working prototype of the converter, and therefore the judges awarded them first place.

Results of the Conducted Hackathon

The participants of the hackathon created 3 working prototypes of a DC-DC converter for operation in an active balancer. In practice, the authors' hypothesis regarding the choice of topology was confirmed. A generalized comparison of the considered topologies is given in Table 1.

The SEPIC converter has advantages of simple design, wide range of input voltages, and low cost. The disadvantages of this converter include high ripple of the output current, complexity of setting up and selecting components for stable operation.

The Push-Pull converter has the advantage of compactness due to the use of a small transformer, but has a disadvantage in the complexity of balancing the switches to avoid transformer saturation.

The DAB converter has high efficiency, flexibility of settings, bi-directionality, but is complex to control and requires complex control circuits. The DAB is ideal for active balancers with a large range of voltage differences between the cells, but requires precise synchronization of the switches and feedback implementation to ensure stable current.

Table 1 Comparative Analysis of Topologies

	SEPIC	Push-Pull	DAB
Control complexity	Average	High	Highest
Bi-directionality	No	No	Yes
Number of switches	1	2	8
The complexity of the circuitry	Low	Average	High
Efficiency	High	High	High
Price	Low	Average	High
Input voltage range	Wide	Narrow	Widest

The disadvantage of DAB converter is its high cost caused by the large number of the circuit components, however, in mass production, this disadvantage may have a small impact. Therefore, DAB converter topology may be considered as the best option for use in active balancer.

Conclusions

The hackathon helped the authors to analyze the topologies of DC-DC converters and to confirm their characteristics in a limited time. This allowed verifying the preliminary hypothesis regarding the choice of a DC-DC converter topology for use in a particular active balancer.

The DAB topology of the DC-DC converter proved its advantage for use in a specific topology of an active balancer compared to other topologies, due to the possibility of operating in a wide range of input-output voltages, high efficiency, and bi-directionality. The combination of these factors makes it possible to fully implement the functionality of this active balancer.

The results of the study may contribute to increasing the efficiency of active balancing systems, which in turn will help to extend the life of battery packs.

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REFERENCES

[1] A. Manzhelii, D. Lipko, and O. Bondarenko, "Comparative Analysis of DC-DC Converters for Micro-Mobility Vehicles," in *2024 IEEE 7th International Conference on Smart Technologies in Power Engineering and Electronics (STEE)*, IEEE, Sep. 2024, p. TT1.45.1-TT1.45.5. **DOI:** 10.1109/STEE63556.2024.10748120.

[2] D. Lipko, A. Manzhelii, I. Yamnenko, and O. Bondarenko, "Possibilities and Challenges of Partially Using a Charge-Discharge Cycle of Battery to Increase Its Resource," in *2023 IEEE 4th KhPI Week on Advanced Technology, KhPI Week 2023 - Conference Proceedings*, 2023. **DOI:** 10.1109/KhPIWeek61412.2023.10312983.

[3] M. Evzelman, M. M. Ur Rehman, K. Hathaway, R. Zane, D. Costinett, and D. Maksimovic, "Active Balancing System for Electric Vehicles with Incorporated Low-Voltage Bus," *IEEE Trans Power Electron*, vol. 31, no. 11, pp. 7887–7895, Nov. 2016, **DOI:** 10.1109/TPEL.2015.2513432.

[4] G. Sugumaran and N. Amutha Prabha, "An Improved Bi-Switch Flyback Converter with Loss Analysis for Active Cell Balancing of the Lithium-Ion Battery String," *Journal of Electrical and Computer Engineering*, vol. 2024, 2024, **DOI:** 10.1155/2024/5556491.

[5] D. Lipko and O. F. Bondarenko, "Modified Active Balancer for Use in Multi-Module Batteries," *Technology and design in electronic equipment*, №1-2, 2024, **DOI:** 10.15222/TKEA2024.1-2.11.

DOI: 10.20535/2523-4455.mea.316127

[6] P. R. R. Somarowthu, S. K. Saxena, and D. B. Mahajan, “Isolated SEPIC Converter with a novel Voltage Clamp Circuit,” in *2018 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*, IEEE, Dec. 2018, pp. 1–6. **DOI:** 10.1109/PEDES.2018.8707789.

[7] M. V. Mosconi Ewerling, T. Brunelli Lazzarin, and C. H. Illa Font, “Proposal of an Isolated Two-Switch DC-DC SEPIC Converter,” in *2019 IEEE 15th Brazilian Power Electronics Conference and 5th IEEE Southern Power Electronics Conference (COBEP/SPEC)*, IEEE, Dec. 2019, pp. 1–6. **DOI:** 10.1109/COBEP/SPEC44138.2019.9065718.

[8] J. Ahmad, C. H. Lin, M. S. Khan, H. D. Liu, and M. Fahad, “Modified Isolated SEPIC Converter for EV Charging and High Voltage Applications,” in *2023 International Conference on Power, Instrumentation, Energy and Control, PIECON 2023*, Institute of Electrical and Electronics Engineers Inc., 2023. **DOI:** 10.1109/PIECON56912.2023.10085847.

[9] N. Mohammad, M. Quamruzzaman, M. R. T. Hossain, and M. R. Alam, “Parasitic Effects on the Performance of DC-DC SEPIC in Photovoltaic Maximum Power Point Tracking Applications,” *Smart Grid and Renewable Energy*, vol. 04, no. 01, pp. 113–121, 2013, **DOI:** 10.4236/sgre.2013.41014.

[10] M. S. Khan, C. H. Lin, J. Ahmad, M. Fahad, and H. D. Liu, “A Novel DC Electronic Load Topology Incorporated with Model Predictive Control Approach,” *Mathematics*, vol. 11, no. 15, Aug. 2023, **DOI:** 10.3390/math11153353.

[11] M. Azizi, O. Husev, D. Vinnikov, and O. Veligorskyi, “Comparative Evaluation of Isolated dc-dc Converters for Low Power Applications,” in *2022 IEEE 20th International Power Electronics and Motion Control Conference (PEMC)*, IEEE, Sep. 2022, pp. 7–12. **DOI:** 10.1109/PEMC51159.2022.9962944.

[12] S. Musumeci and S. Di Mauro, “Low voltage single fuel cell interface by Push-Pull converter: A case of study,” in *2017 6th International Conference on Clean Electrical Power (ICCEP)*, IEEE, Jun. 2017, pp. 541–548. **DOI:** 10.1109/ICCEP.2017.8004741.

[13] H. Zhang and T. Isobe, “A Verification of Applying Superjunction MOSFETs in Dual-Active-Bridge Converters Operated with Minimal RMS Current,” *IEEJ Journal of Industry Applications*, p. 24004235, 2024, **DOI:** 10.1541/ieejjia.24004235.

[14] R. Zgheib, I. Kamwa, and K. Al-Haddad, “Comparison between isolated and non-isolated DC/DC converters for bidirectional EV chargers,” in *2017 IEEE International Conference on Industrial Technology (ICIT)*, IEEE, Mar. 2017, pp. 515–520. **DOI:** 10.1109/ICIT.2017.7913285.

[15] K. Bathala, D. Kishan, and N. Harischandrappa, “Soft Switched Current Fed Dual Active Bridge Isolated Bidirectional Series Resonant DC-DC Converter for Energy Storage Applications,” *Energies (Basel)*, vol. 16, no. 1, Jan. 2023, **DOI:** 10.3390/en16010258.

[16] F. Feng, J. Fang, U. Manandhar, H. B. Gooi, and P. Xie, “Impedance-Based Stability Analysis of DAB Converters With Single-, Double-, or Cooperative Triple-Phase-Shift Modulations and Input LC Filter,” *Front Energy Res*, vol. 10, Apr. 2022, **DOI:** 10.3389/fenrg.2022.874477.

[17] B. Zhao, Q. Song, W. Liu, and Y. Sun, “Overview of dual-active-bridge isolated bidirectional DC-DC converter for high-frequency-link power-conversion system,” *IEEE Trans Power Electron*, vol. 29, no. 8, pp. 4091–4106, 2014, **DOI:** 10.1109/TPEL.2013.2289913.

[18] Kang Xiangli, Shouxiang Li, and K. Smedley, “Analysis and modelling of a bidirectional push-pull converter with PWM plus phase-shift control,” in *IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society*, IEEE, Oct. 2016, pp. 1268–1273. **DOI:** 10.1109/IECON.2016.7793452.

[19] N. Hou and Y. W. Li, “Overview and Comparison of Modulation and Control Strategies for a Nonresonant Single-Phase Dual-Active-Bridge DC-DC Converter,” *IEEE Trans Power Electron*, vol. 35, no. 3, pp. 3148–3172, Mar. 2020, **DOI:** 10.1109/TPEL.2019.2927930.

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Розробка DC-DC перетворювача для використання в системах активного балансування акумуляторних батарей у форматі студентських змагань

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***Анотація*—Виробництво акумуляторних батарей у світі стрімко зростає, що пов'язано із розвитком електротранспорту та альтернативної енергетики. Акумуляторні батареї мають свій обмежений ресурс, а доступної технології утилізації акумуляторних батарей на даний час немає. Явище дисбалансу дуже негативно впливає на ресурс акумуляторних батарей, проте застосування систем балансування протидіє цьому ефекту, тим самим збільшуючи загальний ресурс акумуляторної батареї. Покращення систем балансування може позитивно вплинути на ресурс акумуляторних батарей, та відтермінувати час їх утилізації**

У статті представлено розробку DC-DC перетворювача для систем активного балансування акумуляторних батарей у форматі студентських змагань. Авторами була висунута попередня гіпотеза, вибору оптимальної топології DC-DC перетворювача для використання в певному активному балансирі. Для підтвердження цієї гіпотези, була сформована задача для студентських змагань, а саме побудова ізольованого DC-DC перетворювача, що міг би працювати в даному прототипі активного балансира. Активний балансир розрахований на балансування акумуляторної батареї, що складається з трьох послідовно підключених комірок. Учасникам було надано набір компонентів, а також додатковий фінансовий фонд, для придбання додаткових компонентів необхідних для практичної реалізації DC-DC перетворювача. Змагання проводились в режимі обмеженого часу, і на виконання завдання було виділено 48 годин. Критерії оцінювання були чітко виділенні, а головним критерієм було працездатність DC-DC перетворювача. З п'яти команд, три впорались із завданням, та зайняли призові місця.

На основі студентських змагань було проаналізовано різні топології ізольованих DC-DC перетворювачів, зокрема SEPIC, Push-Pull та DAB, показано принцип їх роботи, розглянуто переваги та недоліки. Особливу увагу приділено топології DAB, яка була визнана найкращим варіантом для використання в даному активному балансирі завдяки можливості роботи в широкому діапазоні вхідних-вихідних напруг, високій ефективності та двонаправленості. В статті наведено результати вимірювань, проведених на прототипі DAB перетворювача, та обговорюються складнощі його реалізації.

Таким чином, результати роботи сприяють підвищенню ефективності активних систем балансування акумуляторних батарей, подовженню терміну їх служби та розвитку технічних навичок студентів.

Ключові слова — DC-DC перетворювач; активний балансир; акумуляторна батарея; перетворення потужності; балансування.