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USPOREDBA PROIZVODNJE FOTONAPONSKIH SUSTAVA U RAZLIČITIM REŽIMIMA RADA

COMPARISON OF PV SYSTEMS IN DIFFERENT MODES OF OPERATION

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Izvorni znanstveni članak

Sažetak: *U današnje vrijeme fotonaponske elektrane u Hrvatskoj ubrzano rastu zbog državnih poticaja u fotonaponsku proizvodnju energije. Takvo stanje tržišta omogućava investicije bez obzira na efikasnost sustava s obzirom na relativno velike cijene otkupa energije. U skoroj budućnosti očekuje se da cijene neće biti toliko visoke pa će svako unaprjeđenje biti od velike koristi ukoliko doprinese povećanju proizvodnje električne energije sustava. Jedan od načina za povećanje proizvodnje fotonaponskog modula/elektrane je uvođenje jednoosnih ili dvoosnog usmjerivača (trackera). U ovom radu uspoređuju se specifične karakteristike za različite režime rada, te se mjerena proizvedena energija uspoređuje za svaki režim rada sa fiksnom instalacijom u urbanoj sredini.*

Ključne riječi: *fotonaponski panel, proizvodnja energije, usmjerivač*

Original scientific paper

Abstract: *In present time PV plants in Croatia are expanding rapidly due to state incentive on PV energy production. Such state of market enables investiture regardless of energy efficiency since prices of energy are very high. In near future prices will not be so high and every improvement will be valuable if it can provide additional energy production. One way of increasing energy production of PV module/plant is implementation of single or dual-axis tracking systems. In this paper some specific characteristics were compared for different PV module modes of operation, and measured energy production is compared for every mode of operation with fixed instalation in urban surroundings.*

Key words: *PV module, energy production, automated tracking system*

1. INTRODUCTION

Fixed installation of PV systems is simplest and cheapest form of PV plant construction. Although it has low price at the beginning, this will always turn out as the most expensive mode of operation as in [1], [2] and [3]. Looses of available energy not gathered trough the day in any longer period will generate money losses that will eventually outgrow all money savings made by cheapest installation [4]. In order to maximize energy production of PV systems some mechanical enhancements must be introduced into PV system.

Automation of such tracking systems is the most reliable form of conducting efficient energy production by PV modules and plants. Although in present many different equipment is available for these tasks, programmable logical controllers are proven to be widespread solutions, not only as a process control unit but also as system supervision central unit. Measurements of various electrical and nonelectrical parameters can be performed parallel to performing mathematical model for calculating references in angular regulation of PV module azimuth and slope. Regulation itself can also be performed inside same controller. In this way system can finally become very effective while producing energy by enabling good insight in system status and historical data. Historical data is a good background for processing energy production and comparison with conventional analytical models of PV technology in order to determine these models accuracy. This can later allow modeling results corrections in estimations on other PV plants in nearby surroundings of such PV system [5].

In this research measurement is conducted trough ten weeks period by prototype PV characterization station in order to get information of energy generation characteristics for measured period. This prototype PV characterization station allows analysis for all four modes of operation (fixed, single for each separate axis or dual-axis tracking) [6], [7] and [8].

2. PV SYSTEM MODES OF OPERATION

Mode of operation describes mechanical characteristics of installation for PV module/plant. Therefore, it is possible to determine four modes of operation: fixed, one-axis azimuth tracking, one-axis slope tracking and dual-axis tracking. The simplest mode of operation is fixed installation and is defined by constant angles of azimuth and slope of PV module. In this way the maximum available production can be reached only once in a day. Optimization of azimuth and slope is very susceptible to location and climate of location as in [9]. Next mode of operation is one-axis azimuth tracking PV system. In this solution very simple mechanical constructions are used, with relatively big additional energy when compared to fixed installation. This mode is defined by constant slope angle of PV module and variable azimuth angle. In such solution digital controller and regulators are used for mathematical calculations of tracking references and for regulation of azimuth actuator. In similar way to described mode, slope tracking PV mode of operation is gained with supstitution of azimuth and slope functionality. This mode does not need many angle adjustments because azimuth fixation is dominant condition for gathering additional energy compared to fixed installation. This mode is often done manually two or four times in a year. These angles are available for every location based on geografical coordinates and cilmate, for example in [9]. Last mode of operation is dual-axis tracking in which simultaneous regulation of both azimuth and slope is provided. The biggest obsticle for this solution implementation is very complex mechanical construction, although in return will provide significant additional energycompared to any other PV module mode of operation.

3. MODELING OF PV MODULE U-I CHARACTERISTIC

In order to compare productions for all modes of operation, measured results of prototype PV characterization station (Figure 1 which shows prototype station realization, and further details are available in [10] and [11]) are used. Measurements are made for selected positions while the position (orientation) of the PV modules is continuously changed. For each position electrical and non-electrical values of the PV module are recorded and written in data-base.

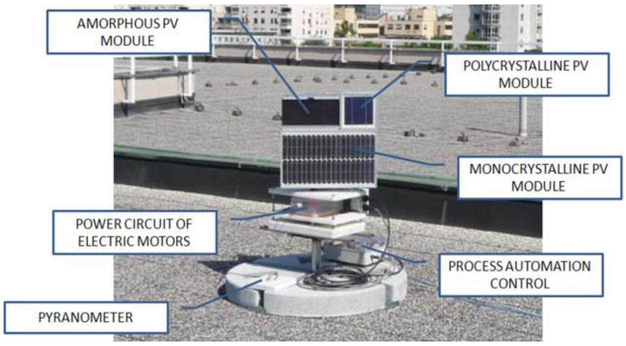

Figure 1. Prototype PV characterization station

The measured values for the PV module are stored into a database. Data are stored within columns that are prepared for post processing and analysis. Table 2 presents a sample of measured data for one PV module. The first group of data refers to general data: the measuring reference number, time noted as "dd.mm.yyyy. hh:mm:ss" and insolation. The measured insolation results will not be processed in this research. These data will be used in subsequent results analyses, so they are kept in the database. These data are followed by a group of data referring to the orientation of the PV module: azimuth angle ***xd*** and inclination angle ***yd***, both represented in angles from 0° to 180°, and 0° to 90° respectively. Electrical parameters follow describing three operating points of the PV modules' U-I characteristics and P-U characteristics. Data records are designed in the way that all PV module operating points are described by using the smallest quantity of data possible. The data input is as follows: the open-circuit operating point by open-circuit voltage U_{PH}, while the current and power are assumed to equal 0; then the short-circuit point by short-circuit current I_{KS}, while voltage and power are assumed to equal 0; and finally one PV module operating point (of the constant load for each measurement) described by voltage U_{L1}, current I_{L1} and operating force P. External additional resistance of measuring equipment can be ignored, as described in next section.

If PV module is presented trough four element model, some changes can be made in order to be able to use measured data from Prototype measurement station. Internal diode cannot be modelled, so it is ejected from the model. Also, singe current source is not appropriate for the measured results, it is replaced by the equivalent voltage source. Wiring length does not exceed 2 meters, with section of 1.5 mm². The relays used in measurements have low resistance when contacts are closed. Therefore, cumulative resistance of external measurement system is estimated not higher than 30 mΩ. Compared to model results for series resistance, it can be concluded that these resistances can be ignored. The final equivalent circuit of PV module is shown in Figure 2.

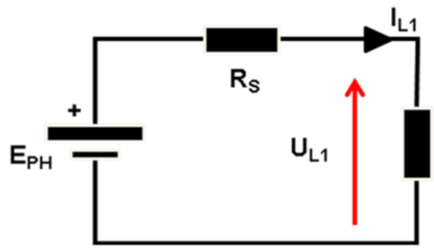

Figure 2. Equivalent circuit used for the calculation of internal series resistance of the PV module

All of the parameters necessary for describing U-I characteristic of PV module can be calculated from input data base using the described equivalent circuit. Some of calculations need iterative method for determining result values of certain parameters. The operating point of maximum power is then calculated from the derivation of the PV module operating force, as shown in equation (1) [12]. Therefore, voltage at the operating point of maximum power is also generated iteratively by using equation (2) [12] because voltage expression is not explicitly given. By simply inserting all the parameters of the PV module and iteratively calculated voltage into equation (3) [12], the current at the operating point of maximum power is calculated.

$$\frac{dP}{dU}=\frac{dUI}{dU}=\frac{d\left\{UI_{ks}-UI_0\left[\exp\left(\frac{U+IR_s}{U_t}\right)-1\right]\right\}}{dU}=0 \quad (1)$$

$$U_m=U_{ph}-\frac{kT}{q}\ln\left(1+\frac{U_m}{U_T}\right) \quad (2)$$

$$I_m=I_{ks}-I_0\left[\exp\left(\frac{U_m}{U_T}\right)-1\right] \quad (3)$$

The final results are written as addition to original database. New data base contains data on the orientation of the PV module (xd and yd), and maximum power of the PV module at that moment. Such database is base for further researches of PV system production in observed region.

4. COMPARISON OF MEASURED ENERGY PRODUCTION

Energy production for different modes of operation should be increasing when upgrading instalation from fixed to dual-axis tracking, as concluded earlier. In measured energy production results shown in Figure 3., Figure 4., Figure 5. and Figure 6. empirical optimal orientation of PV module is already taken into consideration. Since steps of measuring orientation grid is 9°, therefore the measured optimal orientation is rather near theoretical optimum. Also, urban suroundings are introducing some small deviations in optimal parameters from theoretical optimum since high buildings are not placed in direction of true south.

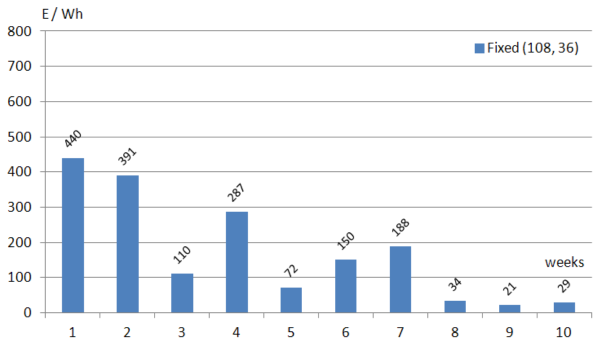

Figure 3. Absolute energy production of PV module in fixed instalation (108°, 36°)

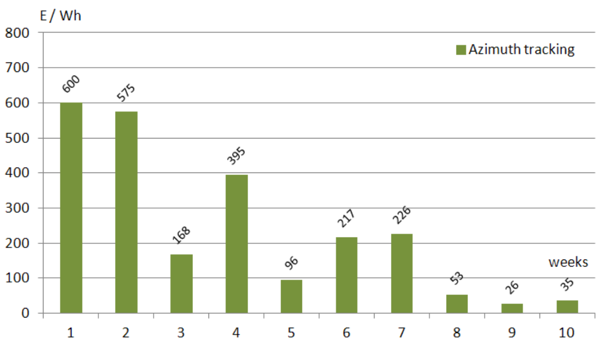

Figure 4. Absolute energy production of PV module with azimuth tracking (slope 36°)

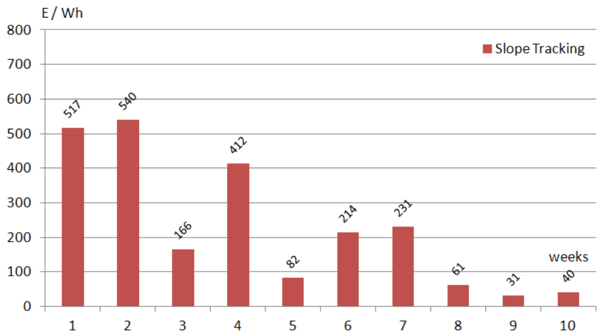

Figure 5. Absolute energy production of PV module with slope tracking (azimuth 108°)

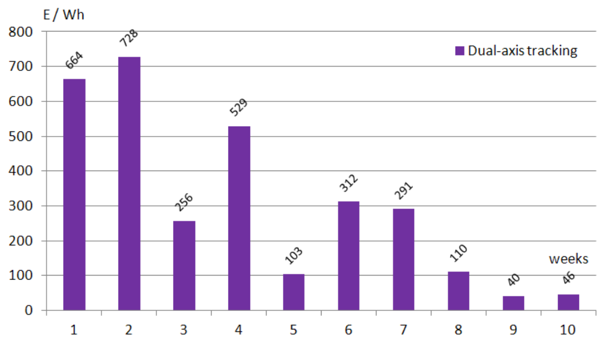

Figure 6. Absolute energy production of PV module with dual-axis tracking

In order to discus results of optimal orientation for current location of Prototype measurement station it is necasary to point out that measurement period was very unstable in terms of weather conditions. It can be seen that first four weeks energ production is rather high, which means that weather was rather good. From fifth till seventh week weather was changing in the way od decreasing of energy production. In last three weeks energy production was very low due to bad weather conditions. Since energy production was very good in the begginig of measurment time period and poor towards the end of period, optimal parameters are more determined by first weeks of time period than by last weeks.

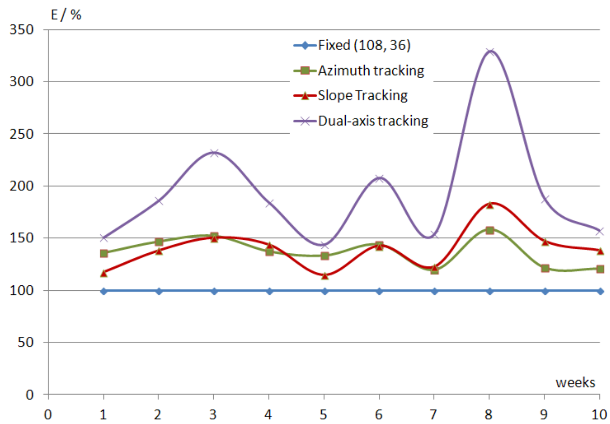

Figure 7. Relative energy production of PV module in different modes of operation

It should be kept in mind that these data result measured for the current location of the prototype measurement station installation in many ways diverts from optimal parameters. Therefore, it can be expected that the optimal inclination [12] would be somewhat different from the annual average optimal inclination for the geographical location of Zagreb (33° to 35°).

5. CONCLUSION

Tracking systems for PV modules/plants are in start somewhat expensive regarding additional complex mechanical construction and regulation subsystem. Every aditional tracking option brings new complications in construction which adds on standard instalation demands. But in longer time period tracking systems will achieve better results in energy production than fixed mode of operation. Programmable logical controllers are justified when considering prices and mechanical solutions necessary for tracking systems. Presented energy results are measured in 10 weeks time period. While working in urban surroundings energy gains from dual-axis tracking are rather big considering fixed instalation, while one-axis tracking systems are somwhere in the middle. W open spaces outside urban surroundings this difference is smaller due to greater production of PV module in fixed mode of operation.

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