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Determination of the tracking system's trajectory considering the electric drive losses

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Abstract. This paper deals with optimal sun-tracking of a photovoltaic system considering the electric drive losses. The Sun tracking photovoltaic system assures that the highest possible share of the available solar radiation reaches the surface of the photovoltaic modules. The electric drive which enables tracking is considered as the loss of the energy produced in the photovoltaic system. The maximum of the energy produced in the photovoltaic system is achieved by the continuous tracking of the photovoltaic system. Since the electric drives are determined by constant speed and time, and angle quantization the maximum of the energy produced can only approximate. The results presented in this paper show, that the optimal trajectories can help to increase the electrical energy production within photovoltaic systems by sun tracking.

Key words

Photovoltaic system, tracking system, electric drive, optimization.

1. Introduction

European union‘s directive upon increasing the production of electricity from the renewable energy till 2020 has contributed to the growth of photovoltaic (PV) systems connected to the electric grid. The main elements of the PV systems are solar modules which convert the solar radiation directly into the electricity. The efficiency of this conversion depends on the solar radiation that reaches the surface of the solar cells, the temperature of the solar cells, the impedance matching between the solar modules and dc/dc converters, and the quality of the inverters.

Solar radiation that reaches the earth's surface, cannot be influenced by the control of the PV system, since it depends primarily on the conditions in the atmosphere. However, the total solar radiation that reaches the surface of the solar cells in the form of direct and diffuse radiation, can be influenced by a proper control of the sun-tracking system.

The sun tracking systems are mechatronic systems, consisting of mechanics, electric drives and information technology [1]. The authors in [2], [3] deal with single-axis tracking system, while the ones in [4], [5] deal with two-axis tracking system.

This paper presents a new method which maximizes the efficiency of the solar energy conversion in PV systems. The goal is to determine those trajectories of the PV module tilt angle and azimuth angle, which change the position of the PV modules in such a way that the production of electric energy in the given time interval of the observation reaches its maximum. To find its solution a stochastic search algorithm called Differential Evolution [6] is applied.

2. Sun tracking system

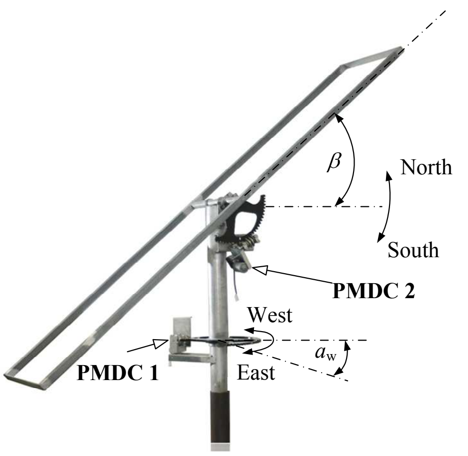

Fig. 1. Two-axis sun tracking system with changing azimuth angle a_w and tilt angle β.

The discussed two-axis tracking system is shown in Fig. 1. It follows the path of the sun in two axes which are mechanically decoupled and move independently from each other. In the discussed two-axis tracking system a_w is the azimuth angle, while β is the tilt angle. The lower electric drive (permanent magnet dc - PMDC 1), shown in Fig. 1, moves the PV panels from East to West while the upper electric drive (PMDC 2) moves the PV panels from North to South. The gear ratio for changing the tilt angle β

is 12:40:15, while the gear ratio for changing the azimuth angle a_w is 12:40:52.

After the start-up, the PMDC motors operate at constant the angular speed as it is shown in Figs. 2 and 3. For each test, the energy consumption in the sun tracking system $E_c(t)$ is calculated by (1), using the measured voltage $u(t)$ and current $i(t)$.

$$E_c(t) = \int_0^t u(\tau) i(\tau) d\tau + E_C(0) \tag{1}$$

where $E_c(0)$ is the initial condition of the energy consumption.

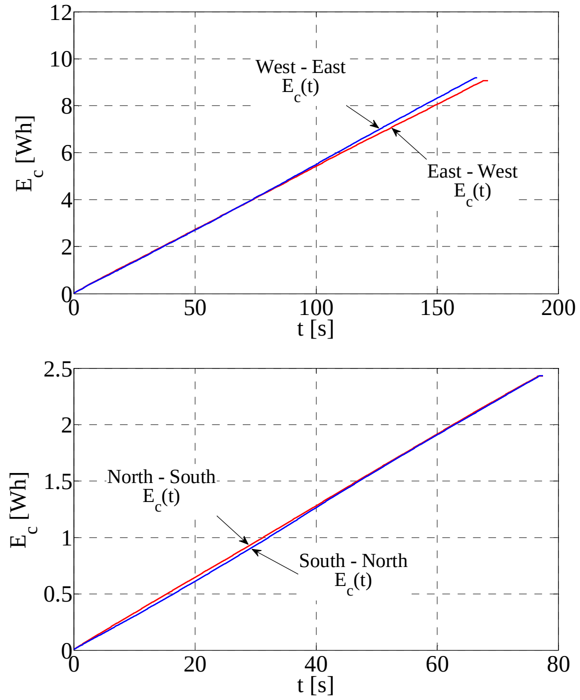

Fig. 2. Measured energy consumption $E_C(t)$ of two-axis tracking system.

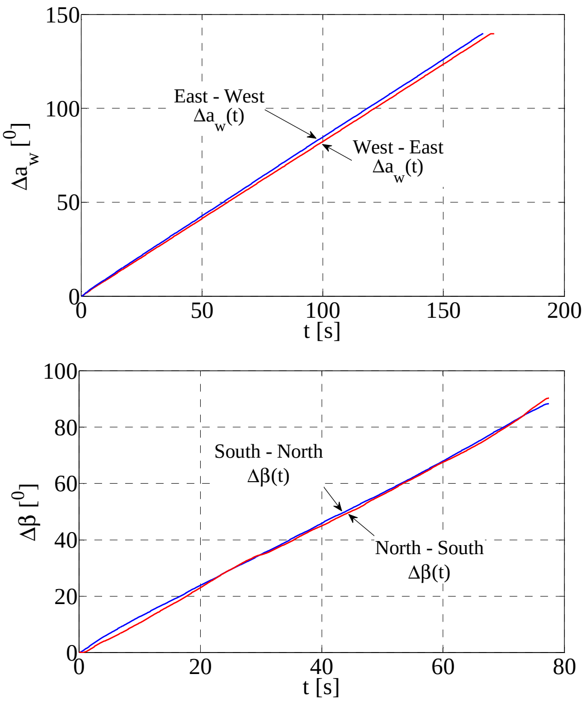

Fig. 3. Measured tilt β and azimuth a_w angles of two-axis tracking system.

Fig. 2 shows the time behavior of the measured PMDC energy consumed $E_c(t)$.

Fig. 3 shows the corresponding time-dependent changes of the measured azimuth angle $a_w(t)$ and tilt angle $\beta(t)$.

Fig. 4 shows the characteristics $E_C(\Delta a_w)$ and $E_C(\Delta\beta)$, which represent the energy consumed within the sun tracking system, in order to change the azimuth angle for Δa_w and the tilt angle for $\Delta\beta$. They are given for the increasing and decreasing angles a_w and β.

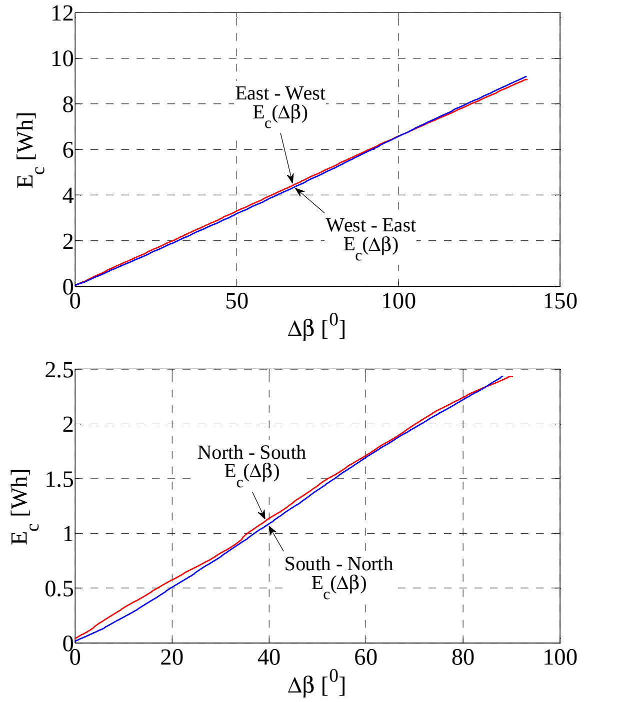

Fig. 4. Measured characteristics of energy consumption $E_C(\Delta\beta)$ and $E_C(\Delta a_w)$.

3. Sun tracking system's trajectories determined by Differential evolution

The authors in [7-9] have presented the different sun tracking algorithms which should maximize the energy produced in the PV systems considering the consumption of the tracking system. These intuitive algorithms are based on the maximal change of the angle and the operating time of the tracking system.

This section presents the procedure for determining those trajectories of the tilt angle β(t) and the azimuth angle $a_w(t)$, which give the maximum of the energy produced in the PV system, considering the energy consumption in the sun tracking system. The energy is consumed for changing the tilt and the azimuth angle during the day and to move the system in its initial position at the end of the day. The optimization goal is the maximum of the energy produced in the PV system considering the sun tracking system consumption. The optimal trajectories are determined by the Differential evolution DE [6].

DE is a direct search stochastic algorithm capable of solving the global optimization problems subject to the nonlinear constraints. It operates on a population of candidate solutions and does not require a specific starting point. The population is of the constant size *NP*. In each iteration, a new generation of solutions is created and compared to the population members of the previous generation. The process is repeated until the maximum number of generations G_{max} is reached.

The interaction between the DE and the procedure used to evaluate the objective function is schematically shown in Fig. 5.

The driving PMDC motors can only be switched-on and -off, which means that after the start-up they run at constant the speed. In this way the tilt and the azimuth angles can be changed causing the energy consumption according to the characteristics shown in Fig. 4. Thus, the trajectories of the tilt angle β and the azimuth a_w are functions changing in steps. The height of the individual step changes $\Delta\beta$ and Δa_w as well as the time between the two changes of the individual angles Δt_β and Δt_{aw} are determined in the optimization procedure. The objective function q is defined by (2):

$$q = E_{ideal} / \left(E_{PV} - E_c\right) \qquad (2)$$

where E_c is the electrical energy consumed by moving the tracking system, as shown in Fig. 4, whilst E_{PV} is the electrical energy produced within the PV system. The interval of observation is 24 h on the specific day of the year.

4. Results

The model used in the optimization procedure is confirmed through the comparison of measured and calculated power of a fixed PV system with the tilt angle 23°.

All results presented in this section are given for the PV system with the active surface of 15 m2 and the coordinates 46°33' N and 15°39' E. The trajectories of the tilt β_{opt} and the azimuth $a_{w\ opt}$ angle determined in the optimization process are shown in Figs. 6 and 7, while Fig. 8 shows the corresponding power of the PV system with the sun tracking P_{opt} and the power of the fixed PV system P_{fix}. The fixed PV system is oriented to the South and has the tilt angle β=50°. All results are given for the 172th day in the year. The Figs. 6 to 8 are given for the tracking system consumption presented in Fig. 4 and the PV system efficiencies η=9,8 % respectively.

As it can be seen from the results, shown in Figs. 6 to 8, the optimization process determines the optimal trajectories of the tracking system according to the input data. The optimal trajectories of the tracking system depend on the efficiency of the PV system and the tracking system consumption.

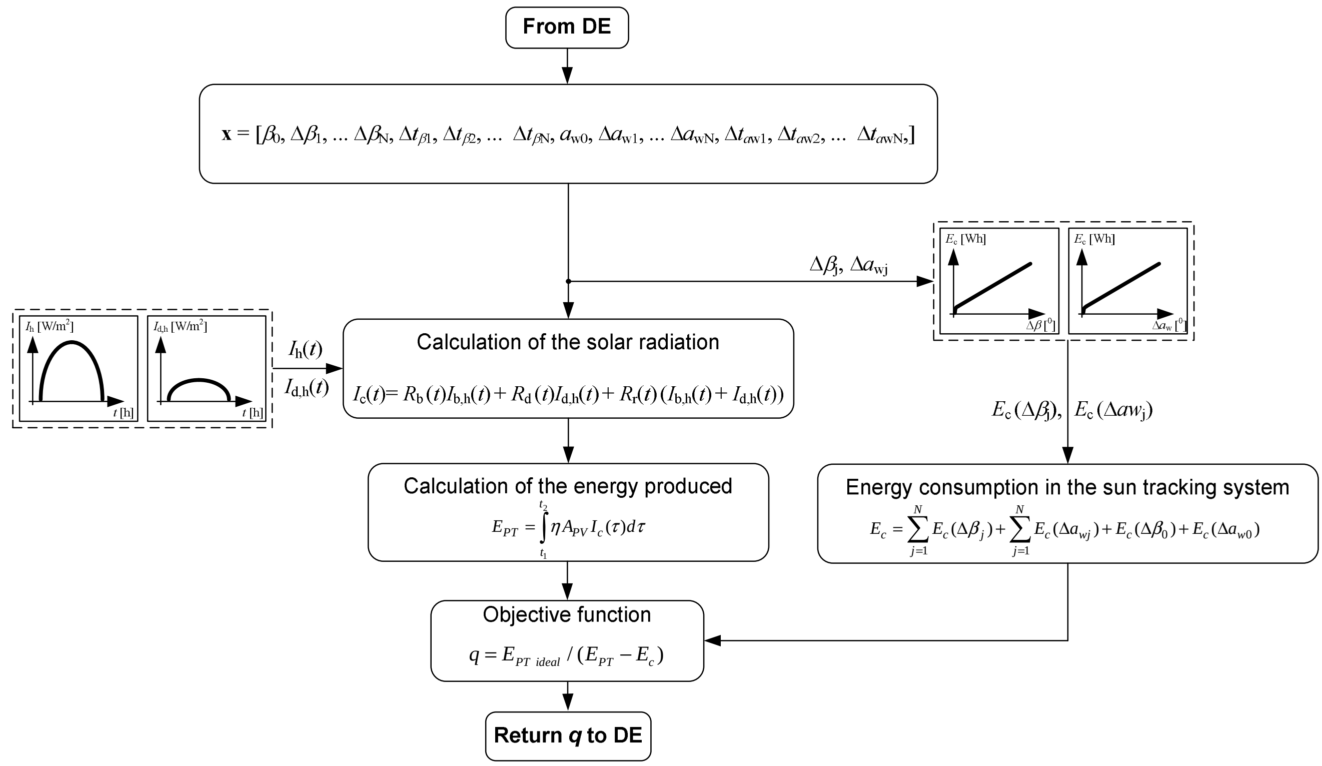

Fig. 5. Interaction between the DE and procedure used to evaluate the objective function.

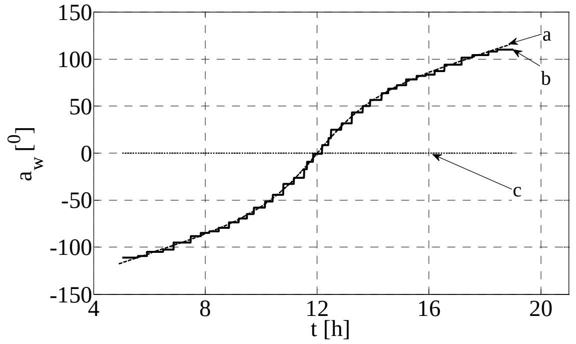

Fig. 6. Calculated results for summer day: the azimuth angle a_w given for the continuous sun tracking a, tracking with the proposed method determined trajectories b, and the system with constant tilt and azimuth angle c.

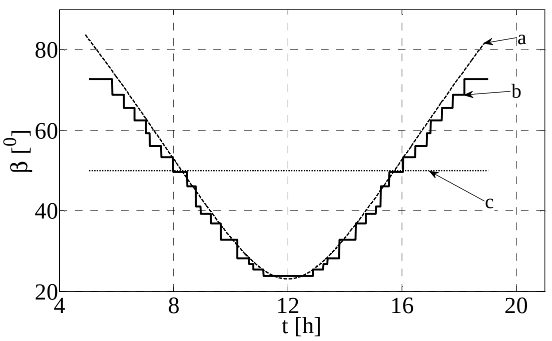

Fig. 7. Calculated results for summer day: the tilt angle β given for the continuous sun tracking a, tracking with the proposed method determined trajectories b, and the system with constant tilt and azimuth angle c.

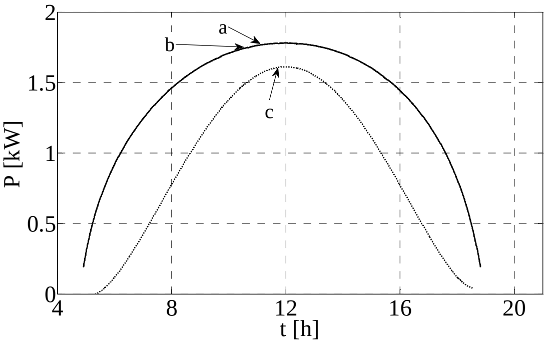

Fig. 8. Calculated results for summer day: the power of the PV system given for the continuous sun tracking a, tracking with the proposed method determined trajectories b, and the system with constant tilt and azimuth angle c.

5. Conclusion

This paper proposes a new method for prediction of the time dependent solar radiation on a tilted surface. It is applied in the new procedure for determining the tilt and azimuth angle trajectories, which assures the maximum energy production in the PV system, considering the energy consumed in the tracking system. The proposed method is general and gives the optimal results for the applied solar radiation prediction and the tracking system model. Generality of the proposed method remains even in the case when the applied tracking system model and the prediction of the solar radiation are replaced with the more advanced ones.

The results presented in the paper show that the new procedure for determining the optimal trajectories of the tracking system has increased the efficiency of energy production in the PV system for 10–45%. However, the efficiency increase depends on the location of the PV system as well as on the time and day in the year.

These drawbacks could be eliminated with a maximum efficiency sun tracking system using sky-monitoring. Based on the prediction of clouds' movements and the tracking system's energy consumption, the trajectories of the tilt and azimuth angles could be determined, in order to reach maximum energy gain even during cloudy days.

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