СЕУТТОО

ХДМА

№ 15

МАТЕРІАЛИ МІЖНАРОДНОЇ НАУКОВО-ПРАКТИЧНОЇ КОНФЕРЕНЦІЇ

2024

https://ksma.ks.ua/

Міністерство освіти і науки України
Херсонська державна морська академія
Одеський національний морський університет
Національний університет «Одеська морська академія»
Національний університет кораблебудування ім. адмірала Макарова
Державний університет інфраструктури та технологій
Литовська морська академія (Литовська Республіка)
Akademia Morska w Szczecinie (Республіка Польща)
Batumi State Maritime Academy (Грузія)
University of Plymouth (Велика Британія)
Крюінгова компанія «Marlow Navigation» (Республіка Кіпр)

МАТЕРІАЛИ

15-ї Міжнародної науково-практичної конференції

«СУЧАСНІ ЕНЕРГЕТИЧНІ УСТАНОВКИ НА ТРАНСПОРТІ, ТЕХНОЛОГІЇ ТА ОБЛАДНАННЯ ДЛЯ ЇХ ОБСЛУГОВУВАННЯ»

(СЕУТТОО-2024)

Херсон – 2024

Науковий комітет:

Агєєв М.С. – д.т.н., доц., ХДМА;
Білогуб О.В. – д.т.н., проф., НТУ «ХАІ»;
Білоусов Є.В. – д.т.н., проф., ХДМА;
Варбанець Р.А. – д.т.н., проф., ОНМУ;
Грицук І.В. – д.т.н., проф., ХДМА;
Дакі О.А. – д.т.н., доц., ДІВТ;
Єпіфанов С.В. – д.т.н., проф., НТУ «ХАІ»;
Колегаєв М.О. – к.т.н., проф., НУ «ОМА»;
Кравченко С.О. – д.т.н., с.н.с., НТУ «ХПІ»;
Лещенко А.М. – д.філос.н., проф., ХДМА
Мельник О.В. – к.т.н., доц., ДУІТ;
Наглюк І.С. – д.т.н., проф., ХНАДУ;
Парсаданов І.В. – д.т.н., проф., НТУ«ХПІ»;
Подригало М.А. – д.т.н., проф., ХНАДУ;
Полив'янчук А.П. – д.т.н., проф., ХНУ міського господарства імені О.М. Бекетова;
Рева О.М. – д.т.н., проф., НАУ;
Редчиць Д.О. – д.ф.-м.н., інститут транспортних систем і технологій НАН України;
Сараєв О.В. – д.т.н., проф., ХНАДУ;
Сербін С.І. – д.т.н., проф., НУК;
Сьомін О.А. – к.т.н., доц., ДУІТ;
Тимошевський Б.Г. – д.т.н., проф., НУК;
Тулученко Г.Я. – д.т.н., проф., НТУ «ХПІ»;
Чередніченко О.К. – д.т.н., доц., НУК;
Шарко О.В. – д.т.н., проф., ХДМА;
Шумило О.М. – к.т.н., проф., ОНМУ;
Klyus Oleh – prof. dr hab. inz, Akademia Morska w Szczecinie (Республіка Польща);
Rima Mickienė – Deputy director for academic affairs at Lithuanian Maritime Academy (Литовська республіка);
Teona Dzneladze – Ph.D, Associate Professor Batumi State Maritime academy (Грузія);
Yong Ming Dai – Ph.D, Senior Lecturer in Marine Technology, Associate Head of School – Mechanical Engineering, University of Plymouth (Велика Британія)

Організаційний комітет:

Голова – Василь ЧЕРНЯВСЬКИЙ, в.о. ректора ХДМА.

Заступники голови – Андрій БЕНЬ, проректор з НПР ХДМА.

Олександр АКІМОВ, декан факультету суднової енергетики.

Володимир САВЧУК , зав. кафедри експлуатації суднових енергетичних установок.

Вчений секретар конференції – Дмитро ЗІНЧЕНКО, доцент кафедри експлуатації суднових енергетичних установок.

Технічний секретар – Дар'я КУРНОСЕНКО, завідувач лабораторії кафедри експлуатації суднових енергетичних установок.

Сучасні енергетичні установки на транспорті і технології та обладнання для їх обслуговування. 15-а Міжнародна науково-практична конференція, 13-15 березня 2024 р. – Херсон: Херсонська державна морська академія.

У матеріалах 15-ї Міжнародної науково-практичної конференції «Сучасні енергетичні установки на транспорті і технології та обладнання для їх обслуговування» представлені тези, які присвячені проблемам експлуатації, виробництва та проектування енергетичних установок та устаткування на транспорті, а також підготовці спеціалістів у сфері транспортної енергетики й устаткування.

APPLICATION OF THE DIFFERENTIAL POWER CONVERTER IN THE SYSTEM OF SOLAR POWER PLANTS

Volodymyr Nerubatskyi, Denys Hordiienko✉

Ukrainian State University of Railway Transport, Ukraine

Keywords: *current and voltage balancing, differential power converter, photovoltaic panel, solar power plant.*

Abstract

An analysis of energy collection architectures for large-scale solar power plants was carried out. The topology of a two-stage differential power converter with the characteristics of a DC collection network, which provides a higher energy output for large-scale solar power plants, is presented. The principle of operation of the converter and the flow of current in the circuit during switching are presented. The calculation of the current balancing and voltage equalization cascades, which process partial power and allow groups of photovoltaic panels to work at maximum power under the influence of environmental conditions, has been calculated.

Introduction

The capacity of photoelectric installations continues to grow and reaches hundreds of megawatts [1, 2]. Large-scale photovoltaic systems (VLS-PV) are valued for their high efficiency when their architecture is renewable and reliable. In addition, energy conversion costs are low, and the VLS-PV installation is capable of mitigating the consequences of partial shading. VLS-PV installations with distributed power electronics converters demonstrated higher energy output, better reliability, a significant reduction in design costs, and greater flexibility in the construction of photovoltaic installations [3].

The latest achievements in power electronics made it possible to develop central inverters with higher power density [4]. ABB's central high-power inverter (PVS800) is capable of achieving a maximum output power of 2 MW from up to 24 separate DC inputs from multiple PV lines. In addition, with the advent of a higher voltage of around 1500 V, a larger number of photovoltaic modules can be connected in series, thereby reducing the number of junction boxes, reducing current and improving overall efficiency [5].

The architecture of distributed maximum power point tracking (DMPPT) is one of the most promising solutions for overcoming the shortcomings associated with the low energy efficiency of photovoltaic panels [6].

This architecture has a DC-DC converter designed to track the maximum power point of each photovoltaic panel. To ensure maximum flexibility, converters must be able to step up and down the voltage.

Relevance of research

In scientific research, some authors have achieved high efficiency using converters that control only part of the output power, such as series-connected converters, parallel power converters, and converters with direct power transmission [7, 8]. However, such converter topologies are inefficient for use in photoelectric systems.

In works [9, 10], general approaches used for load reduction, power distribution in proportion to the generator rating, and battery life extension are given, but modular sub-panel photoelectric converters cannot regulate voltage on the DC bus in response to load changes.

Research on topologies that can increase or decrease the power of photovoltaic panels is also known [11, 12]. These topologies have the effect of increasing efficiency, however, the efficiency of the system itself is limited, since the intensity of sunlight hitting the panels varies depending on the season, time and weather conditions.

Thus, the use of photovoltaic panels with the aim of improving the operating conditions of energy systems, means of transport and reducing the harmful impact on the environment, as well as further research into highly effective and inexpensive energy creators, is an actual unsolved task.

The main material of the study

Fig. 1 shows the topology of the two-stage differential power converter with the characteristics of the medium-voltage DC collection network.

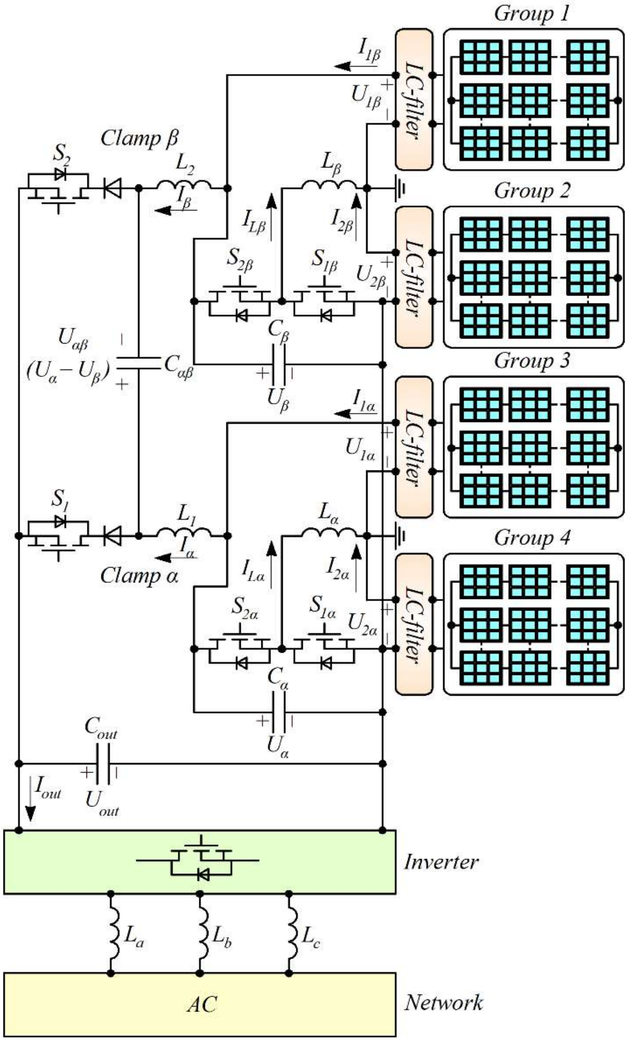

Figure 1. *Topology of a two-stage differential power converter for large photovoltaic installations*

As can be seen from Fig. 1, two sets of photoelectric installations (groups 1 and 2) are connected in series with grounding in the center. They are internally connected to a current balancing converter with a partial nominal value that facilitates independent control of the photovoltaic currents ($I_{1\beta}$, $I_{2\beta}$), thus guaranteeing individual tracking of the maximum power point (MPPT) for groups 1 and 2 of sections of the photoelectric installation.

At the stage of current balancing, two switches ($S_{1\beta}$, $S_{2\beta}$) are used, which work in the pulse width modulation mode to control the current $I_{L\beta}$ of the inductor L_β. The current balancing approach handles only a fraction of the total harvested power and requires power converters with fractional power ratings. The current balancing stage processes the differential power from the two solar systems.

Groups 3 and 4 also have an analog current balancing converter. The negative output terminals of Groups 1 and 2 and Groups 3 and 4 are connected together to form a common point. Two positive output terminals α and β are connected to the voltage balancing converter. The function of the voltage equalization cascade consists in processing the differential power of two parallel sets: groups 1, 2 and groups 3, 4 with the help of the appropriate control of pulse width modulation by switches S1, S2. The capacitor Cαβ in the stationary state holds the voltage difference ($U_\alpha - U_\beta$).

The given concept of current and voltage balancing guarantees that each group of photoelectric installations will work individually. MPPT point, due to which the total maximum power collection is achieved in conditions of partial shading and temperature difference.

The advantages of the proposed two-stage differential power converter include:

– current and voltage balancing cascades process partial power to achieve maximum power in conditions of partial shading;

– the current balancing stage uses switches with partially rated higher voltage and lower current, while the voltage balancing stage uses switches with higher current and lower voltage;

– high efficiency is achieved at the expense of daily power processing compared to other schemes;

– a smaller number of power converter processing units;

– the proposed approach can be scaled to several solar energy systems with a nominal capacity of several MW, consisting of many groups of photoelectric installations;

– the approach allows creating homogeneous and heterogeneous photoelectric installations using photoelectric panels from different manufacturers.

The proposed architecture is scalable to multiple inputs with efficient localized power management for multi-row PV installations, residential and large-scale PV power plants. Mass power is processed once with partial losses. The balancing capacitor Cαβ plays an important role in balancing voltages to achieve MPP. Such an approach effectively eliminates the need for a DC-DC converter, which is required for MPPT tracking.

A homogeneous photoelectric installation is defined as an installation that has the same number of series/parallel connected modules per group.

Table 1 shows the technical characteristics of a homogeneous photoelectric installation.

Table 1. *Technical characteristics of a homogeneous photoelectric installation*

Parameter	***Value***
Photoelectric module	SPR-305-WHT
Configuration in four groups	24 consecutive / 40 parallel modules with a capacity of 293 kW
Total power of four groups P_{Σ}, MW	1.1
Switching frequency of the balancing state f, kHz	20
Capacitor $C_{\alpha\beta}$, µF	40
Inductances L_{α}, L_{β}, mH	1.65
Inductances L_1, L_2, µH	100

According to Fig. 1, it is assumed that groups of photoelectric installations 1, 2, 3, 4 are in different working conditions due to environmental factors. Fig. 2 shows the operating characteristics of each group at different temperatures and insolation conditions.

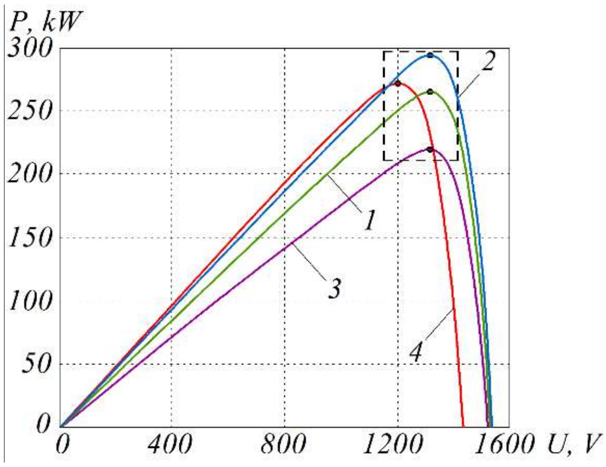

Figure 2. *Characteristics of a two-stage differential power converter for large photoelectric installations: 1 – group 1 (25 °C, 0.9 kW/m²); 2 – group 2 (25 °C, 1 kW/m²); 3 – group 3 (25 °C, 0.75 kW/m²); 4 – group 4 (50 °C, 1 kW/m²)*

From Fig. 2, it can be seen that there is a unique operating condition in which the voltage and current values for each group correspond to the maximum power of the panels. The characteristics of the cascades of current balancing and voltage equalization for the construction of the plant in question, at which the maximum available power is achieved, are shown in Fig. 3, 4.

Both balancing current / voltage converters according to Fig. 1 work with their special switching duty cycles to get the maximum power available.

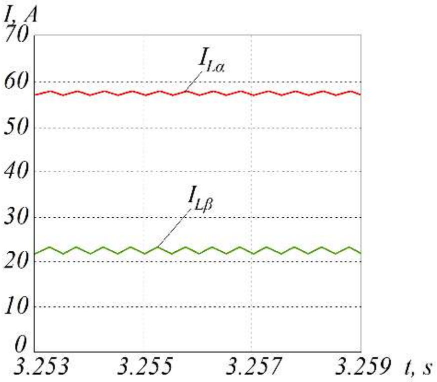

Figure 3. *Maximum balancing currents of inductances L_{α}, L_{β}*

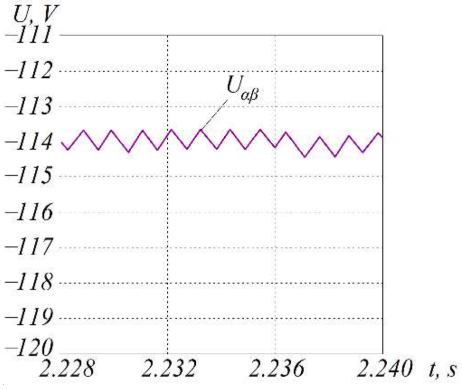

Figure 4. *Capacitor voltage $C_{\alpha\beta}$*

The current balancing stage for terminal β and terminal α handles currents $I_{L\beta} = 22$ A and $I_{L\alpha} = 57.3$ A, which is part of the total current. In addition, the given voltage equalization scheme works at a voltage of $U_{\alpha\beta} = -144$ V, which is a much smaller value. Thus, the number of volt-amperes processed by the current / voltage balancing cascades is small for operation at different temperatures and insolation conditions.

Conclusion

The proposed two-stage differential power converter topology is able to work with a large-scale solar power plant at different points of maximum power, because there is a unique operating condition in which the values of voltage and current for each group correspond to the maximum panel power. At the same time, both balancing current and voltage converters work with their special switching duty cycles.

The proposed architecture is scalable to multiple inputs with efficient localized power management for multi-row PV installations, residential and large-scale PV power plants. Mass power is processed once with partial losses. The balancing capacitor plays an important role in balancing voltages to achieve MPP. Such an approach effectively eliminates the need for a DC-DC converter, which is required for MPPT tracking.

References

[1]. Alblooshi A., Masoud M. I. Design of a 1 MW Grid-tied photovoltaic system. *2021 International Conference on Engineering and Emerging Technologies (ICEET)*. 2021. P. 1–6. doi:10.1109/ICEET53442.2021.9659704

[2]. Nerubatskyi V. P., Plakhtii O. A., Hordiienko D. A., Khoruzhevskyi H. A. Study of the energy parameters of the system "solar panels – solar inverter – electric network". *4th International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters (ICSF-2023). IOP Conference Series: Earth and Environmental Science*. 2023. Vol. 1254. 012092. P. 1–12. doi:10.1088/1755-1315/1254/1/012092

[3]. Khadka N., Bista A., Adhikari B., Shrestha A., Bista D. Smart solar photovoltaic panel cleaning system. *IOP Conference Series: Earth and Environmental Science*. 2020. Vol. 463. P. 1–8. doi:10.1088/1755-1315/463/1/012121

[4]. Singh D., Sandeep N. Multiport multilevel inverter for high-frequency AC applications. *2022 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES)*. 2022. P. 1–6. doi:10.1109/PEDES56012.2022.10080506

[5]. Khomenko I. V., Nerubatskyi V. P., Plakhtii O. A., Hordiienko D. A., Shelest D. A. Research and calculation of the levels of higher harmonics of rotary electric machines in active-adaptive networks. *4th International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters (ICSF-2023). IOP Conference Series: Earth and Environmental Science*. 2023. Vol. 1254. 012040. P. 1–15. doi:10.1088/1755-1315/1254/1/012040

[6]. Plakhtii O., Nerubatskyi V., Hordiienko D. Efficiency analysis of DC-DC converter with pulse-width and pulse-frequency modulation. *2022 IEEE 41st International Conference on Electronics and Nanotechnology (ELNANO)*. 2022. P. 571–575. doi:10.1109/ELNANO54667.2022.9926762

[7]. Moghassemi A., Rahman S., Ozkan G., Edrington C., Zhang Z., Chamarthi P. Power converters coolant: past, present, future, and a path toward active thermal control in electrified ship power systems. *IEEE Access*. 2023. Vol. 11. P. 91620–91659. doi:10.1109/ACCESS.2023.3308523

[8]. Cheng L., Wu W., Qiu L., Liu X., Ma J., Zhang J., Fang Y. An improved data-driven based model predictive control for zero-sequence circulating current suppression in paralleled converters. *International Journal of Electrical Power & Energy Systems*. 2022. Vol. 143. P. 108401. doi:10.1016/j.ijepes.2022.108401

[9]. Muttaqin E. F., Maulana M. A., Fadlika I., Aripriharta A. Design and validation non-isolated boost converter for cascaded photovoltaic application. *2022 5th International Conference on Power Engineering and Renewable Energy (ICPERE)*. 2022. P. 1–6. doi:10.1109/ICPERE56870.2022.10037506

[10]. Zheng Y., Cheng Z., Liu C., Liu H., Amirabadi M., Lehman B. Modular wireless power transmission for photovoltaic subpanel system. *2021 IEEE Energy Conversion Congress and Exposition (ECCE)*. 2021. P. 546–553. doi:10.1109/ECCE47101.2021.9595115

[11]. Hegazy E., Saad W., Shokair M. Studying the effect of using a low power PV and DC-DC boost converter on the performance of the solar energy PV system. *2020 15th International Conference on Computer Engineering and Systems (ICCES)*. 2020. P. 1–8. doi:10.1109/ICCES51560.2020.9334581

[12]. Kareem M., Kurnaz S. Improving the efficiency of solar photovoltaic power generation using improved MPPT method. *2020 International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*. 2020. P. 1–4. doi:10.1109/HORA49412.2020.9152882

Authors' information

Volodymyr Nerubatskyi, PhD, Associate Professor, Department of Electrical Energetics, Electrical Engineering and Electromechanics, Ukrainian State University of Railway Transport, Kharkiv, Ukraine, ORCID: 0000-0002-4309-601X.

Denys Hordiienko, Postgraduate, Department of Electrical Energetics, Electrical Engineering and Electromechanics, Ukrainian State University of Railway Transport, Kharkiv, Ukraine, ORCID: 0000-0002-0347-5656.