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Increasing the energy efficiency of an autonomous station for unmanned aerial vehicles

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Abstract. This paper addresses the issue of increasing the energy efficiency of an autonomous station for unmanned aerial vehicles. Low efficiency of modern solar cells is the most important problem of the entire industry of solar energy. The problem of increasing the energy efficiency of installations with solar batteries (photovoltaic installations) for the power supply system of autonomous objects is urgent and connected with the task of maximizing the autonomous operation time. The simulation results showed that the use of extreme regulation increased energy production by 23%, and the use of fuzzy logic significantly increased the speed of reaching the operating point and neutralized voltage fluctuations, which in turn reduced the underproduction of power by an additional 2%.

1. Introduction

The autonomous station of an unmanned aerial vehicle (UAV) performs the functions of a storage, weather station, charger, and communication center. The autonomy of the system is achieved using photovoltaic modules that provide power to the station and charge the unmanned aerial vehicle. Such a system has the possibility of modification in order to increase the energy efficiency of the power supply system. A general view of the station is shown in Figure 1.

The purpose of this work is to increase the energy efficiency of the power supply system of an autonomous UAV station. The tasks of the work include implementation of an effective adaptive charge control algorithm, reorienting photovoltaic modules, and development of an additional block of photocells with a Sun-pointing system.

The well-known and widely used methods for improving the energy efficiency of systems with photovoltaic cells include extreme power control and implementation of the solar tracker. Extreme power control is a method, in which a special charge process algorithm is implemented providing energy extraction at the maximum point of the volt-watt characteristic, which maximizes the energy received from photovoltaic cells. The implementation of the solar tracker is a system for automatic guidance of solar cells on the sun, which increases the amount of incoming energy.

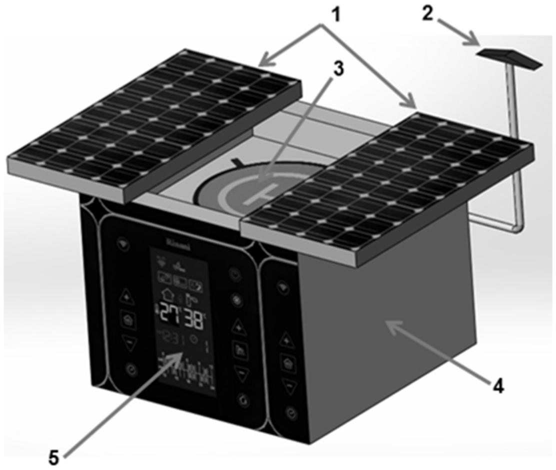

Figure 1. Autonomous UAV station: 1 – movable covers with solar panels; 2 – weather station; 3 – landing field; 4 – frame; 5 – control panel.

Extreme power control or Maximum Power Point Tracking (MPPT) is one of the methods to increase the energy efficiency of photovoltaic modules and wind power plants by obtaining the maximum possible output power of these systems. To implement the MPPT, digital devices are used that analyze the current-voltage characteristic (CVC) to determine the optimal current-voltage pair providing the maximum output power. Figure 2 shows an example of the current-voltage characteristic of a photovoltaic module with the maximum power point indicated on it.

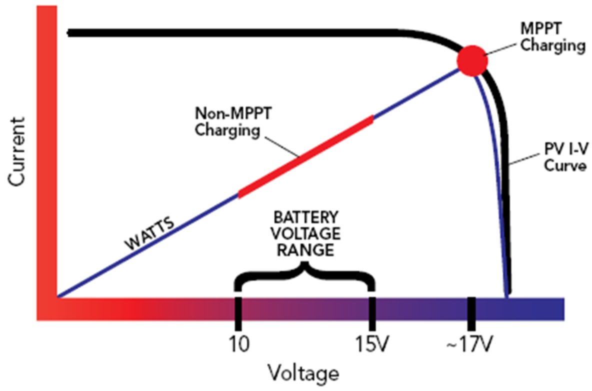

Figure 2. MPPT on the current-voltage characteristic of the photovoltaic module.

The most common MPPT algorithm is the ‘perturb and observe’ algorithm. In this method, the MPPT device changes the input resistance by a small amount (which results in the voltage changes of the solar installation) and measures the power; if the power increases, the controller continues further adjustments in that direction until power no longer increases. The principle of the ‘perturb and observe’ algorithm is shown in Figure 3.

The disadvantages of the ‘disturb and observe’ algorithm include the power fluctuations and the fixed time for hill climbing (the search time for the maximum power point) [1]. Reducing the time for hill climbing leads to an increase in the amplitude of oscillations, which leads to underproduction of power. A decrease in the amplitude of power fluctuations leads to an increase in the search time for the maximum power point. These problems can be solved by using a fairly accurate predictive and adaptive algorithm [2].

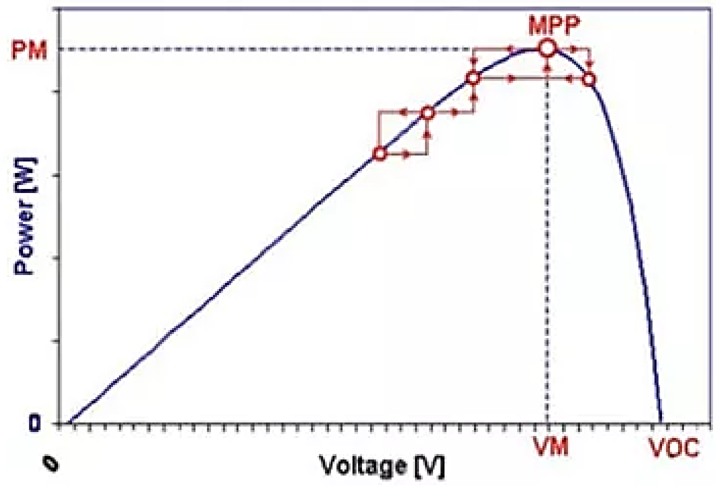

Figure 3. The principle of the maximum power point tracking according to the ‘perturb and observe’ algorithm.

As an additional measure to increase the energy efficiency for power supply system of the autonomous station, we propose an additional reorientation of photovoltaic modules in order to increase the amount of received light (implementation of a solar tracker). Figure 4 shows the principle of this improvement.

It is known that the maximum of the selected energy is reached when sunbeams are perpendicular relative to the photocell plane, therefore, the concept 3 (in Figure 4) has the best indicators of energy selection.

Adding an extra module of photovoltaic cells allows significant increasing of the amount of energy withdrawn in such a system. However, such a module placed outside the main unit of an autonomous station, may adversely affect the mobility of the plant under development because makes it becomes more cumbersome.

To study the energy efficiency of the charging station, using Matlab / Simulink, we developed a simulation model of the system including models of all the required elements of the system.

The relevance of the presented development is related to the problem of maximizing the autonomous operation time of the UAV. Improving the energy efficiency of the power supply system of the UAV station can significantly increase the autonomy of the presented object.

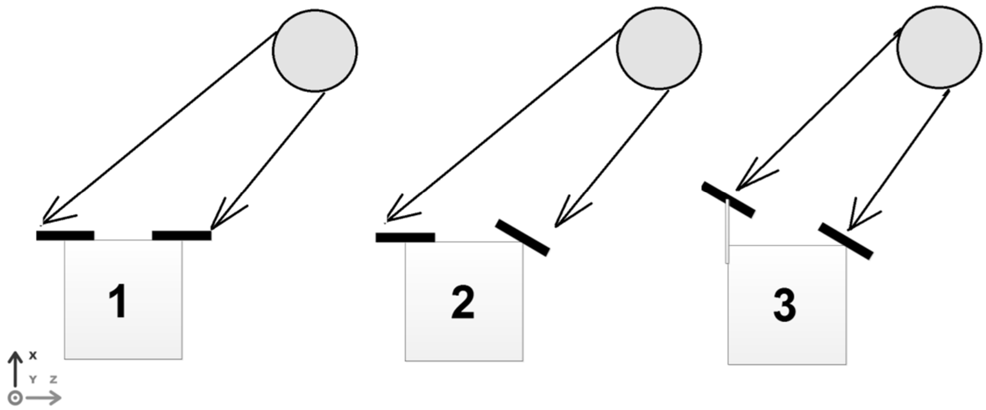

Figure 4. Reorientation of photovoltaic cells (relative movement of the Sun along the y-axis): 1 – solar panels are rigidly fixed; 2 – solar panels can change the angle of inclination; 3 - solar panels on additional lifting frames.

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2. Development of the autonomous power supply system

An autonomous object with a solar-powered supply system designed for fast transport must use light and high-strength materials and electronic circuits that consume little energy. The lower is the consumption of electrical energy and the mass of the structure, the more promising is the use of solar panels.

There are several options for building power supply systems based on solar cells [3, 4]. One of the options is to use solar cells as a source of secondary power to recharge batteries. In such a power supply system, power requirements for solar cells are lower in comparison with direct solar power supply. However, in this case, the autonomous system will operate actively only part of the time, and for the rest part of the time, it will recharge its batteries. Another option for using solar cells is direct powering (recharging) of an autonomous object from solar cells. There is also a combined option when solar cells are used as sources of direct and secondary power.

This paper considers the development of a combined power supply system based on solar cells. The idea of building a charger based on a single-board microcontroller for a photovoltaic installation is as follows. A Buck converter is used as a charger and a microcontroller controls its key. When the voltage/current of the photovoltaic module increases, the PWM generator (which is a MPPT controller) increases the pulse frequency, which in turn leads to an increase in the output current.

The functional diagram of the photovoltaic system is shown in Figure 5.

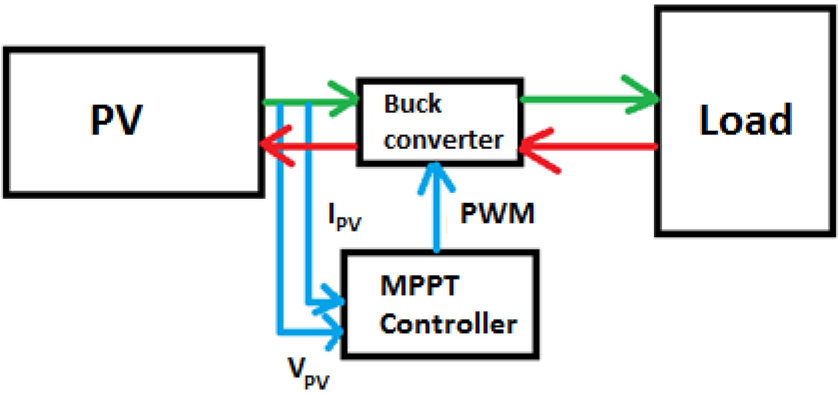

Figure 5. Functional diagram of the photovoltaic system

3. Simulation modeling of the system

The MATLAB/Simulink environment was used to create the autonomous power supply model [5].

In order to evaluate the efficiency of using the MPPT algorithm and the fuzzy regulation-based MPPT algorithm, in addition to the controller itself, we developed a photovoltaic system with a solar battery, a charge controller, a storage battery and a load. The developed model is shown in Figure 6.

The ratio of the change in the power of the solar battery to the change in the voltage of the solar battery (E), and the nature of the change E (dE) are used as input linguistic variables of the fuzzy controller.

$$E(k) = (P(k)–P(k\text{-}1))/(V(k–V(k\text{-}1)) \quad (1)$$

$$dE(k) = E(k)–E(k\text{-}1) \quad (2)$$

The output variable of the fuzzy logic block is the scaling factor of the MPPT algorithm step. The dependence of the output variable value on the input linguistic variables is determined by the set of rules given in the table 1.

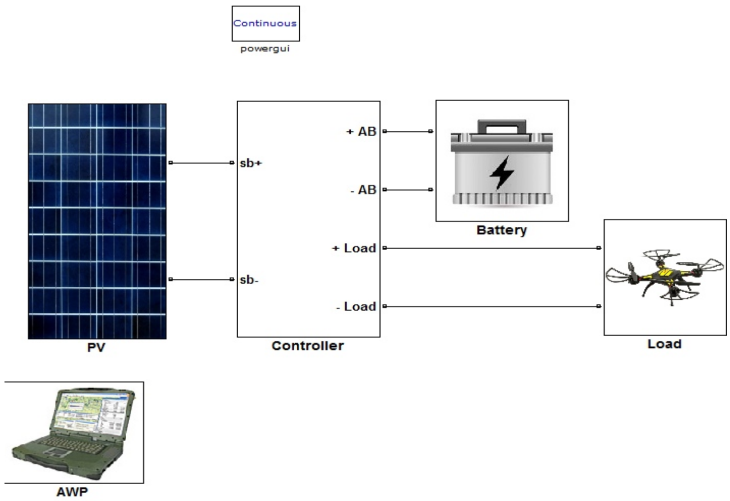

Figure 6. Model of photovoltaic installation.

Table 1. Rules of the fuzzy controller.

E↓ \ dE→	low	middle	high
low	low	low	low
middleL	midL	midL	low
middleH	midH	midL	low
high	high	midH	midL

4. Study of the influence of the fuzzy logic unit on the MPPT controller

To study the effect of a fuzzy logic unit on a solar photovoltaic installation, the following initial model parameters were set:

- Solar battery with a nominal voltage of Un=12V.
- Normal conditions: temperature 25°C, level of solar insolation W = 1000 kW/m^2, angle of rays incidence α = 90° (with the condition that the constant right angle is provided by the solar tracker).
- Consumer load is shutdown.
- The solar battery charges the storage battery with a nominal voltage of 9V.

The simulation results are presented in Figures 7 and 8 (a normal MPPT algorithm is highlighted in green; a fuzzy logic-based algorithm is highlighted in blue).

Figure 7 shoes that the use of the fuzzy logic block in the MPPT controller significantly increased the speed of finding the maximum power point, and also reduced the voltage fluctuations, which in turn neutralized the power fluctuations (Figure 8).

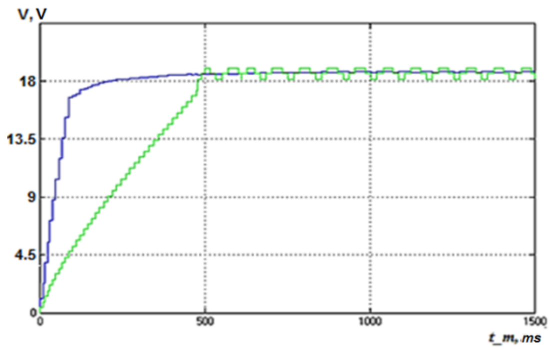

Figure 7. Voltage comparison of the modes of maximum power point tracking: a normal MPPT algorithm is highlighted in green; fuzzy logic-based algorithm is highlighted in blue.

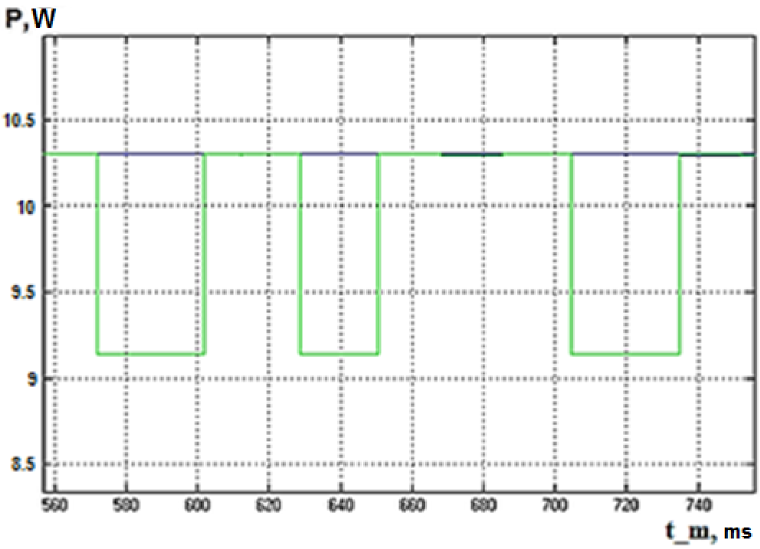

Figure 8. Power comparison of the modes of maximum power point tracking: normal MPPT algorithm is highlighted in green; a fuzzy logic-based algorithm is highlighted in blue.

5. Conclusion

In the course of this work, a power supply system for a solar battery-based autonomous station for an unmanned aerial vehicle has been developed. The effectiveness of the developed system was enhanced by using a solar tracker and MPPT charge controller with an adaptive fuzzy logic-based algorithm. The effectiveness of the MPPT 'disturb and observe' algorithm with adaptation was studied using simulation modeling. As a result of simulation modeling, it was proved that the use of MPPT technology increased energy production by 23%; introduction of a fuzzy logic-based algorithm in the MPPT controller significantly increased the speed of finding the maximum power point, and also neutralized voltage fluctuations, which in turn reduced power underproduction by 2%.

Acknowledgments

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