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OPTIMAL TOPOLOGY OF ELECTRIC CIRCUITS IN PV-PANELS AND PV-PLANTS WITH USING CONTROLLED CONNECTIONS

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Bondarenko D.[1]

Corresponding author: Bondarenko Dmytro,
e-mail: dima7007bond@gmail.com

[1] PhD.
https://orcid.org/0000-0002-5629-930X

[1] Institute of Renewable Energy NAS of Ukraine, Kyiv, Ukraine

Abstract. *The article considers the topology of electric circuits of photovoltaic panels and photovoltaic plants. The existing principles of connection are considered, advantages and disadvantages are analyzed. A parallel-serial connection cell for connecting two power sources is proposed. It is possible to implement parallel connection, serial connection and shunt, simultaneously, in one device. Switching in this cell is controlled and dynamic. The topology of combining a large number of photovoltaic devices is demonstrated. A topological structure in the form of a tree is used. The advantages and disadvantages of this approach are shown. A modern technological approach to the implementation of such a controlled system is proposed. Conclusions are made.*

Keywords: *electrical circuit topology, photovoltaic panel, solar power plant, parallel-series combination, controlled connection, dynamic switching.*

ОПТИМАЛЬНА ТОПОЛОГІЯ ЕЛЕКТРИЧНИХ КІЛ В СОНЯЧНИХ ПАНЕЛЯХ ТА СТАНЦІЯХ З ВИКОРИСТАННЯМ КЕРОВАНИХ З'ЄДНАНЬ

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Бондаренко Д. В.[1]

Автор для кореспонденції: Бондаренко Дмитро,
e-mail: dima7007bond@gmail.com

[1] канд. техн. наук.
https://orcid.org/0000-0002-5629-930X

[1] Інститут відновлюваної енергетики НАН України, м. Київ, Україна

Анотація. *В статті розглядається топологія електричних кіл у фотовольтаїчних панелях та сонячних станціях, а також існуючі принципи з'єднання, проаналізовано їхні переваги та недоліки. Запропоновано паралельно-послідовну комутуючу комірку для з'єднання двох джерел живлення. Можлива реалізація паралельного з'єднання, послідовного з'єднання та шунтування одночасно, в одному пристрої. Комутація в такій комірці є керованою та динамічною. Продемонстровано топологію об'єднання більшої кількості фотоелектричних пристроїв. Застосовано топологічну структуру у вигляді дерева. Показано переваги та недоліки такого підходу. Запропоновано сучасний технологічний підхід для реалізації такої керованої системи. Зроблено висновки.*

Ключові слова: *топологія електричного кола, фотовольтаїчна панель, сонячна електростанція, паралельно-послідовна комірка, кероване з'єднання, динамічна комутація.*

Introduction. The development and implementation of energy systems using renewable energy sources, especially solar photovoltaic systems, prompts us to conduct theoretical research on establishing the optimal topology of electrical circuits in solar photovoltaic panels and solar power plants. Also, it should be noted that the development of microelectronics has led to the introduction of automatic control systems based on microcontrollers in power equipment. And developments in the field of commutation of large currents and voltages, with the help of semiconductor devices, made it possible to dynamically adjust the main energy parameters.

Setting objectives. Investigate the topology of electric circuits in photovoltaic panels and solar power plants, taking into account the possibility of dynamic control of circuit commutation. To propose an optimal scheme for automatic control of power equipment parameters in real time.

Topology of electrical circuits of solar cells. A traditional solar semiconductor photovoltaic cell is usually made of silicon in various condensed states. Note that the open circuit voltage of silicon is 0.5-0.6 Volts [1]. We should also note that modern technology for the production of photovoltaic elements involves the production of elements with an output power of 2-5 Watts at maximum illumination. Such a value of power, in real conditions, is too small for the construction of power equipment, which prompts us to combine such elements in circuits of different topologies. It should also be mentioned that other semiconductor elements, such as arsenide-gallium, telluride-cadmium and others, have the open-circuit voltage and output power, and these are also within the limits of a standard semiconductor, such as silicon.

Common topological solutions are parallel and series connections of electrical circuit elements. So, to increase the voltage in the pv-modules, photovoltaic cells are connected in series, and to increase the current characteristics, they are connected in parallel. Similarly, at solar pv-plants, photovoltaic panels are connected in series in strings, and strings are connected in parallel. But there are other, mixed, topological solutions that allow obtaining various energy characteristics and increasing the stability of operating parameters. Thus, works [2,3,4] show serial-parallel connections (SP) (Fig. 1), total cross tide connections (TCT) (Fig. 2), bridge link connections (BL) (Fig. 3), honey comb connection (HC) (Fig. 4). The advantages and disadvantages of such topologies are described in works [2,3,4]. The main advantage is the stability of operating modes and the possibility of bypassing fauls [5,6], but the main disadvantage is the impossibility of generating arbitrary parameters of electricity.

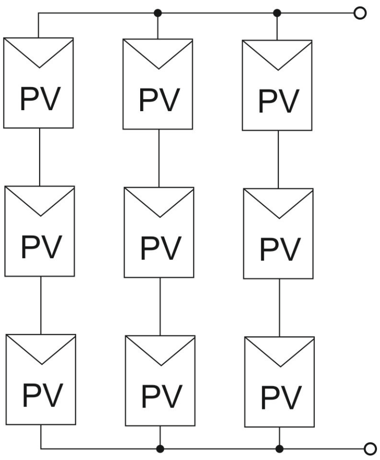

Fig. 1. Serial-parallel connection

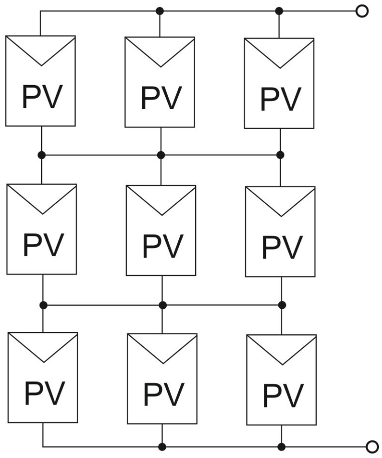

Fig. 2. Total cross tide connection

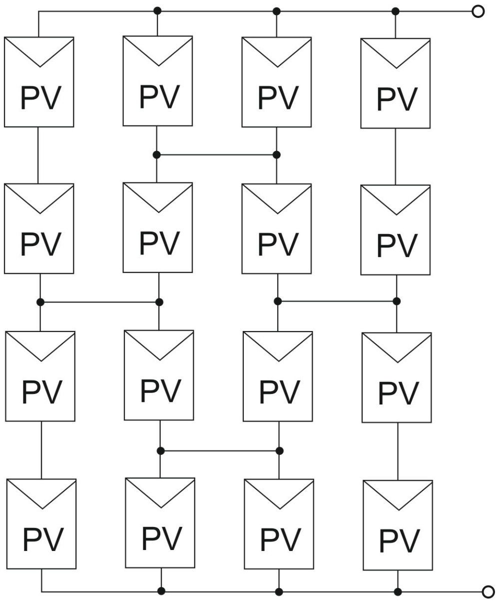

Fig. 3. Bridge link connection

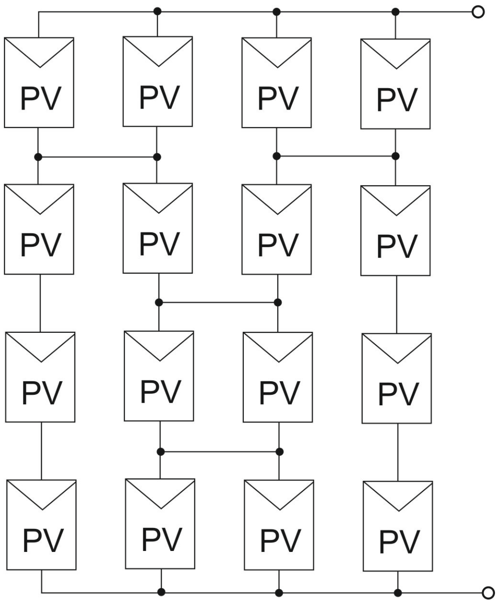

Fig. 4. Honey comb connection

An interesting approach is the creation of a universal topology in the form of matrix switching [7]. With the use of such a topology, there is a need for a large number of conductors, since, in fact, it is necessary to connect all the cells in the module (or panels in the station) to each other with individual connectors, which can overload the implemented circuit. But the advantage of this topology is the ability to dynamically control energy parameters in a certain range.

Therefore, to implement dynamic commutation, fixed connections are replaced by switching elements, such as electro-mechanical relays or power semiconductor elements that work in the switch mode (thyristors, field-effect transistors, etc.) [8].

In this work, it is proposed to use the advantages of all the above approaches.

Topology based on a parallel-serial cell. To implement dynamic commutation, it is proposed to use a parallel-serial cell in which two generating elements are connected by four switching elements (Fig. 5), two elements for parallel connection, one element for serial and one more for full shunting. Such a cell can be the basic unit for the formation of a universal generating photovoltaic module or a universal solar pv-plant, which can form a certain range of operating voltages and currents.

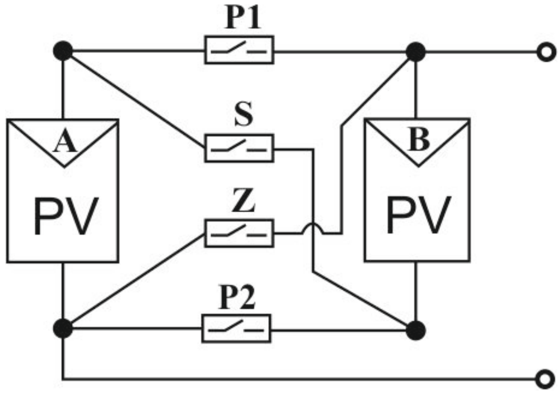

Fig. 5. Commutation of two sources (PV- pv-element, P1 and P2- parallel connection, S- series connection, Z- bypass connection)

The approach, using a universal, basic, element-cell, is convenient to apply to the topological scheme of switching elements in the form of a tree (Fig. 6). That is, there will be switching that will allow to form a wide range of currents and voltages according to the topological structure of such a tree. But such currents and voltages will be multiples of 2^n, where n are natural numbers that mean the number of tree branches. This factor is a certain drawback, because it limits us in the range of initial values. For example, when using 16 photovoltaic elements, or 8 commutation cells, we will have output working voltages of 0.5 Volts, 1 Volt, 2 Volts, 4 Volts, 8 Volts. But the above-mentioned approach allows you to significantly reduce the number of current conductors and switching elements in comparison with matrix switching.

When implementing such an approach, as shown in Figure 6, it is convenient to move the switching elements to a separate block (PSZ). This is convenient from the point of view of actual implementation, as the generating and switching parts are structurally and electro physically separate elements.

Switching elements, which are indicated in Figure 6, must be controlled from the outside manually or automatically according to a predetermined algorithm. Thus, such controlled elements will allow to realize dynamic commutation of photocells in a panel, or commutation of panels at a pv-plant [9].

It should be noted that from a modern point of view it is convenient to use MOSFET transistors for controlled commutation of power electric circuits. They have ultra-low internal resistance, there is a large elemental base of such transistors, and based on them there are well-developed circuit solutions [10, 11]. To control such transistors, it is appropriate to use programmable microcontrollers [12], which can implement arbitrary algorithms and scenarios of the system as a whole.

Use of transistor assemblies and microcontrollers. When implementing a switching PSZ-node, it is appropriate to use a group combination of transistors into assemblies, for example, two MOSFET-transistors assembled in pairs in one SO-8 case, or assemblies with greater integration. It should also be noted that SiC and GaN technologies are gaining popularity, which allow controlling larger currents with lower heat losses [13, 14].

To control such commutating cells and the system as a whole, it is appropriate to use modern programmable microcontrollers that have the ability to flexibly control generation processes using various algorithms. The communication line between the microcontroller and the commutating cells can be a power transmission line, coupled two in one.

Modelling. From Figure 6, we can see that the union of electric circles into one circle in the form of a tree was formed. Therefore, to calculate such a circle, it is advisable to use calculation and modelling algorithms that are intended for this configuration. On the other hand, to model and calculate the currents and voltages in the parallel-series cell from Figure 5, it is advisable to use the matrix-vector representation. Thus, at each step of calculating such "a tree", the PSZ-cell will be represented by a matrix with elements that correspond to the topology of the required circuit.

Conclusion. After conducting research, the optimal topology of electric circuits in solar photovoltaic panels and in solar power pv-plants was established. Such a topology requires the implementation of dynamic switching for operational management of the output parameters of the energy system. Modern microcontrollers and semiconductor power elements make it possible to dynamically adjust the main energy parameters.

A great advantage of dynamic control of the output parameters and modes of the generating device is the possibility of implementing smart energy systems of various scales [15], as well as the possibility of complex simultaneous control of generation, accumulation and consumption, depending on needs.

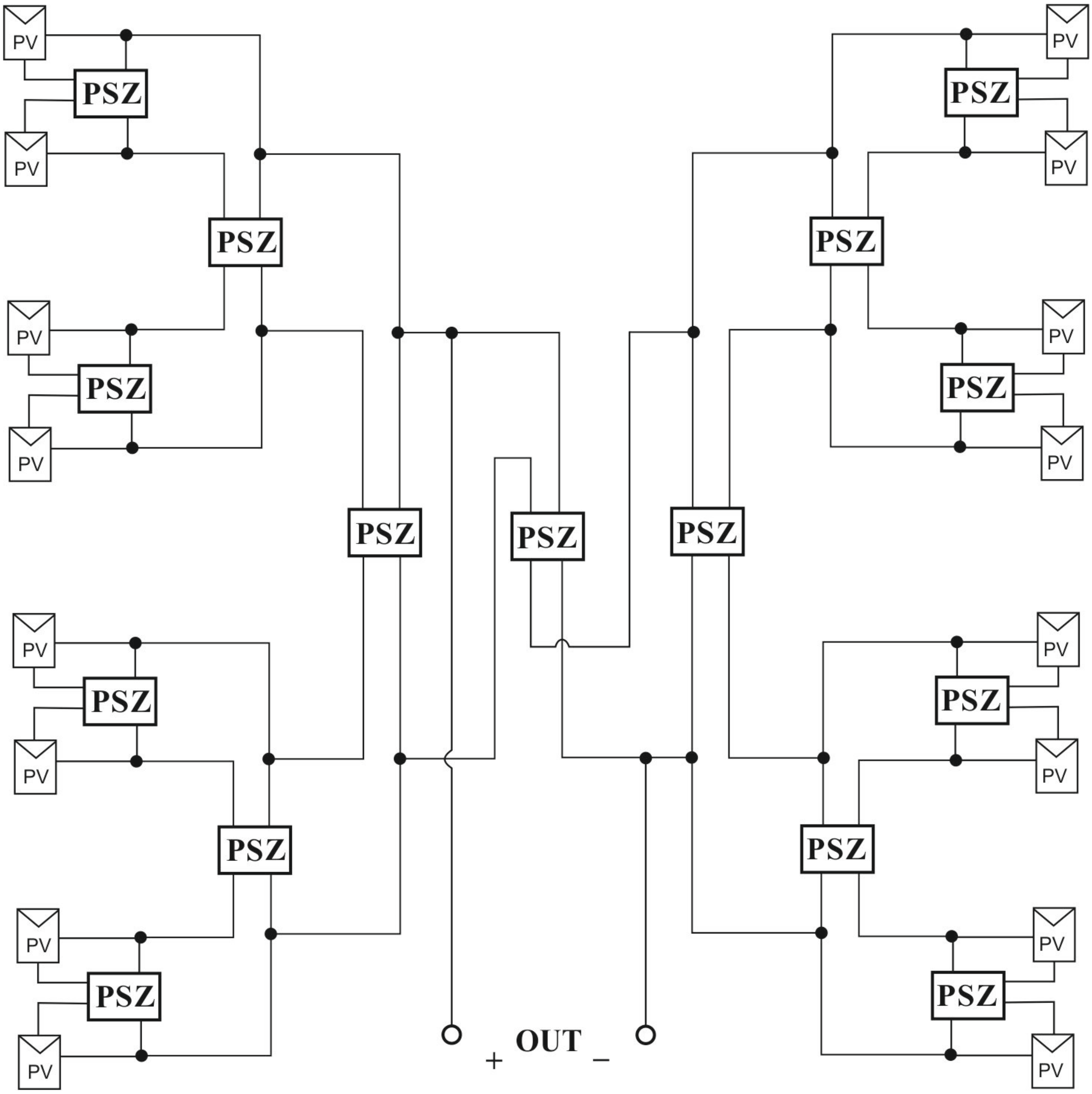

Fig. 6. Connection of commutation element in tree style (PV- pv-element, PSZ- commutation cell, OUT- output terminals)

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