Automated photovoltaic panel positioning device for solar radiation monitoring

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Abstract – Electricity generation from photovoltaic plant is dependent on the panels position and it can be improved with sun tracking device. Decision about such implementation of such devices is always doubtful because in many cases no relevant data are available to make certain decision. In order to empirically test such questions device with a fully automated two axes rotator is equipped with three solar panel of monocrystalline, polycrystalline and amorphous PV solar cells to permanently obtain data for the different preprogrammed positions in azimuth range between 0º (East) to 180º (West) and elevation between 0º (vertical) to 90º (horizontal). Relevant parameters are continuously measured and acquired for each panel and position in to the database: short circuit current, open circuit voltage and fixed load current-voltage values. These data are permanently acquired during one year and after processing could be relevant base to help make better decision when different positioning or sun tracking device is considered for photovoltaic plant at measured location.

I. INTRODUCTION

It is observable and well known fact that the amount of electrical energy produced from the photovoltaic (PVP) panels depends on the PV technology and the amount of the solar energy received on the surface of which depends on the position of PVP. This optimal position of PVP depends on the current position of the Sun and on the weather condition. Considering Sun and weather influence for the practical PN technology applications is uncertain and therefore it is not easy to make best practical decision about optimal position or application of Sun tracking device.

For these reasons fully automated device is constructed which is able to empirically test the influence of the various positions for different PVP technologies.

This paper is first describing basic device construction and functioning. Then first results from the initial usage are presented.

II. PANEL POSITIONING DEVICE

The block diagram of the PV panel positioning device is schematically shown on Figure 1.

The panel positioning device consists of two axes motorized rotator carrying panel holder as shown on Figure 2.

Panel holder carries three PV panels (polycrystalline, amorphous and monocrystalline Si) as shown on Figure 4.

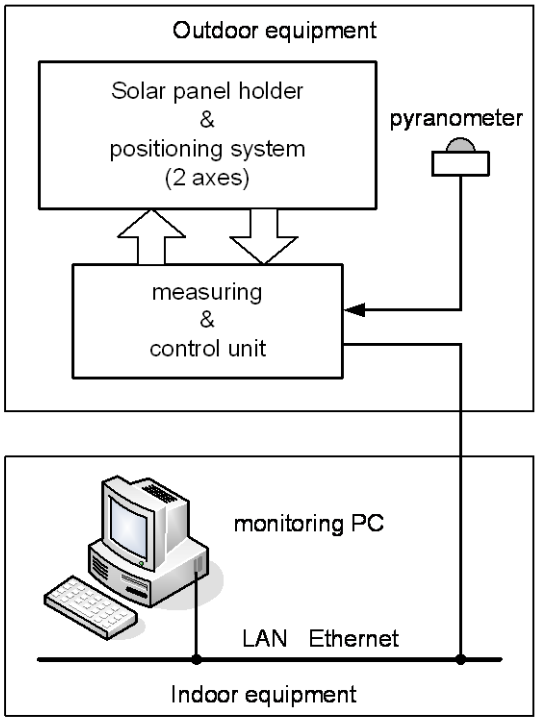

Figure 1. Block diagram

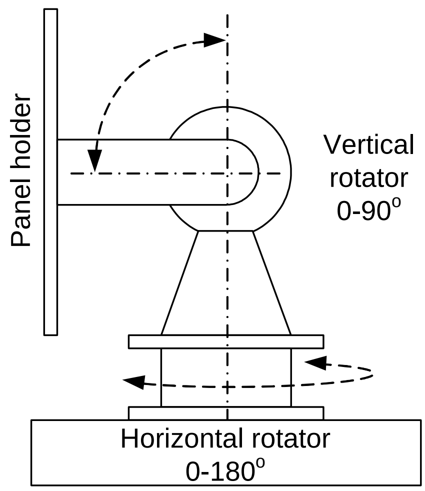

Figure 2. Two axes rotator

This device in general can have different number of PVP, specifications of three installed PV panels is as follows:

SP 1 - polycrystalline:

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Isc = 8,71 A
Voc = 0,63 V
Wmp = 3,47 W @ 7,7 A / 0,45 V
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SP 2 - amorphous:

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Isc =  0,165 A
Voc = 22,5 V
Wmp =  2,0 W @ 0,138 A / 14,5 V
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SP 3 - monocrystaline:

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Isc =  1,36 A
Voc = 20,5 V
Wmp = 20,0 W @ 1,21 A / 16,5 V
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Panel holder can be oriented in any azimuth between East (0º) and West (180º) and elevated between vertical (0º) and horizontal (90º) position in preprogrammed steps. Choosing a 9º step in each ax there are total of 231 (with horizontal repeated 20 times) discrete unique sky scanning positions defined for one measuring cycle.

Using programmed movement and measurement in duration of approximately 5 second between two steps, the total cycle duration becomes approximately 20 minutes which means that the panel holder reaches the same position three times in an hour. This is adjustable.

The complete working device is installed on the roof of the University building as show on Figure 3.

Motorized rotary actuators (24 V, 4 Nm) [1] are controlled by microprocessor based control unit using 0-10 Vdc set-point control signals for full range movement as shown on Figure 4. The feedback position signals 0-10 Vdc are used for accurate positioning.

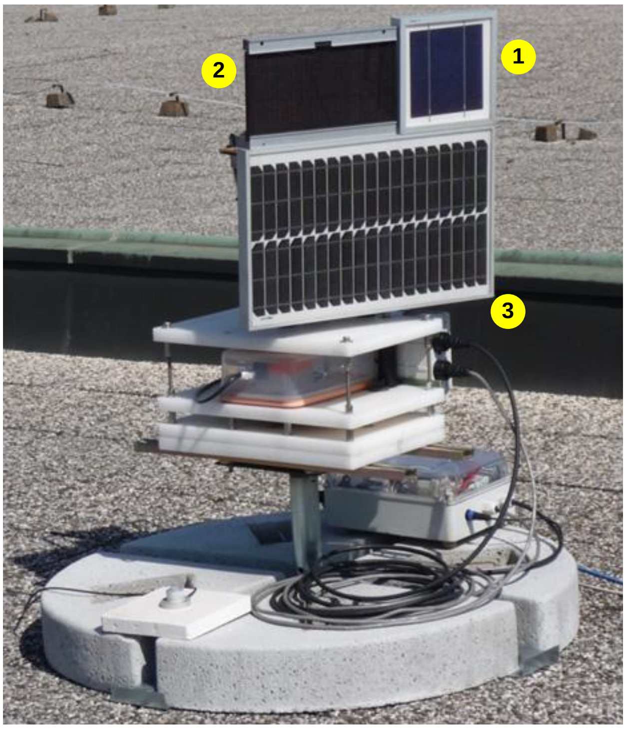


Figure 3. PV panel positioning device

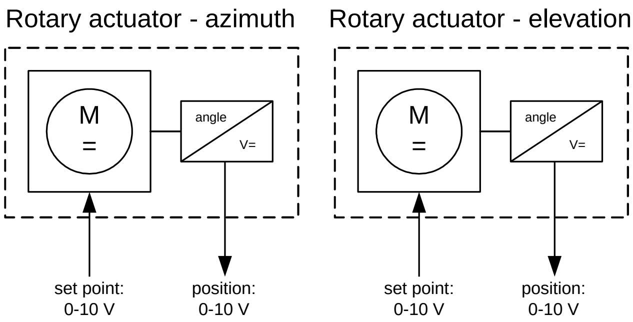


Figure 4. Two axes rotary actuators

III. CONTROL UNIT

The programmable automation control (PAC) unit [2] consists of CPU module and appropriate I/O analog and digital modules as shown on Figure 5.

Analog output module uses 2 channels 0-10 V to control rotary actuators. This 2-channel analog input module acquires 0-10 V actual position signals from rotary actuators.

The referent measurement of the total solar radiation is obtained using SP Lite semiconductor pyranometer [3] with sensitivity of 70 $\mu V/Wm^{-2}$ located on the horizontal plate near the PV panel positioning facility.

The low level pyranometer output signal is measured using 0-100 mV analog input module.

PV panel outputs are measured using power-measurement module containing triple dedicated voltage/current analog input channels.

The 8-chanel 24 Vdc digital output module is used to control corresponded relays for open circuit voltage, short circuit current and load voltage/current measurement of each PV panel in every achieved position.

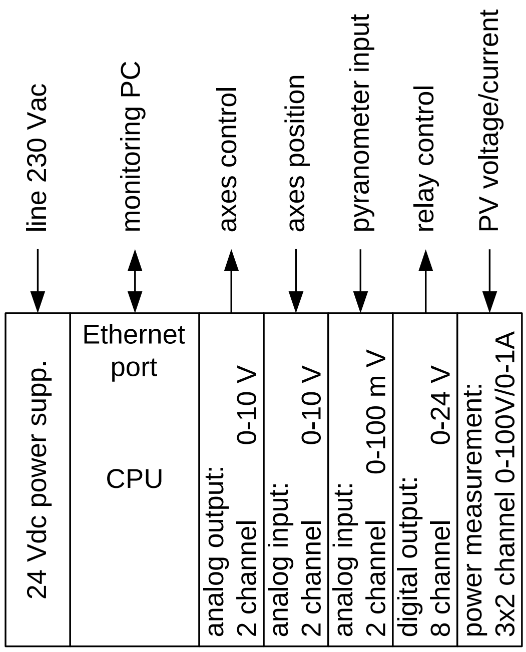


Figure 5. Control unit configuration

IV. MEASURING ALGORITHM

Data acquiring process starts with the panel holder movement in the new position. The load relay R1 is closed. At the moment when the new position is reached the load data (I_{load}, V_{load}) value pair is measured. The load relay R1 is opened and the short circuit relay R2 is closed with delay of 200 ms (t1). The short circuit current is then measured after delay of 200 ms (t2) when R2 is opened again. Following delay of 200 ms (t3) the open circuit voltage is measured at the end of measuring period Tm. Then the R1 is closed again for the next load measurement in new position as shown on Figure 6.

The measuring and control circuitry for each measuring channel is shown on Figure 7. The value of load resistor R_{load} is chosen according the characteristic of each PV panel to meet maximum load at nominal condition.

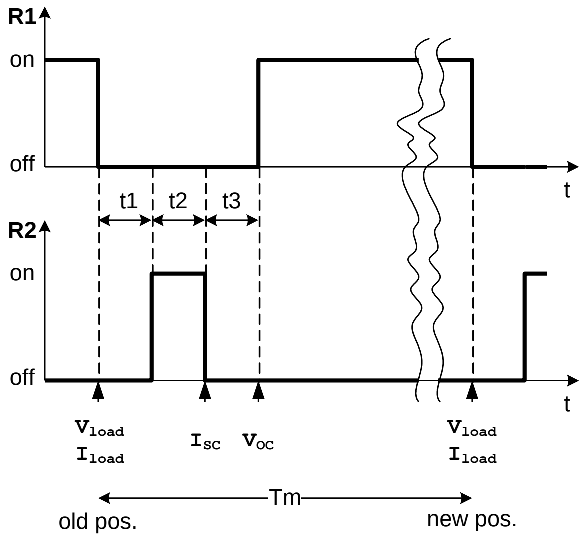


Figure 6. Measuring period (Tm)

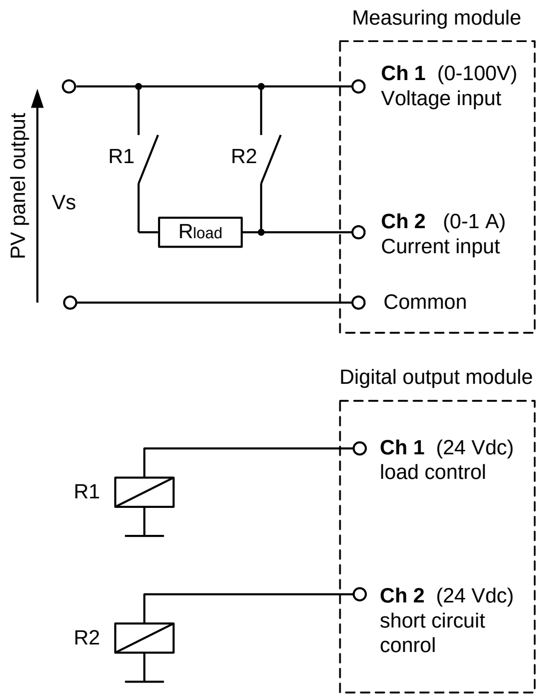


Figure 7. Measuring and control circuitry

The flowchart of the programmed algorithm [4] for PAC is shown on Figure 8. The measurements for all three PV panels are carried out simultaneously.

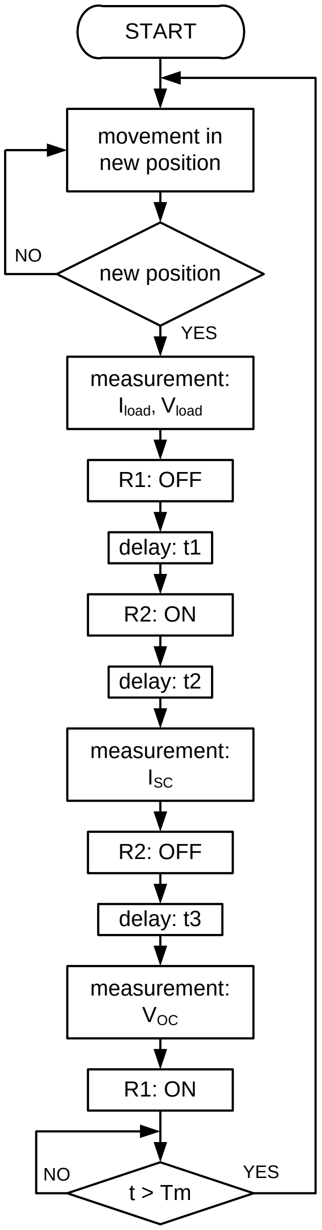


Figure 8. Data acquiring flowchart

V. MONITORING SOFTWARE

The PC based software application is developed for monitoring and data acquiring purposes [5]. The current position and measuring data are graphically presented on the on-line control screen shown on Figure 9.

Panel holder position control can be run in manual or automatic mode using appropriate screen controls. In manual mode slider screen controls are used for on-line azimuth and elevation settings. When switched in automatic mode the required number of azimuth and elevation steps should be entered using on-screen keyboard. The system calculates the appropriate azimuth and elevation angle steps and automatically starts measuring cycle.

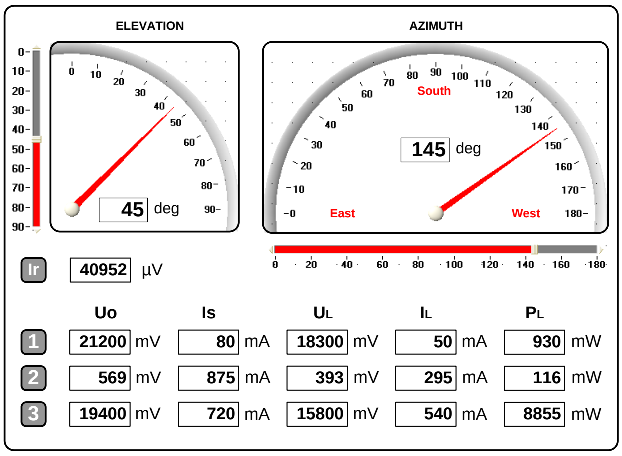


Figure 9. Control screen layout

The acquired data are saved in historical data base resident on the monitoring PC disk storage. The data base is automatically updated when the system is running.

All saved data can be searched and graphically presented on the dynamic data viewer selecting the time period and traces of interest.

The monitoring PC is connected to the local computer network enabling remote access to the acquired data from any location provided with internet connection. The acquired data can be exported from historical data base as an ASCII format file for various analyzes in time period of interest.

VI. Data Processing

The data record for every measuring position contains time stamp, irradiation, azimuth, elevation, open circuit voltages, short circuit currents and load values for correspondent PV panel.

Figure 10 shows azimuth plot consisting of 21 measuring points which differ for azimuth step α = 9º (relative value 9/90=0.1) during one elevation step **E** = 9º (relative value 9/180=0.05). Using settling time (Tm) of 5 second between two measuring positions the duration for each elevation step becomes t_ε = 105 s. Since there are 11 elevation positions for chosen **E** consequently 231 (horizontal is repeated 20 times) data records are saved during one of 75 measuring cycle per day (exact cycle duration is 19 minutes and 15 seconds).

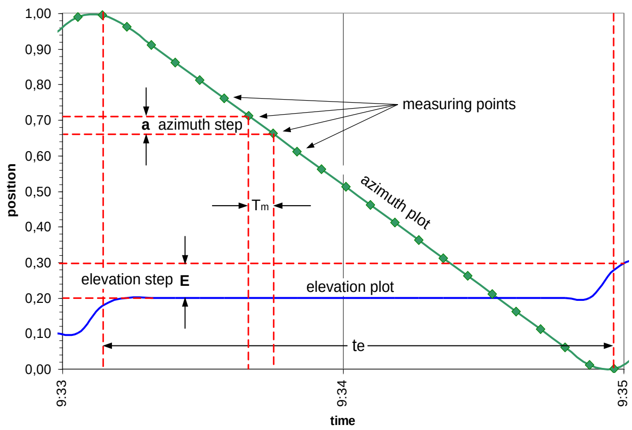


Figure 10. Measuring position plot

Versatile analyzes can be performed using stored data to find influences on the PV panel output due to the location specific attributes, climate conditions, panel orientation but also to applied PV technology.

A. Irradiation effect

Since the PV panel output depends not only on the orientation but also on the weather condition in observed period the global irradiation data (Figure 11.) are used as references for panel performance comparison as shown on correspondent short circuit current plots for SP1, SP2 and SP3 panel in percentage of the nominal short circuit current (Figure 12.).

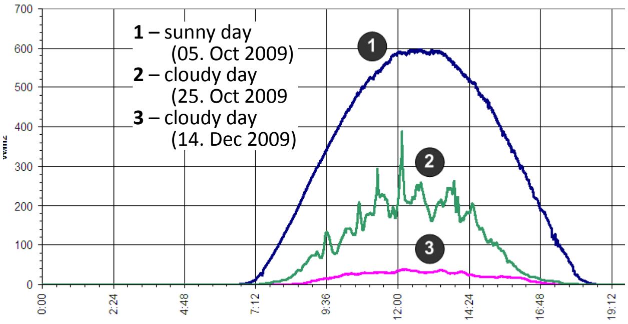
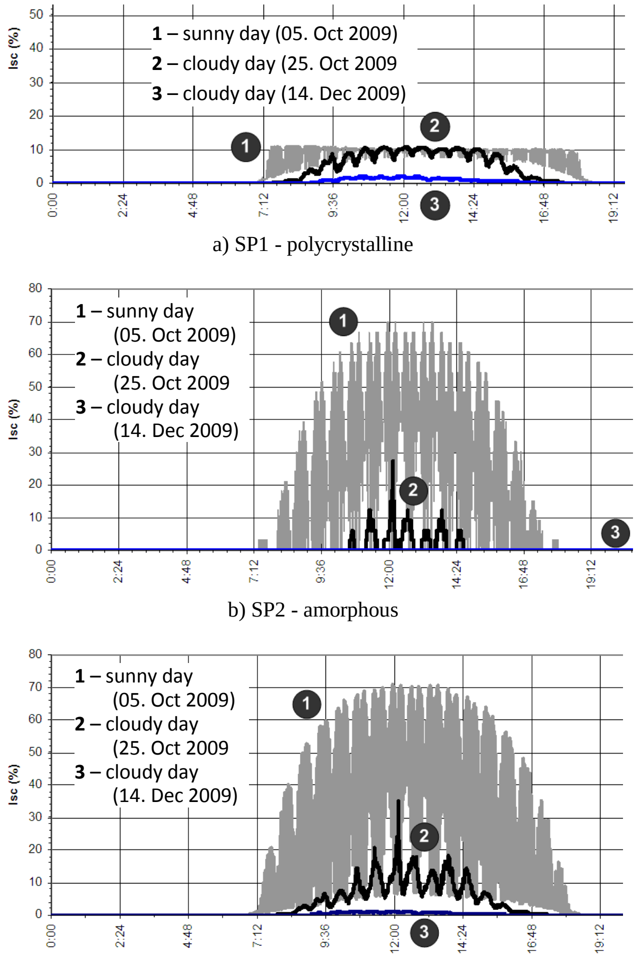


Figure 11. Global sun radiation – Zagreb



a) SP1 - polycrystalline

b) SP2 - amorphous

c) SP3 - monocrystalline

Figure 12. PV panel short circuit current plots for irradiations presented on Figure 11

It is obvious that the PS2 and SP3 outputs are linearly depended on the irradiation level but the SP1 output shows significant nonlinearity – practically constant output (about 12% of nominal) for irradiation level changes between 50-600 W/m^2. This requires further investigation because it might be the problem with special once cell FV panel in use (i.e., small voltage and measurement related problem).

B. Orientation effect

To find out PV panel output dependency on panel orientation to the Sun, the sun calculator [6] is used to obtain azimuth and elevation values of exact sun position on the sky as shown on

Figure 13.

The maximum panel output occurs when the rotator position match the sun position (point of coincidence) during the sky scanning cycle as shown on Figure 14.

Since the rotator and sun position coincidences ones in every scanning cycle the corresponded panel output values are used as 20-minutes mean powers for output energy calculation simulating PV panel sun tracking facility.

To obtain energy produced as simulation of fix mounted PV panel facility in optimum position – south oriented (relative position 0,5) with elevation 45º (relative position 0,5) the appropriate output power values are extracted from stored data for each 20-minutes cycle.

The comparisons of energy produced from simulated sun tracking (*Es)* and fix mounted (*Ef*) PV panels are presented on Figure 15. for used panels SP1, SP2 and SP3.

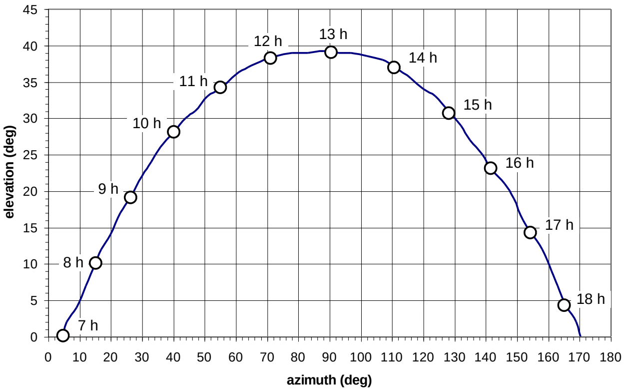


Figure 13. Sun position – Zagreb 05.Oct 2009

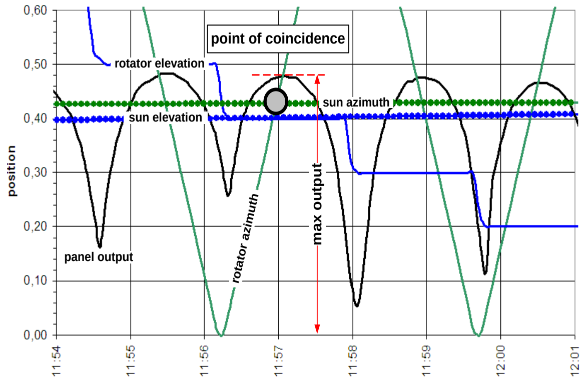
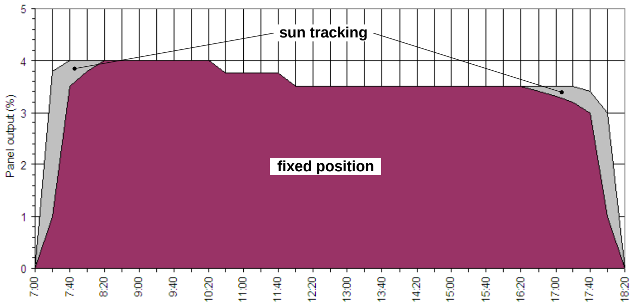
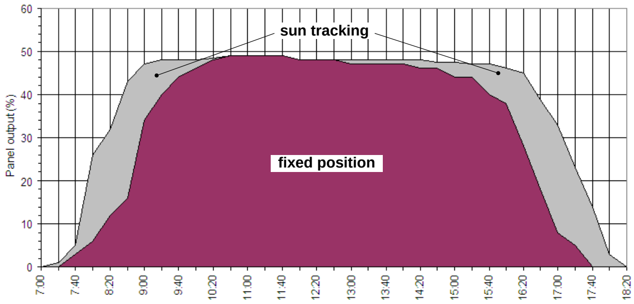


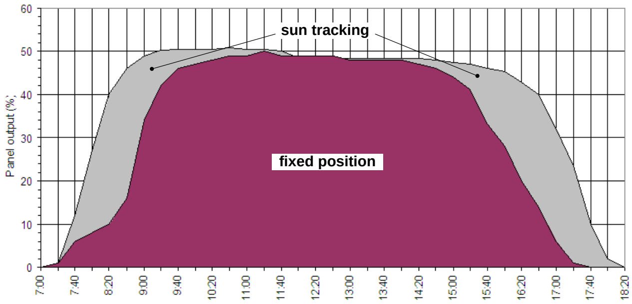
Figure 14. PV panel output at point of coincidence



a) SP1 - polycrystalline



b) SP2 - amorphous



c) SP3 - monocrystalline

Figure 15. Calculated energy

Figure 16.-a shows small energy production increase (mean power less than 4% of nominal) from polycrystalline panel SP1 at 60% of nominal irradiation, with relative ratio *Ef/Es* equal to 0,94.

SP2 and SP3 panels produce much more energy at same weather condition - mean power around 40% of nominal during daylight, but they are much more sensitive on the orientation to the sun: *Ef/Es* of 0,83 for SP2 and 0,79 for SP3.

VII. Conclusion

Local solar data are rarely available especially with sufficient resolution. Different photovoltaic technology characteristics are more and more tested in the field but their dependence on the local conditions might be important for specific installation.

Installed device enables collecting detailed data about behavior of different PV panels in numerous positions at various irradiation and different weather conditions. Since all of mentioned parameters are depended on local conditions number of described facilities should be installed on specific locations for efficient data collecting in region of interest. Croatia might be well represented with 10 or more devices like this one.

In normal operation, data are transmitted daily from each location to the center of the remote control through the available communication links (i.e., Ethernet, radio modem or GPRS).

In the center where supervisory PC is installed to perform cyclic polling of individual measurement stations, collects and stores data. Through web server applications will be available for possible access and visualization of data from remote locations via the Internet suitable for public, educational, and research goals.

Expected outcomes of annual measurements from proposed device could be used for different purposes. For example, they would help improving the correlation and verification procedures.

Then, the results will help to demonstrate the actual performance of certain photovoltaic technology depending on the actual conditions (solar irradiation, temperature, etc.).

Finally, this measurement would empirically show advantage or lack of it for the application of advanced solutions that drive photovoltaic panels toward the sun. It would also give realistic prediction of best fixed position of photovoltaic panels for maximizing the annual or seasonal electricity production.

Tasks for future work which will improve both different PV technology coverage and measurements:

- Expanding positioning device with two additional PV panels in CdTe and CIGS thin-film technology,
- Applying controlled electronic load for whole I-V panel characteristic evaluation in every measuring point during sky scanning cycle.

LITERATURE

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