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ENERGY-SAVING LED LIGHTING SYSTEM WITH PARALLEL POWER SUPPLY BY PHOTOVOLTAIC MODULES AND BY NETWORK

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ABSTRACT

The current state of LED lighting systems with parallel power supply by photovoltaic modules and central power supply network is analysed. The approach to implementation of parallel operation of LED luminaire powered by two sources of power is presented. It is simple, cheap and highly reliable as compared to the existing solutions. Based on this approach, four diagrams are developed which are applicable correspondingly to lighting applications and characteristics of photovoltaic modules and power consumers. The first and the second diagrams contain minimal quantity of transformers, but a number of operational constraints shall be taken into account when using them. The third diagram contains standard transformers and implies minimal number of various constraints, which makes it an optimal solution for the low-power lighting system being designed. The fourth diagram is expensive due to utilisation of equipment with automatic maximum power point tracking (the *MPPT* technology); it provides maximum possible energy efficiency of the lighting systems but the advantages of the *MPPT* technology apply only to high-power systems.

It is preferable to use such objects where lighting is mostly required during daytime as consumers of such systems (shopping malls, underground passages, storage facilities, poultry farms, etc.). A positive aspect is increase in reliability of consumer power supply since power supply of LED luminaires will be also provided by an additional source.

The proposed approach leads to reduction of power consumption for LED lighting, saving of fossil energy sources and therefore to ecologisation of the environment.

Keywords: solar radiation, photovoltaic module, direct current micro-grid, voltage stabiliser, current stabiliser, parallel operation, LED lighting

1.INTRODUCTION

The sphere of application of photoelectric transformers (PET) has been continuously expanding. Large-scale introduction of photoelectric systems is mostly promoted by reduction of the cost of PET [1–3] and growth of tariffs for electric energy generated using conventional sources of energy. Development of photovoltaic energy is also affected by environmental issues [3, 4] and development of energy-efficient electronics and direct-current lighting devices.

Application of photovoltaic modules (PVM) as sources of energy allows us to connect direct current consumers directly without an inverter establishing a direct current micro-grid. Such concept is being studied constantly throughout the world [5–7] and relevant technologies will become more popular and be introduced all over the world as soon as the cost of photovoltaic energy drops.

Many devices use direct current for operation in our homes and offices. A significant part of household and office appliances and other electric equipment operates using direct current being supplied by the alternate current network thanks to built-in power transformers. These devices are technically capa-

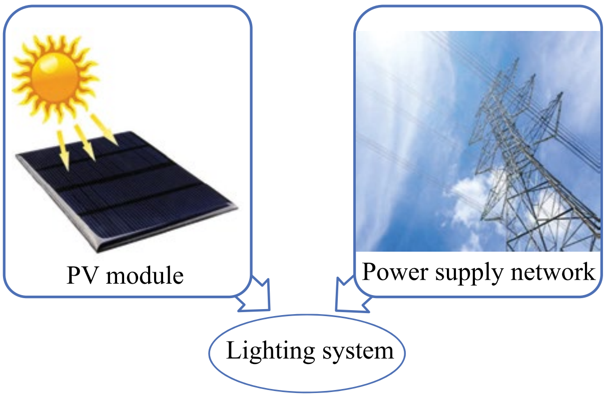

Fig. 1. Lighting system with parallel power supply by two sources

ble to use direct current directly; however, manufacturers do not design such functionality. Devices that are capable to use AC and DC networks for operation simultaneously can be rarely encountered recently, but the number of such devices will increase following the observed trend. It is important that it does not lead to significant technical complication of devices and to rise in their prices. They will operate in hybrid DC and AC networks [8].

With consideration of the above described circumstances and trends, photovoltaic systems supplying direct-current loads will allow to reduce customers' expenses for power supplied by power network operators. A system of lighting by means of LED-based luminaires with parallel power supply by PET and general-use power network (Fig. 1) is one of distinctive examples.

2. METHODS

Various methods of matching parallel operation of a lighting system powered by a PVM and an electric network are possible. For instance, one of the designs comprises super capacitors and a relay for switching between sources of energy [9]. With such approach, relays suffer large load – due to frequent switching, their operation cycle will be short and will require frequent replacement of elements. Moreover, transition processes occurring in case of fast and frequent switching will impair quality of power. Another design comprises application of a special control device (driver) which matches parallel operation of LED sources powered by the network and by PVM by means of a high-frequency transformer [10]. This device also operates as an inverter outputting excessive energy to the network. However, the quality of output power does not comply with standards. There is one common disadvantage of the two above mentioned systems: their complexity and expensiveness.

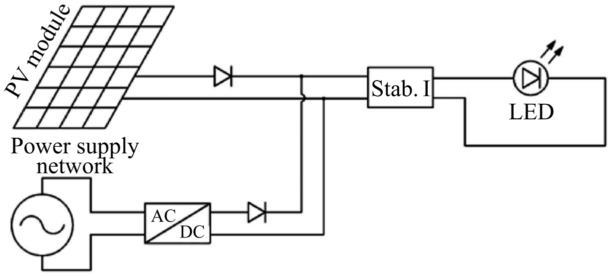

Fig. 2. Wiring diagram of the lighting system with combined power supply

This article proposes a different approach to parallel operation of LED sources which is significantly different from similar solutions being very simple and less expensive. The method comprises of matching two parallel sources of power by voltage level (Fig. 2).

With such connection, it is important that nominal voltage of photovoltaic modules (PVM) is higher than nominal output voltage of the *AC-DC* network supply. Then the entire energy will be consumed by the luminaire with sufficient power generation by PVM. When output of PVM is not sufficient for supply of the luminaire, lack of photovoltaic energy is compensated by the network supply. Lack of photovoltaic energy will lead to decrease of voltage at input of the current stabiliser Stab. I (Fig. 2) of the luminaire, and the network supply will stabilise input voltage of this stabiliser compensating insufficient power at this moment. The current stabiliser is necessary for stabilisation of LED light source's operation in this diagram. In case the latter is equipped with a built-in current stabiliser, it will be removed from the diagram.

The diagram proposed above is the basic one, and some other variants are developed on its basis; the differences are primarily additional elements or

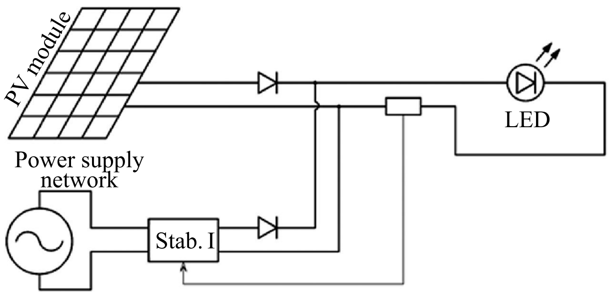

Fig. 3. Lighting system wiring diagram with the combined power supply and modernised network current stabiliser

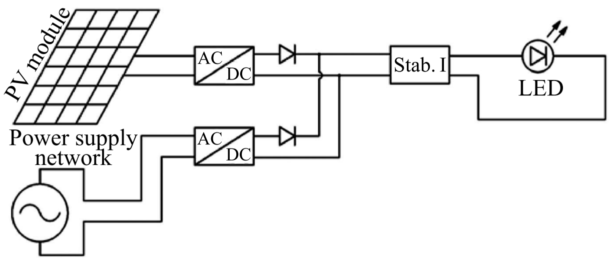

Fig. 4. Lighting system wiring diagram with combined power supply and an up/down converter

modernisation of some elements. One of the variants is presented in Fig. 3. It is based on division between the network current stabiliser and its measurement unit. The measurement unit of the network current stabiliser is located at the input of the luminaire downstream of the connection point of two sources of power. Controlling current of the luminaire, the network transformer compensates lacking power from PVM (as required).

This variant looks very similar to the standard variant of LED-based luminaires powered by the network; the difference is just addition of another source of power and modification of the structure of the current stabiliser. Therefore, it is one of the cheapest variants of connection of a PVM to a conventional supply circuit of LED-based luminaires.

In search for compromises for low-power LED-based luminaires, a widely applicable variant is developed. It comprises application of step-up and step-down converters with voltage and current stabilisers (Fig. 4). With that, in the diagram for out-feed of energy generated by the PVM, an ordinary *DC-DC* voltage transformer-stabiliser is used.

In the case of high-power lighting systems, it is necessary to apply the *Maximum Power Point Tracking* (*MPPT*) technology; the power circuit of such system is shown in Fig. 5. The *MPPT* technology allows users to out-feed more power from the PVM. Different types of such devices (*MPPT* controllers) are being developed for LED-based lighting systems [11, 12].

3. RESULTS

The diagram variants presented above have advantages and disadvantages. Let us consider them in more details.

The variant with direct connection of PVM to a network supply (Fig. 2) has a number of disadvantages associated with impossibility of maximum out-feed of power from PVM and necessity of its output voltage selection. The diagram is efficient only with correctly selected characteristics of elements.

In the second variant, with the modernised current stabiliser (Fig. 3), a minimal number of elements are required for functioning of the system. However, to prevent burnout of LEDs, peak power of PVM should not exceed operating power of LED. It is also possible to apply special limiter of PVM output power. Like in the previous variant of the diagram, it is important to select the PVM based on voltage: nominal voltage should be approximately equal to operating voltage of the luminaire.

After comparing the two above mentioned variants, it should be noted that the first one is preferable with PVM power comparable to that of a luminaire and the second one is preferable with PVM power less than that of a luminaire.

The third variant is preferable for low-power lighting systems. Its advantages are lack of mandatory necessity to select PVM and load voltage, which is necessary for the two previous variants. The PVM output voltage stabiliser operates within a broad range of input voltage and exceeds power out-feed from photoelectric transformers as compared to the first two variants, and the input current stabiliser of the luminaire protects its LED from burnout. Additional advantage of such diagram is capability to establish an AC micro-grid which may be supplemented with new sources and consumers of electric energy.

Although it is the most energy-efficient, the last diagram variant using the *MPPT* technology (Fig. 5) requires additional evaluation of feasibility of specific application due to its expensiveness. The advantages of this technology mostly manifest themselves in high-power lighting systems. For low-power systems, it is more beneficial to increase power of the photovoltaic part by means of additional photoelectric transformers than by means of a *MPPT* controller.

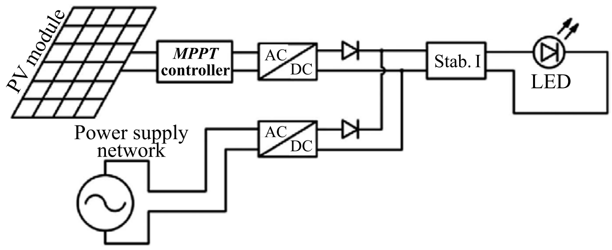

Fig. 5. Lighting system wiring diagram with combined power supply and *MPPT* controller

The variant of a controller designed specifically for parallel operation with a PVM and an electric power is more promising; a *DC-DC* voltage transformer with the *MPPT* technology will be integrated with an *AC-AC* network supply.

The problems of optimal selection of equipment and comparison of different variants of the diagrams are more conveniently solved using special means of mathematical modelling like *MATLAB-Simulink* etc. Therefore, operation of these diagrams will be considered in detail with use of such means in further studies related to this subject.

A special attention shall be paid to unavailability of a battery in the circuits, which allows us to develop cost-efficient LED-based lighting systems, since the batteries would have significantly risen the price of generated power. And even application of lithium iron phosphate batteries which are optimal in terms of the cost of the charge/discharge cycle nowadays will not provide significant reduction of prime cost. However, application of batteries is necessary and feasible, for instance, in emergency lighting networks with LED-based luminaires. Also, application of low-capacity batteries is necessary for achievements of high characteristics in some cases, but it is necessary to solve problems of optimisation with consideration of specific criteria for this purpose. However, in any case, the power of batteries used for lighting will be minimal, which is caused by their inability to compete with PVM and electric network in terms of prime cost of energy.

4. CONCLUSION

Development of PET and lighting installations with LED-based luminaires leads to a large number of designs using them, but most of such installations are autonomous and accumulate energy throughout the day [13]. To make them cheaper, it is necessary to reduce capacities of batteries to a minimum and use general-use power networks as a guaranteed source of power. It is such approach that is implemented in LED-based luminaires with parallel supply from PVM and electric power under development, which reduces consumption of power from the general-use network and losses for transformation.

Moreover, complex supply circuits often have extensive functionality but their large costs lead to high expenses. In this context, it is very important to create simple solutions with their functionality limited to some extent which, however, solve major set problems and are efficient in terms of price and reliability. Therefore, different variants of supply circuits are developed, which are applicable depending on the objectives and distinctions of PVM and power consumers.

It is important to wisely select the loads; it appears that buildings with spaces requiring artificial lighting throughout the day are the most optimal. For instance, we would like to note shopping malls, underground passages, storage facilities and poultry farms. Reliability of power supply plays a very important role for such responsible consumers and is increased by LED-based luminaires being supplied by two to three sources of power (depending on power supply rating of a consumer).

As noted above, the price reduction of PVM over the last years has significantly increased their competitive ability as compared to other sources of energy [1–3]. In this view, a larger number of solar power plants operating directly for power networks have been appearing in Russia [14]. Nowadays, the prime cost of power generated by photovoltaic panels is able to compete with the cost of power from the network for enterprises in some regions. Consequently, such systems allow users to reduce consumption of power from the network in some cases even today allowing consumers to save on electric power bills and contributing to environmental safety growth.

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