THE INCREASING OF PHOTOVOLTAIC POWER SUPPLY SYSTEM EFFICIENCY FOR THE MOBILE UNIT OF POLYMER WASTE PROCESSING INTO AN ALTERNATIVE TYPE OF FUEL

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2. Introduction

A very important task is to prevent plastic waste from entering natural ecosystems, as well as their recycling for reuse [1]. The production of fuel from plastic waste will not only help clean the planet of plastic waste, but will also save the planet's energy resources and reduce the negative impact on the environment from the process of oil production and refining [2].

The polymer waste processing mobile unit (PWPMU) of Obolon Oil (Ukraine) [3, 4] requires an autonomous power supply using photovoltaic technologies and a storage system for use directly at waste disposal sites, and sorting stations. This eliminates the need to transport the waste to recycling points and reduces recycling costs and the induced transportation air pollution.

Today, autonomous energy supply systems, which use renewable energy sources, are intensively studied, both theoretically and experimentally, and applied in different geographical parts of the world [5, 6]. The publications analyze the performance of autonomous power supply systems, taking into account the average hourly insolation of sunlight, ambient temperature and load power profile [7]. The mathematical models are developed to estimate the size, control and evaluate the efficiency of the autonomous power supply systems, which contain solar photovoltaic modules (PM), a diesel generator and rechargeable accumulator batteries [7-9]. In publications on autonomous power supply systems, there are no studies of the processes and methods to increase the efficiency of energy extraction from solar module, compensation of the peak (starting) load currents, balancing electrochemical capacitor cells, operating temperature control and multi-stage battery charge for longevity. All these scientific problems require in-depth research.

We propose the structure of the highly efficient autonomous power supply system for the PWPMU. It includes solar photovoltaic modules, rechargeable accumulator batteries, and electrochemical capacitor batteries, with smart model-based control technology. We developed and investigated the dynamic solar tracking system (DSTS) with optimized control of the PM in fog, clouds, heavy rainfall, and strong winds. The overall robust and optimal performance is achieved by using the improved control methods for DSTS. It will increase the PM productivity by up to 30% and reduce the land occupied by the PM.

1. Improving the efficiency of energy extraction from photovoltaic modules by tracking the sun position

The maximum energy can be received by the photovoltaic module from the sun when the panel of photocells is located perpendicular to the direction of solar radiation. Even small deviations (5 to 15 degrees) from the perpendicular orientation can reduce the generated power by 25 percent or more [10-12].

Thus, to obtain high efficiency of energy extraction from the photovoltaic module, it is necessary to implement a device for tracking the sun position, which can provide constant support of the angle between the solar module surface and the direction of solar radiation as close as possible to 90 degrees. Fig. 1 shows the process of tracking the sun position with the angle of 90 degrees [10, 11].

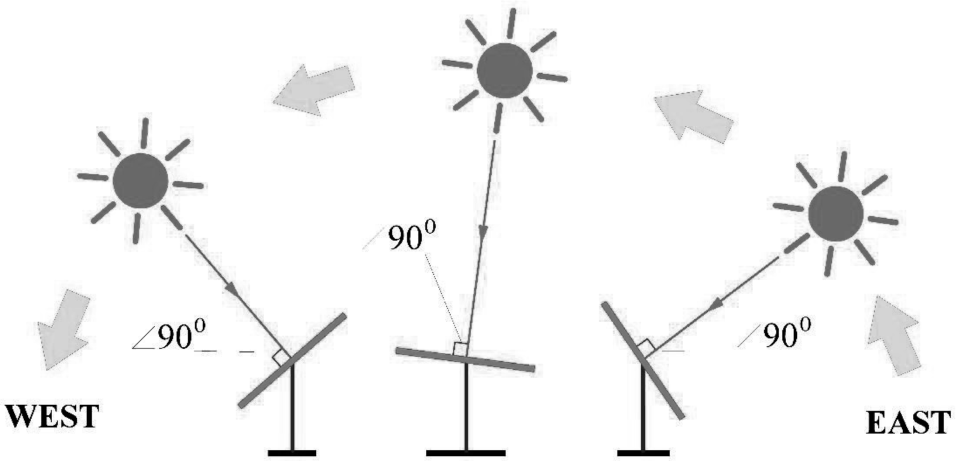

Fig. 1 shows the three optimal positions of the photovoltaic module for different times of the day. The arrows show the direction of the solar radiation.

The generalized block diagram of the device for tracking the sun position is shown in Fig. 2.

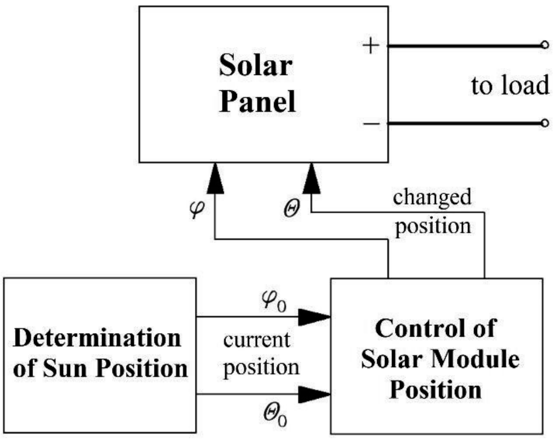

Fig. 2. Structure of sun tracking device

The device for tracking the sun position includes a unit for determining the sun position, which transmits to the control device the required values of the angles of azimuth φ_0 and zenith θ_0 of solar module. Then, the solar module position control device rotates to the appropriate angles φ (azimuth) and θ (zenith).

Characteristics such as tracking accuracy, the energy consumed by the sun tracking device, and the reliability of mechanical devices and structures are important in the development of a solar position tracking device. According to these characteristics, the basic conditions for the development of a sun position tracking device can be formulated as

$$\begin{cases} 90° - \alpha \to \min, \\ 90° - \beta \to \min, \\ W_T << W_{SM}, \end{cases} \quad (1)$$

where W_T - the energy consumed by the sun tracking device;

W_{SM} - energy produced by the solar module;

α - the angle of deviation from the perpendicular in azimuth;

β - the angle of deviation from the perpendicular to the zenith.

In addition, important characteristics are the weight and strength of the mechanical structure of the tracker. Increasing the mass of the structure leads to an increase in energy consumption for its rotation. At the same time, increasing the strength of the structure requires increasing its mass.

Among the electric elements of the tracker, electric motors consume the most energy. Therefore, to ensure high efficiency of energy extraction from solar modules, the calculation of electric motors requires special attention.

2. Development of new types of electric drives for turning the solar panel

In most electromagnetic stepper motors of linear and rotating types, the tangential component of traction force in the air gap is used according to the principle of operation [13]. This component is an order of magnitude lower than the normal component of the traction force of the lifting electromagnet.

In this work, the design of a linear stepper electric motor is proposed. Accordingly to the principle of operation, the motor uses the electromagnetic force of gravity between the inductor and the armature, and has a large length of movement.

The disadvantage of the known designs of electric motors is that the friction force of the brake pads must exceed the traction force of the traction electromagnets, which requires a large area of the brake pads. In addition, when operating in the positioning modes of the winding of the brake electromagnets are energized, which in terms of power loss is inefficient.

In the course of research, the design of the linear stepper electric motor which does not have the above-stated shortcomings and can be applied for turning of solar panels, is developed. The design is made in a cylindrical version.

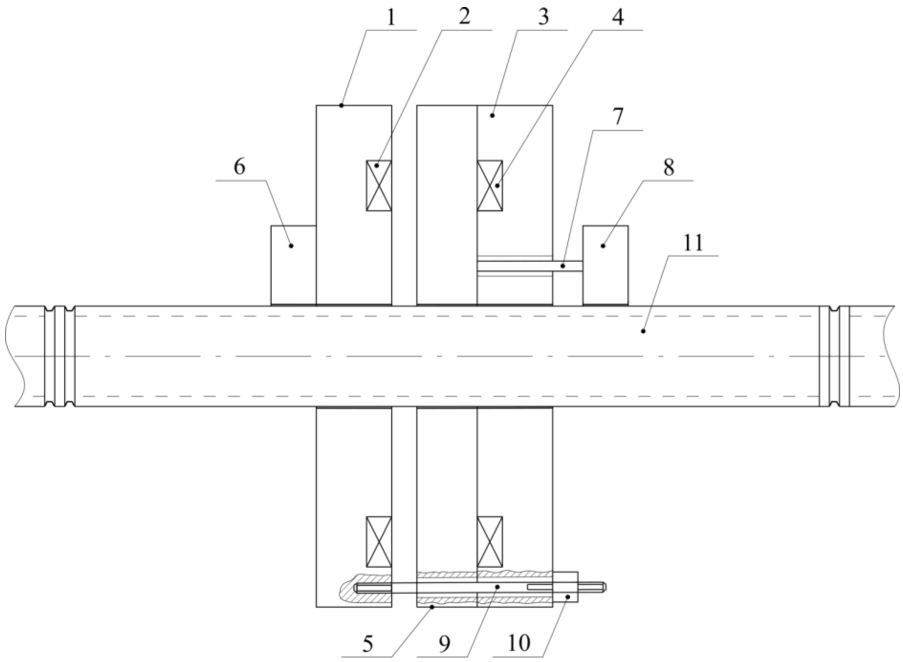

Fig. 3. The design of a linear step electromagnetic motor.

In the design (Fig. 3) the active part of the motor contains a traction electromagnet 1 with a winding 2, a traction electromagnet 3 with a winding 4, an anchor 5 and electromagnets-clamps 6 and 8.

The latch 6 is rigidly connected to the electromagnet 1, and the latch 8 by the rod 7 is connected to the armature 5. Each latch includes its own magnetic circuit, excitation winding, spring, which acts on the movable stopper.

The electromagnets 1 and 3 are connected by a pin 9. The pin 9 is screwed into the body of the electromagnet 1. The electromagnet 3 has the ability to move on the pin 9 to adjust the total air gap between the traction electromagnets and the armature 5. Adjustment is nut, which is rigidly connected to the electromagnet 3 and on which the limb is applied to establish the required size of the gap (movement step).

The moving part is a non-ferromagnetic guide - a rod (for example, stainless steel, bronze, etc.). In the simplest case, when the working gap (movement step) is not adjustable, the rod 11 has transverse grooves with a distance between them equal to the movement step, and the width corresponds to the size of the stopper clamps 6 and 8.

To be able to adjust the movement step on the guide rod, several longitudinal rows of non-through holes are made with each for its series of center-to-center distance between the holes (movement step). Then, to change the movement step, a corresponding step (gap) is set between the electromagnets 1, 3. The armature 5, and the guide 11 are attached to the drive mechanism so that in front of the stoppers 6, 8 there was a corresponding number of holes.

The engine works as follows. Let the rod guide move to the left relative to the fixed traction electromagnets. In this case, the electromagnet of the latch 8 is de-energized and its stopper engages with the rod 11, and power is supplied to the electromagnet 1 and the electromagnet-latch 6 (the stopper of the latch is disengaged from the rod 11). Then the armature 5 is attracted to the electromagnet 1 and moves the rod 11 by the amount of air gap between the electromagnet and the armature.

The electromagnetic force of gravity is determined by the formula:

$$Q = \frac{B_0^2}{2\mu_0} S \tag{2}$$

where B_0 is the magnetic induction in the air gap; μ_0 is the magnetic constant; S is the total area of the pole pieces of the cylindrical electromagnet.

Next, the electromagnet latch 6 is turned off and its stopper engages with the rod 11, and the electromagnet latch 6 is connected to the power supply with a time delay and its stopper is disengaged with the rod 11. Then power is supplied to the electromagnet 3 and the armature 5 is attracted to it. Now the latch 8 is de-energized and the system is ready for a new step.

7) The anchor movement time is described by the next expression:

$$t_n = \sqrt{\frac{2m(\delta_0 + \delta_f)}{Q_H}}, \tag{3}$$

where m is the mass of the moving part; δ_0 - the initial value of the air gap; δ_f - the final value of the air gap (technological gap).

Then the total time of the electromagnet operation

$$t_{cnp} = \tau \ln \frac{1}{1 - \frac{I_p}{U/R}} + \sqrt{\frac{2m(\delta_0 + \delta_f)}{Q_H}}. \tag{4}$$

8) If at a certain resistance R and current I_p the supply voltage exceeds the allowable range, you must choose a larger wire diameter d_w, calculate the number of turns, winding resistance, current I_p and check $U = I_p \cdot R$.

For example, if you increase d_w twice, the number of turns will decrease 4 times (the length of the winding wire will also decrease 4 times), and the area of the wire will increase 4 times. Therefore, the resistance of the winding will decrease 16 times, and the current Ip will increase 4 times. Then the required voltage will decrease 4 times.

The energy for one working cycle (for one step):

1) The energy for time t_p:

$$\begin{aligned} W_p &= \int_0^{t_p} i^2 R dt = R \int_0^{t_p} \left[\frac{U}{R} (1 - e^{-t/\tau}) \right]^2 dt = \frac{U^2}{R} \int_0^{t_p} (1 - 2e^{-t/\tau} + e^{-\frac{2t}{\tau}}) dt = \\ &= \frac{U^2}{R} (t_p - 2(-\tau)(e^{-\frac{t_p}{\tau}} - 1) + (-\frac{\tau}{2})(e^{-\frac{2t_p}{\tau}} - 1) = \\ &= \frac{U^2}{R} \left[t_p + 2\tau e^{-\frac{t_p}{\tau}} - 2\tau - \frac{\tau}{2} e^{-\frac{2t_p}{\tau}} + \frac{\tau}{2} \right] = \frac{U^2}{R} \left[t_p - 1{,}5\tau + 2\tau e^{-\frac{t_p}{\tau}} - 0{,}5\tau e^{-\frac{2t_p}{\tau}} \right] \end{aligned} \tag{5}$$

2) The energy during the time t_p provided that $I = I_p = const$ (considering $t_F < t_p$):

$$W_F = I_p^2 R t_F. \tag{6}$$

3) The energy in one step:

$$W_{st} = W_p + W_F. \tag{7}$$

3. Power supply system based on solar photovoltaic modules with sun position tracking

Based on the results of the research, a structural diagram of the power supply system based on photovoltaic modules with tracking the sun position is built with the possibility of electrical energy accumulation by supercapacitors and batteries [14].

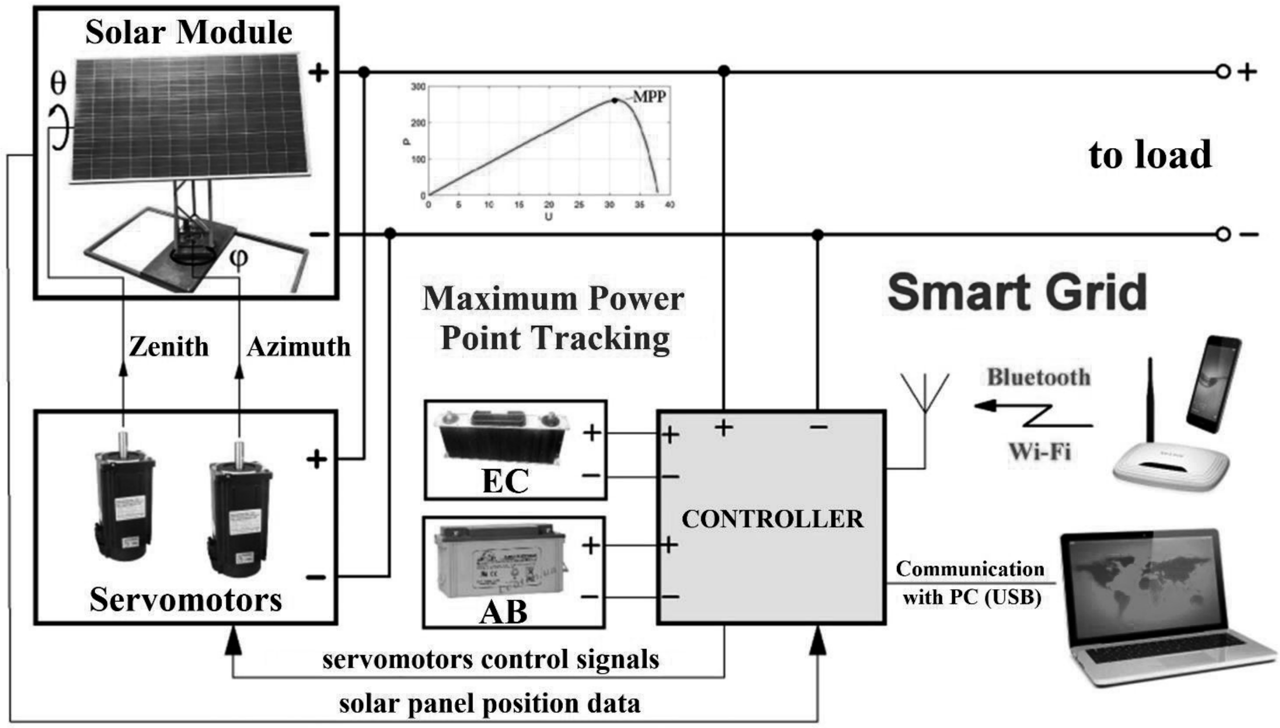

Fig. 4. Block diagram of the power supply system based on photovoltaic modules with sun position tracking

The developed system can be connected to the Internet using wired and wireless technologies. It is possible to integrate the system with a PC via a USB port for additional settings and measurements.

The connection of additional energy storage devices based on batteries and supercapacitors is provided. It can significantly increase the efficiency of tracking the maximum power point of the solar module in conditions of long-term high-power loads.

Fig. 5. The research of the developed solar power supply system

The proposed power supply system (Fig. 5) can be used in mobile waste recycling units. The use of solar energy can significantly reduce the negative impact of the unitss on the environment by reducing emissions of carbon compounds and greenhouse gases. Solar trackers can be deployed on the roof of a mobile unit or near it. The power supply system allows remote control and adjustment of parameters according to the operating conditions of the mobile waste recycling unit.

4. Conclusions

As a result of research, the new methods are developed for tracking the maximum power point using electrochemical capacitors, battery and solar tracker control, which provide maximum light flux and operation of the solar module at the point of maximum power in different weather conditions. To implement the development, new methods of the theory of fractional calculus and nonlinear dynamics are used, which make it possible to increase the accuracy and adequacy of the used models. In the course of researches of converter circuits, the analysis of current source energy harvesting methods with nonlinear parasitic elements is performed.

An experimental study of the maximum power point for the solar module was performed. The mode of the maximum power point is supported by the inverting converter with the filling factor which is defined from the proposed model. The experiments show that the proposed model provides the values of the fill factor of the inverter converter, which practically correspond to the values obtained experimentally in the mode of the point of maximum power.

In the process of research, the main scientific results were obtained as follows:

1. The method of two-coordinate tracking of the sun trajectory with dynamic positioning of the solar module working surface perpendicular to solar radiation and appropriate control of the tracker in difficult weather conditions (fog, clouds, heavy precipitation, strong wind);

2. The method of electrical energy harvesting from the solar module using electrochemical capacitors, which in comparison with analogues works effectively even in rapidly changing weather conditions as well as unlike works with sufficient accuracy, can determine the point of maximum power without power fluctuations.

3. The design of a linear step electromagnetic motor is proposed. The electromagnetic motor energy losses are reduced due to the improvement of the stopping mechanism.

An additional advantage of using electrochemical capacitors (over existing analogues) in the device of tracking maximum power point is the ability to obtain a large instantaneous output power (power gain effect) due to the low internal resistance and high discharge currents.

Due to the scientific and applied solutions based on tracking the maximum solar radiation and the maximum power point of the photovoltaic module, the developed power supply system allows to obtain a significant increase in the efficiency of energy extraction from photovoltaic modules and provides a significant reduction of harmful effects on the environment from plastic waste processing units.

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