Conference Paper

The Efficiency Improvement of the Stand-alone Photovoltaic Power Systems

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Abstract

An automated solar tracking system was developed to improve the power generation efficiency of standalone photovoltaic systems. In the system, the discrete-continuous tracking with the adjustable discrete pitch was implemented. In addition, the technique and the algorithm of the standalone photovoltaic power system control was developed for the positioning. The technique provides the minimization of the power consumption when tracking and controlling and supports tracking accuracy adopting it to actual illumination changes.

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Received: 10 February 2018
Accepted: 14 April 2018
Published: 7 May 2018

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1. Introduction

The development of an efficient standalone photovoltaic power system (SPVS) with the power of 3– 5 kW is based on the development of an automated control system (ACS) which provides through the solar tracking the maximum efficiency of the photovoltaic (PV) cells as well as the minimization of the power consumption when tracking and controlling.

Based on the above, the following problems of the automated control development were set up. The first problem – the two-coordinates solar tracking with the predefined accuracy is solved in the following way: by a non-linear algorithm for solar tracking; by increasing the statistical accuracy in positioning using the stepper motor (SM); by using the solar tracking controller, a two-coordinates solar sensor, a two-coordinates electromechanical actuator with the SM. The second problem – the minimization of the power consumption by the electromechanical actuator with the SM when tracking is solved as follows: by switching from the continuous solar tracking to the discrete-continuous tracking with the variable pitch and by cutting the SM power consumption when there is no relocation [1]. All the above considered, the flowchart of the ACS of a SPVS was developed (fig.1).

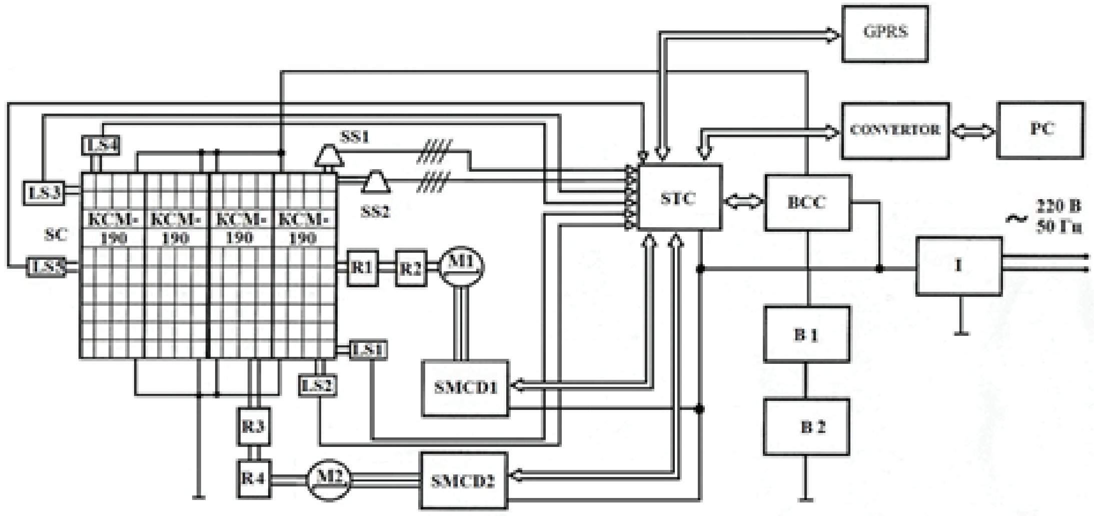

Figure 1: The flowchart of the automated control system for a standalone photovoltaic power system.

The flowchart abbreviations: SC – a solar cell (which combines several photovoltaic panels); STC – a solar tracking controller; SMCD1, SMCD 2 – stepper motor control drivers; SS1, SS2 – solar sensors in azimuth and elevation; LS1–LS5 – limit switches; M1, M2 – stepper motors; R1–R4 – reduction gears; BCC – a battery charge controller; I – inverter; B1, B2 – batteries, CONVERTOR (I - 7561 type) – a communication device between the computer and controller via RS 485 channel; GPRS – a communication unit with GPRS. Increasing the tracking accuracy of the solar cell results in the increased power consumption by the electromechanical actuator. While the pitch extension in tracking leads to loss in the tracking accuracy. It is apparent from the foregoing that the more intensive the illumination, the shorter the pitch. E.g., the 1 degree pitch is under the maximum illumination and when the illumination decreases by five times, the pitch extends to 3 degrees. Figure 2 presents the relation of the discrete pitch change to the level of illumination.

2. Development of a two-coordinate tracking system

For the tracking ACS the two two-coordinates solar sensors were developed [2, 3]. The sensors are of the four-face truncated pyramid shape, where four photocells are set at the side faces, the fifth photocell is set on the sensor base and there is one more site for the sensor on top for the sixth photocell.

The tracking algorithm using the developed solar sensor runs as follows. Firstly, the current in photocells set at the sensor faces (I_1– I_6) is measured. Then, the average current at the opposite faces (I_{p1}, I_{p2}) is calculated as well as the relative current

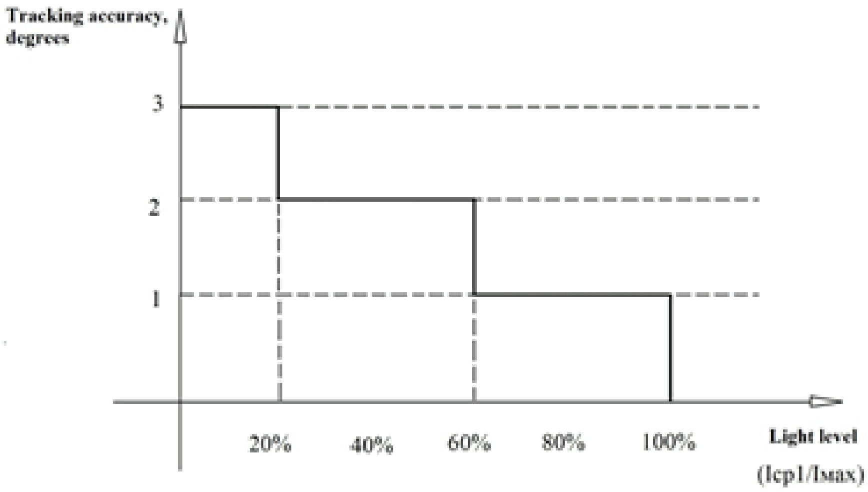

Figure 2: The discrete pitch change.

errors at the opposite faces of the sensor ($\Delta I_1 = \frac{I_1 - I_3}{I_{p1}}$, $\Delta I_2 = \frac{I_2 - I_4}{I_{p2}}$, the frame with photovoltaic cells moves to a certain position according to the relative error. When $\Delta I_1 > 0$, there is a path lag and then, the relocation should be done when the relative error ΔI_1 exceeds the predefined value, which is defined as a dead zone K_{3H} ($\Delta I_1 \geq K_{3H}$). Here, the azimuth transition is performed generating the preset angular positioning path.

If $\Delta I_1 < 0$, there is a path leading in azimuth, so the movement of the frame with photovoltaic cells is not required. If $\Delta I_1 \leq K_{3H}$, the frame with photovoltaic cells is targeted at the sun with the specified accuracy. If the condition $I_1 = I_3 = I_5$ is met, there is no relocation and the photovoltaics frame is in the shadow.

If $\begin{cases} I_5 > I_1 \\ I_5 > I_2 \\ I_5 > I_3 \\ I_5 > I_4 \end{cases}$, it means that the sun shines from the opposite side of the frame, so the azimuth turn in to the reference position is required. The azimuth turn of the frame is performed under the highest possible speed of the stepper motor (under the highest developed torque). When approaching to the predefined position (when the error is reduced up to 0.5 degrees), the braking is performed under the lower speed and acceleration. When the relative error ΔI_2 exceeds the predefined value, which is defined as a dead zone $K_{3H}(\Delta I_2 \geq K_{3H})$, the frame with photovoltaics cells to be moved up. Then, the movement path is generated for the preset angle. If $\Delta I_2 \leq -K_{3H}$, the photovoltaics frame to be moved down, and here, the movement path is also generated for the preset angle. If $-K_{3H} < \Delta I_2 < K_{3H}$, the photovoltaics frame is not moved, it is in the shadow or accurately directed to the sun. The discussed processes are performed by the position controller (PC). It is a relay unit with the variable dead zone value calculated by the formula

$$U_{BbIXp\pi}=\begin{cases}-U_{\max} \text{ if } U_{BX}<-K_{3H}\\ 0 \text{ if } -K_{3H}<U_{BX}<K_{3H}\\ +U_{\max} \text{ if } U_{BX}>K_{3H}\end{cases},$$

where $U_{BbIX\,p\pi}$ – output signal; U_{BX} – input signal; K_{3H} – the dead zone coefficient for the relay element.

The dead zone coefficient K_{3H} could be defined based on the 5–10% tracking accuracy. However, with the 1 degree relocation and the 5–10% of the dead zone coefficient the sensitivity of the solar sensor of 0.05–0.1 degrees should be provided, which is difficult to carry out in solar sensors. It was proposed to vary the dead zone value with regard to the transition pitch (table 1). Figure 3 presents the flowchart of the tracking system (for one coordinate) considering the tracking algorithm and the data from table 1.

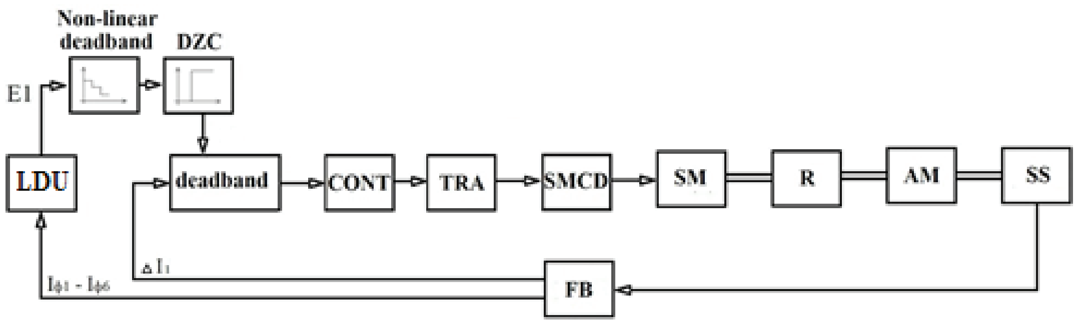

Figure 3: The tracking flowchart.

While the frame moves, the relocation in a predefined angle can be completed ahead of or behind the end time of the calculated path. So, the following path correction algorithm was proposed: as soon as the relocation error value is lower than the dead zone value (if the positioning is not completed), the relocation will stop by switching off the SM drivers.

If the positioning is completed, but the relocation error is higher than the dead zone value, the correction of the frame position should be done by introducing the additional relocation parameters. It was proposed to introduce the correction path, which is equal to 0.5 degree by position. The correction path tasks can be set several times in the tracking microcycle up to the positioning error compensation. The presented

Table 1: Variation of the dead zone coefficient.

The preset resolution in the solar tracking mode of the photovoltaic cell, degree	1	2	3
Relocation accuracy, %	25	25	25
Current illumination, % of the maximum value	100–60	60–20	20–0
The dead zone coefficient, degree	0.25	0.5	0.75

above algorithm considerably reduces the system overshoot on positioning. The path correction algorithm is presented in Figure 4.

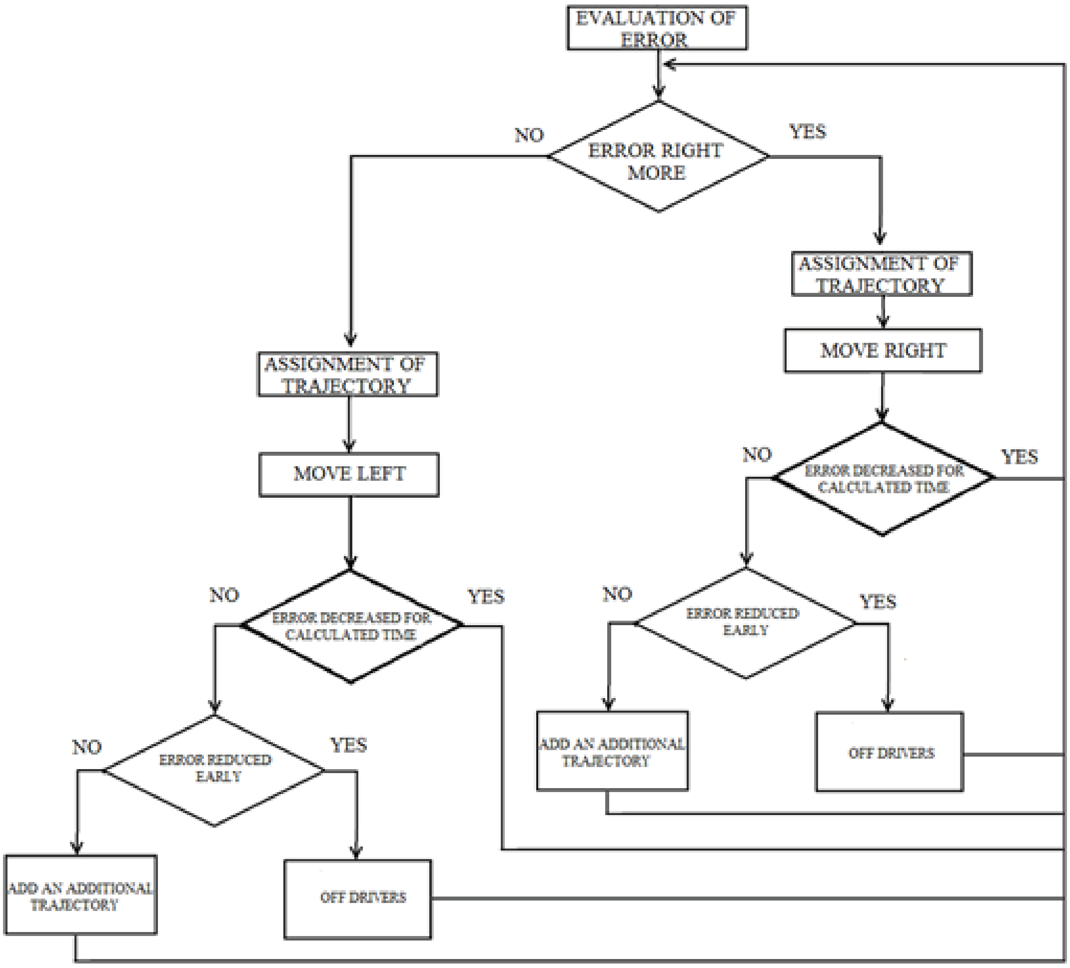

Figure 4: The path correction algorithm.

3. Development of the system model in MatLab Simulink

Figure 5 displays the model of the tracking system developed in *MatLab Simulink*. This model considers the special feature of the relay controller with the variable dead zone;

the positioning path generation unit; the stepper motor transfer function considering the frame inertia; the dead zone of the position sensor. The SM model adjusted to the current amplitude in the motor phases is shown in Figure 6. The transition characteristics for the 2 degree (Figure 7,*a*) and 3 degree relocation (Figure 7,*b*) are presented in Figure 7.

It was proposed to increase the SM current amplitude in the positioning mode (to increase the starting current amplitude up to 1,5 I_H), then, after breaking the initial dry friction, the SM current amplitude could be decreased (to reduce the operational current down to 0,75 I_H). It provides the fault removal at the SM start-up as well as the reduction of power consumption by the SM during the tracking.

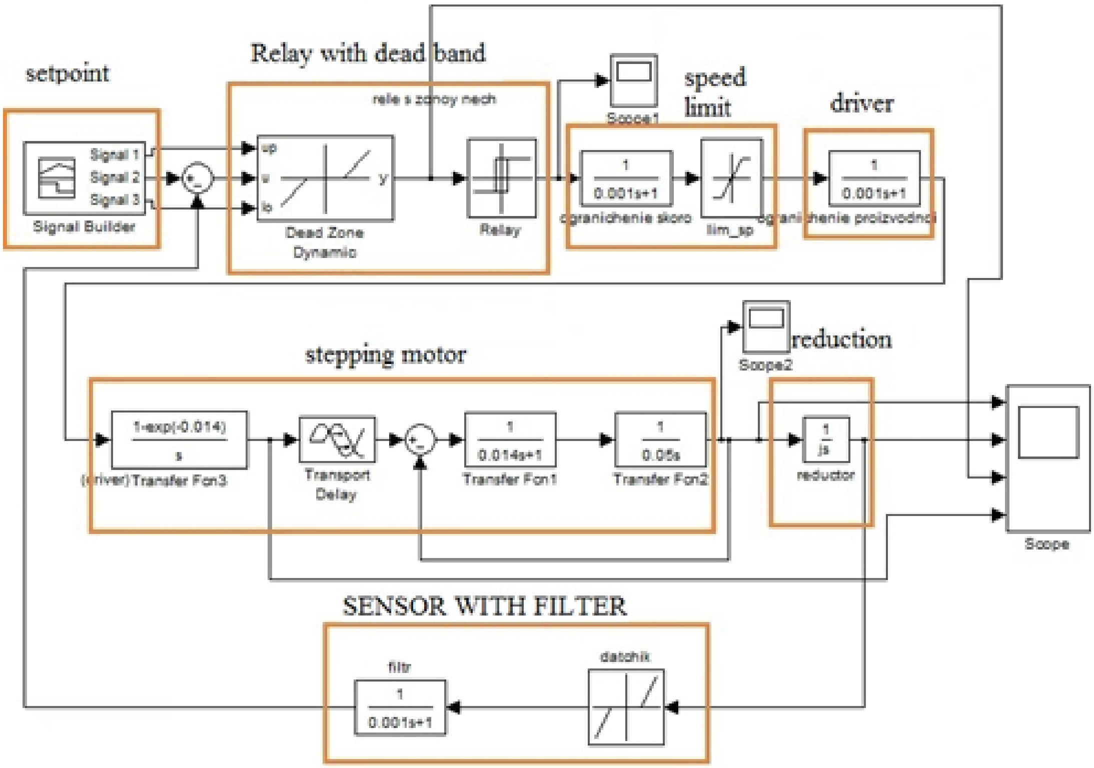

Figure 5: The tracking system model.

4. Results

The increase of the starting current amplitude should be performed under the positive acceleration value (Figure 7). The calculations demonstrated that with regard to some terms, the proposed non-linear positioning system provides the reduction of the power expenses on relocation from 13% to 25% compared with the symmetric positioning algorithm and permanent amplitude of the SM [4].

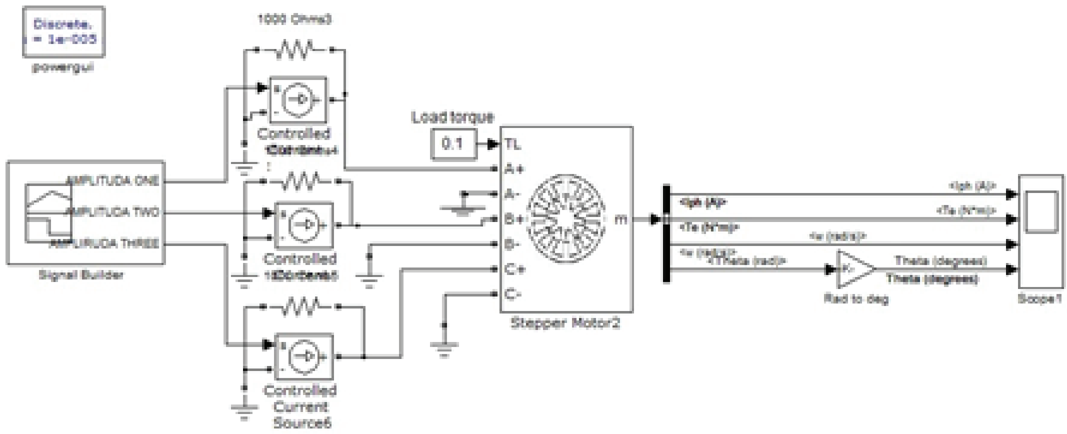

Figure 6: The SM model with the current amplitude accounted.

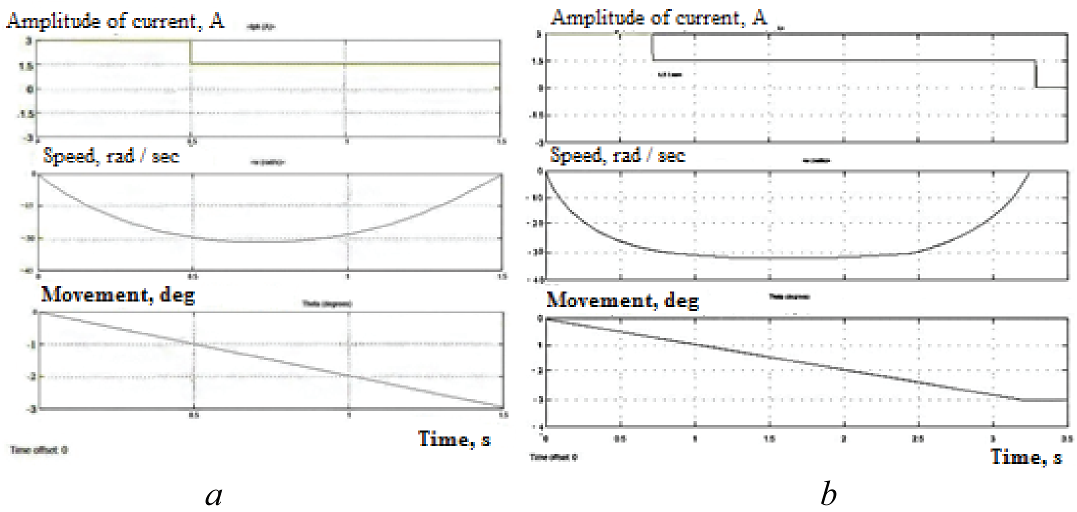

Figure 7: Transition process.

To reduce the power consumption by the SM under the PV discrete continuous solar tracking it was proposed to switch off the SM drivers after completing the PV cell relocation to prevent the power consumption while there is no movement. The worm gears were used to prevent the frame self-motion without the predefined relocation task. In a mechanical system, it is proposed to use the worm gear with the reduction rate up to 10 (to provide the maximum performance), and pass the rest of the reduction rate to the parallel-shaft reduction gear. The evaluation of the consumed power on standby for two stepper motors (of the SM 5D type) demonstrated that the power reached the value of 1–1.7 kW/h. That is commensurable to the performance of two KSM-190 PV cells operating 3 – 4.8 hours per day under maximum illumination [5–7].

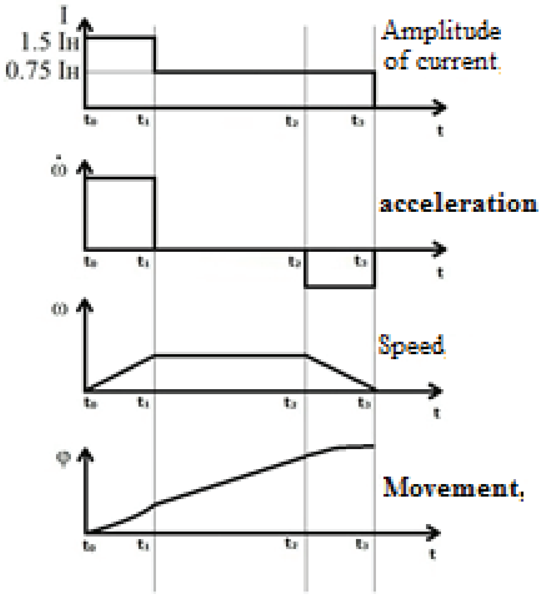

Figure 8: The positioning diagram.

5. Conclusion

1. The development of the efficient SPVS is performed on the following base:

- the discrete continuous solar tracking of the PV cell with the controlled pitch in the actual illumination function;
- the development of the maximum speed relocation on the under the discrete continuous tracking (the positioning mode);
- the nonlinear positioning development;
- the switching off the SM drivers after the relocation was completed.

2. To provide the predefined tracking accuracy of the SPVS, the following algorithm was proposed:

- a relay controller with the nonlinear characteristics of the dead zone is used in the positioning control circuit;
- the relocation mode is switched off when the positioning error is lower that the dead zone value;
- the correction relocating path (0.5 degree) is introduced if the positioning error is higher than the dead zone value, and the positioning is completed.

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