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Research paper

A methodology for the construction of efficient PLC based low-power photovoltaic generation plants

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Abstract

The research of the operation of low-power photovoltaic generation plants used for self-contained electric power supply in Siberian climatic conditions is performed in this paper. It provides an analysis of the operation of individual units of an automated control system, and gives recommendations for the selection of hardware components. The article describes the operational principles, developed based on functional modules of the programmable logic controller, ensuring maximum possible use of solar energy in this continuous power supply system. The results of plant operation have been obtained, in the form of a power counter log, as well as data on the volume of solar energy produced in both overcast and in sunny weather, throughout the observation period. The article provides visual illustration of generated energy, which could be used to assess the efficiency and economic viability of the low-power photovoltaic plant. Authors would like to point out that examples of the proposed methodology for the construction of self-contained power supply systems can be found in existing industrial facilities, on which further scientific research can be based.

Keywords: Autonomous power generation systems; PLC; MPPT; PV; Battery; PWM; FBD; Charge control switch; Adapter circuit

1. Introduction

The process of the development of autonomous electric power supply systems, based on photovoltaic panels, is hindered by problems related to the selection of the best equipment, which has to ensure the most efficient use of solar power as well as the automatic switching to backup supply [1–3]. The need to use modern technologies ensuring the most efficient exploitation of solar energy, as well as providing crucial functions required for various equipment, places considerable limitations on the possibility of using more complex and effective solutions. The present article describes a fully fledged system with a single programmable controller, allowing for various subsequent upgrades by developers, as well as for further research. In particular, the proposed solution brings together the concept of efficient exploitation of solar energy, and the best choice of power source, in a single controller. Indeed, the proposed structure can also prove useful in research and the performance of other tasks, not envisaged by the present article. As an example, authors can consider the technology used to optimise the charging and discharging cycle of a battery, whilst also ensuring the process' reliance on solar energy as much as possible. However, authors note that, presently, that research is dedicated to the optimisation of the selection of equipment and its concurrent operation with the plant's other systems. The relevance of such a development is further emphasised by the demand for autonomous low-power systems in those regions of the Russian Federation, where it is either impossible or unjustifiably expensive to rely on the central supply system. Such areas include smaller towns in Yakutia, Buryatia, as well as some foreign territories (Mongolia and others), where the weather is mostly sunny, both in winter and in summer. The subject of our research is an autonomous power supply system, with automatic switching to one of three available backup power sources, lined up by priority:

1 Inverter of continuous power from a DC battery, into alternate current.
2 External power supply.
3 Power generator based on the internal combustion engine (petrol generator).

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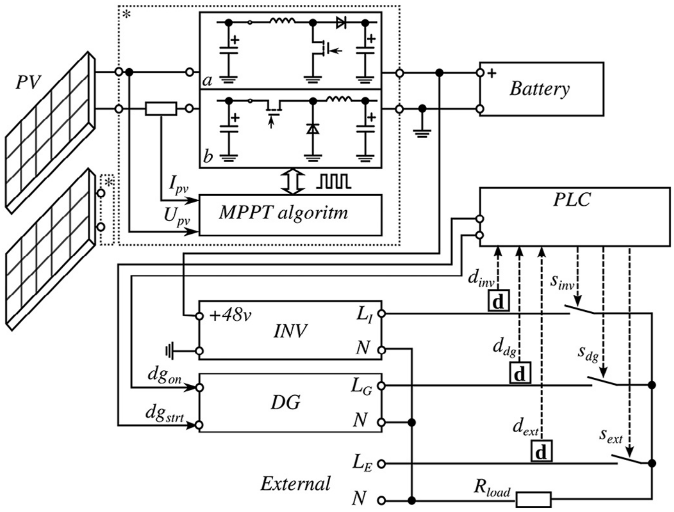

Fig. 1. A functional diagram of the autonomous power system.

A functional diagram of a standard autonomous system is provided in Fig. 1, where the following indications are used: PV, photovoltaic panel; MPPT, a controller capable of locating the maximum power point, operating on one of two possible types of switch-mode transformer; PLC, programmable logic controller; INV, inverter; DG, diesel or petrol generator. Relay circuit for automatic switching to backup power source, including a source detection sensor on three sources (d_{inv}, d_{ext}, d_{dg}) and the corresponding actuators (s_{inv}, s_{ext}, s_{dg}). Battery is a rechargeable battery.

Optimal use of solar energy is ensured by the MPPT battery charge controller, coordinating the supply of energy to the inverter. Industrial MPPT units include functions, such as overcharge protection, charging rate correction, etc. However, several additional functions are also required by autonomous systems, ensuring economic management of the electric power whilst reducing the cost of maintenance [4]. On such an effective and universal device is the programmable logic controller, which can perform a range of tasks, formulated as algorithms [5–7]. Here are some of the functions not normally covered by common MPPT controllers:

1 Automatic selection of power source based on a pre-set priority order, giving preference to the lowest unit price for energy (kWh).
2 The launch and the turning off of the fuel power generator, including several operational modes and interim checking cycles.
3 The activation and deactivation of the inverter (increasingly relevant as the use of an inverter in circumstances where there is no charge is important in low-power autonomous systems).
4 Monitoring and management of charging and discharging cycles of batteries during operation.

Performance of these tasks is not a problem where PLC is used; similar features are being offered by various manufacturers [8]. The issue, however, is the maintenance of the efficiency of MPPT controllers and PLC devices in low-power systems [9].

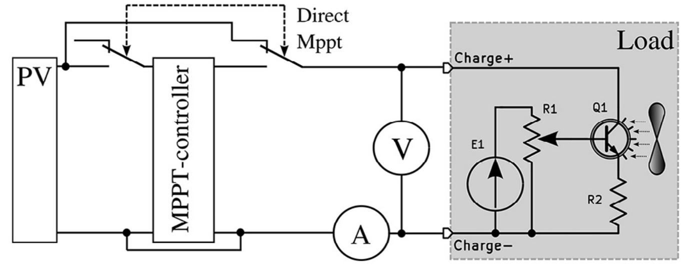

Fig. 2. Functional diagram of the experimental structure.

2. Procedure of experiment

The assessment of the viability of MPPT controllers relies on the ratio between the energy passed to the battery (with or without the controller) and that consumed by an industrial MPPT controller [10]. This ratio can be calculated based on the following formula

$$k_e = \frac{U_{akk} \cdot I_{akk1} - P_{mppt}}{U_{akk} \cdot I_{akk2}} \quad (1)$$

where U_{akk} is the battery voltage; I_{akk1}, I_{akk2} is the charging current with or without the use of an MPPT, P_{mppt} is the power used by the controller.

An example of this principle has been addressed by authors in Kaftanchikovo Tomsk region, which described an experiment involving the construction of an autonomous system, with the view to provide evidence of this efficiency ratio k_e.

Fig. 2 shows a functional diagram of the autonomous system, on which experiments were conducted, where a regulated charge simulator was used instead of a battery. The results of measurements, in different weather conditions, are indicated in Table 1.

As demonstrated in Table 1 a low effectiveness of MPPT controllers (the ratio is lower than one) is clearest in overcast weather conditions, where the battery charge is at its highest: $(U_{akk} > 51V)$. In such circumstances, the power used by the controller exceeds the difference between the power outputs of the two researched systems (both with or without the controller).

In order to assess the effectiveness of the use of controllers in more detail, we can examine the current–voltage ranges $I_{pv}(U_{pv})$, obtained through experiments, described previously, in various lighting conditions in which the photovoltaic (solar) panes were operating. Fig. 3 shows the characteristics, along with the power curves P_{pv} where, on the curves showing the three typical weather conditions, corresponding operational modes of the battery are indicated in grey.

Sections where the peak power is reached in sunny (Fig. 4), partially cloudy (Fig. 5) and overcast (Fig. 6) weather are indicated in a separate drawing.

Table 1
The results of measurements of the efficiency ratio (1).

U_{akk}, V	Overcast	Intermittent clouding	Sunny
45.0	1.16	1.07	1.06
49.0	0.97	0	1.02
53.0	0.93	0.97	0.98
57.0	0.95	0.98	1.01