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SOME ASPECTS OF POSITIONING PHOTO VOLTAIC PANELS IN AGROVOLTAICS APPLICATIONS

NEKI ASPEKTI POZICIONIRANJA FOTONAPONSKIH PANELA U AGROVOLTIČNIM APLIKACIJAMA

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ABSTRACT

The paper addresses some of the challenges which arise from the contemporary initiatives and efforts to advance in the field of agrivoltaics (Solar and Agriculture Co-Location) applications.

Due to the fact that during agrivoltaics applications there is normally a possibility to choose the orientation of photovoltaic panels, a challenge arises: what is their optimum orientation and way of mounting.

This paper describes complex methodology employed in the research (literature analysis, photovoltaic installation, one-year measurement of key quantities, data post processing, and analysis).

The results received are presented in graphical manner. They tackle basic correlation between the electric power produced in correlation to the orientation of photovoltaic panels, all dependable of the time in the day and period of the year.

Based on such results, this paper offers some answers regarding optimal azimuth and tilt angles of photovoltaic panels.

The results and discussion may be of help when deciding the position of photovoltaic panels in agrivoltaics applications, but also for small household units in rural environment.

***Keywords:** agrivoltaics; photovoltaic (PV) panel; position, azimuth; tilt angle; optimization.*

REZIME

Rad se bavi nekim od izazova koji proizilaze iz savremenih inicijativa i nastojanja da se napreduje u oblasti primene agrovoltaike (Solar and Agriculture Co-Location).

Zbog činjenice da tokom primene agrovoltaike obično postoji mogućnost izbora orijentacije fotonaponskih panela, postavlja se izazov: koja je njihova optimalna orijentacija i način montaže.

U radu je opisana složena metodologija korišćena u istraživanju (analiza literature, fotonaponska instalacija, jednogodišnje merenje ključnih veličina, naknadna obrada podataka i analiza).

Dobijeni rezultati su prikazani na grafički način. Oni se bave osnovnom korelacijom između proizvedene električne energije u odnosu na orijentaciju fotonaponskih panela, a sve zavisi od vremena u danu i perioda godine.

Na osnovu ovakvih rezultata, ovaj rad nudi neke odgovore u vezi sa optimalnim azimutom i uglovima nagiba fotonaponskih panela.

Rezultati i diskusija mogu biti od pomoći pri odlučivanju o položaju fotonaponskih panela u agrovoltaičkim aplikacijama, ali i za male jedinice u domaćinstvu u ruralnim sredinama.

***Ključne reči**: agrovoltaika; fotonaponski (PV) panel; položaj, azimut; ugao nagiba; optimizacija.*

INTRODUCTION

Last decades, especially years, there is increasing interest and trend to use photovoltaic systems in combination with agricultural activities. That has led to an introducing of a new term agrovoltaics, or agrivoltaics which involves adding solar panels to agricultural land to generate electricity, improve crop yields, and help farmers increase their revenues. Although some authors make difference between those two terms, most of them do not make such difference.

Regardless of relatively short period of development and application of agrivoltaics, the number of global literature sources dealing with thin very important area is growing intensively. Some sources describe the potential and the challenges for agrivoltaics *(Chatzipanagi et al., 2023)*; Others introduce this innovative approach *(Abidin et al., 2022; Colantoni et al., 2021 and Cho et al., 2020)*. Significant sources emphasize contribution of this technics to the meeting of UN goals for sustainable development *(Aroonsrimorakot et al., 2020 and Libra et al., 2024)*. In any case, what makes significant difference to using the photovoltaic panels on roofs in urban environment is that when using them on land, in most cases, one can choose more freely their orientation. That freedom comes with dilemma what is their optimal position and way of mounting.

In that view, the following conceptual questions arise: Fixed or dynamic positioning of PV?; If fixed, what should be the orientation of photovoltaic panels?; If fixed, the same position the whole year, four for all seasons, or two for winter and summer period?; Is it worth considering to share the photovoltaic panels in several groups with different orientation?, and What are the benefits and downsides of different orientation panels during a day and year during all seasons in terms of energy production and balance with the energy needs?

The questions above defined the research focus of this paper. The hypothesis that is that by clever orientation of PV panels, especially by sharing them, some advantages could be developed, and part of limitations mitigated. This tackles widening the part of the sunshine period in the day when usable energy can be produced, and avoiding pick of production of electric energy (middle of the day), having in mind that it is quite short, and when a problem of its consumption may arise.

Since producing electric energy in agrivoltaics applications is very much related to the needs of a company with agricultural activities, one should try to correlate the production of such energy with the needs (like in food production industry). It is well known that, economically, it is wise to use own produced electric energy than to sell it, and buying it for own needs.

Having in mind that battery systems for energy storing are quite expensive, it is worth examining if there are possibilities of improving the compatibility between energy production and consumption by adopting specific photovoltaic panels orientation.

Literature sources have contributed a lot to the issue, employing analytic and experimental tools, relating to different parts of the Globe. Geographically wise could be divided into different regions. Examples for Europe are: Spain *(Barbon et al., 2022)*, Romania *(Mitiu et al., 2019)*, Cyprus *(Abbasoglu et al., 2014)* and Slovakia *(Božiková et al., 2021)*. North America could be represented with papers from USA (*Jacobson and Jadhav, 2018; Pike et al., 2021)* and Canada *(Hailu and Fung, 2019)*. India has reach sources of literature, as well *(Radhika, 2015; Rao and Sharma, 2022)*. Africa is represented by examples from Egypt *(Abdelaal and El-Fergany, 2023; Hegazy, 2019)* and Libya *(Jumaa and Adbar, 2020)*. There are sources for Middle East: Iran *(Naeimi et al., 2011)* and Saudi Arabia *(Al Garni et al., 2018)*. Turkey itself is a reach source for references too *(Akyürek et al., 2019; Karafil et al., 2015).*

The correlation of using PV systems for agriculture development could be found in a number of literature sources, as well *(Fraunhofer Institute for Solar Energy Systems ISE, February, 2024; Global Environment Facility: Agrivoltaics, 66th GEF Council Meeting, February 5-9, 2024; Van Champen, et. al. FAO, Rome, 2000)*.

The mentioned papers, and number of others, highlight that optimization of the orientation of PV panels is one of the crucial questions in terms of maximizing energy output everywhere on the globe. These researches employ analytic method (calculation), or experimental method (measurement), or both. It is obvious that almost all papers are related to some region or place on the earth.

This research is also location related (east region of N. Macedonia). It deals with rarely researched rural local environment and small installed power (6 kW). Plus, it assumes that there is a possibility of orientation of the PV panels in all azimuth and tilt angles. On top of that, the results will be considered in the light of needs for small autonomous agricultural capacity and households that can be found in large number in such areas. Besides that, the research undertaken has an ambition that its results can be useful for much larger agrivoltaics applications.

METHODOLOGY

Besides the literature research, according to the limited resources, the methodology of research included: using of web available information about sun position and on-line calculations for optimal azimuth and tilt angles for the concrete location, and experimental measurement of the output power of three PV panel sections (packages) fixed in different angles (azimuth).

Information about the sun position for concrete location (Berovo, N. Macedonia) was taken online, followed and registered from the web source: https://sunsetsunrisetime.com/sun?lat=41.7031&lon=22.8578.

Setup of the experiment

Three packages of six PV panels were mounted on three different stands with possibility of changing the azimuth and tilt angles.

The coordinates of the place where the panels were placed are: 41°43'20.2"N 22°50'44.4"E.

Initially, the three packages were placed in three different directions regarding the azimuth: south (azimuth 00), southeast (azimuth +240), and southwest (azimuth -580). The azimuth angles of the PV panel packages are specified in relation to the south. The tilt angle in the first year of research was the same at all PV panels: 42^0.

Figure 1. shows satellite view on disposition of PV panels packages, and figure 2 is a photo of them.

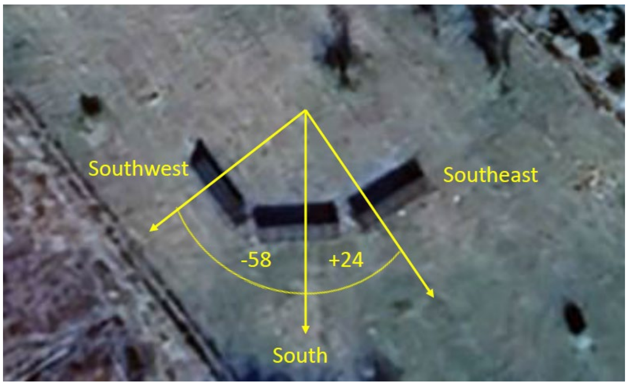

Fig. 1. Satellite view on PV panels packages Fig. 2. Photo of the PV panels packages

PV modules type is BSM410G12-54 HPH with the following characteristics: Maximum Power (Pmax/W) 425 (STC), 318 (NMOT); Operating Voltage (Vmpp/V) 32.03 (STC), 30.0 (NMOT); Operating Current (Impp/A) 13.29 (STC), 10.60 (NMOT), Open-Circuit Voltage (Voc/V) 38.25 (STC), 35.90 (NMOT), Short-Circuit Current (Isc/A) 14.18 (STC), 11.42 (NMOT) and Module Efficiency ηm(%) 21.7.

The figure 3 shows electric diagram of the employed system.

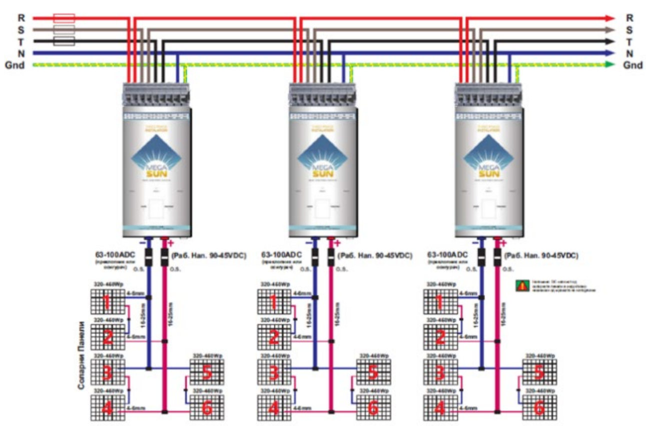

Fig. 3. Electric diagram of the PV system including PV panels, inverters and connection to the grid

The load of the system has been done by very flexible home smart system of electric power consumers (produced by NEDIS).

Methodology of experimental measurement included the following regime of testing: All measurements are done in sunny conditions; At the moment of measurement the time and date were registered; Also, from the web https://sunsetsunrisetime.com/sun?lat=41.7031&lon=22.8578 were registered elevation (altitude) of the sun above the horizon and it's hour angle (with possibility to calculate sun azimuth angle); Electrical load has been applied to each phase which is bigger than capacity of production of the PV system in that phase. This guarantee that reading of produced electric power by PV system is accurate; From the indicators of the each invertor the generated electrical power has been read; All data have been simultaneously written into previously prepared Excel application; Post processing of the data in Excel has been done; Illustrating tables and diagrams have been produced; Analysis of the results has been done.

RESULTS AND DISCUSSION

With the explained experimental methodology, an enormous amount of measurement data was collected. Also with post processing equally large number of results were available for analysis.

It is known that the PV panels produce maximum electric power when sunrays fall perpendicular to the PV surface. It is also well known that is a very rare situation, and therefore it is interesting to know how produced energy depends on the angles between the sunrays and the normal to the PV surface (Fig. 4). Figure 4 also shows orientation angles used in the presentation of results.

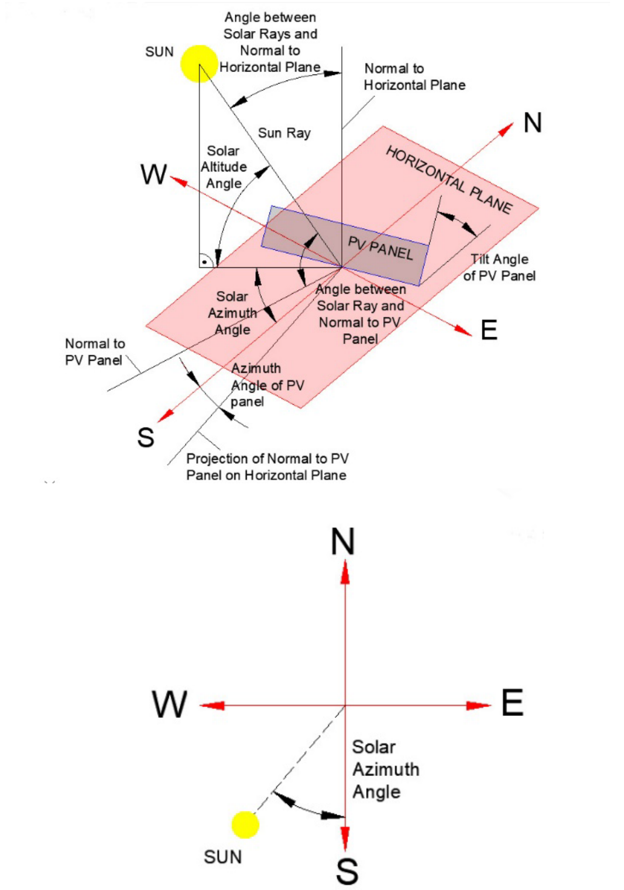

Fig. 4. Tilt angle of the PV panel, azimuth angle of the PV panel, solar altitude angle, solar azimuth angle, and zenith angle (Abbasoglu et al., 2014)

In order to get the actual characteristics for the solar system employed, in the period of late March and early April, 2024, when equinox occurs, a number of measurements have been made with the group of solar panels horizontally oriented to south and with tilt angle of 42 degrees. Figure 5 shows produced electric power during the sunshine period of the day in correlation to the horizontal and vertical angles between the sunrays and the perpendicular (normal) line to the PV surface.

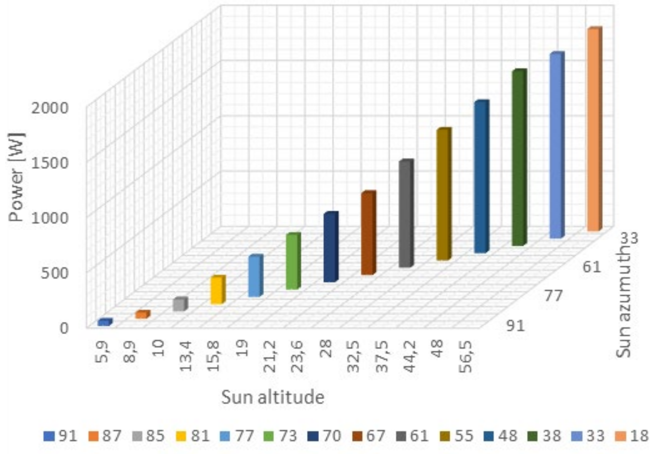

Fig. 5. Produced electrical power in correlation to the horizontal and vertical angles between the sunrays and the perpendicular (normal) line to the PV surface

Due to the complex nature in correlation to the relative movement between sunrays and PV panels during the year, and the need to discover the advantages and disadvantages of different position of solar panels (in this case by azimuth), the measurements of produced electric power has been done the whole year. At this place (due to the restricted space), results received will be presented only for the period of equinox (late March, and early April 2024).

Figure 6 shows the electrical power produced by each package of PV panels (East, South and West) depending of the azimuth angle of sunrays (related to south). The month of measurement is late March and early April, 2024.

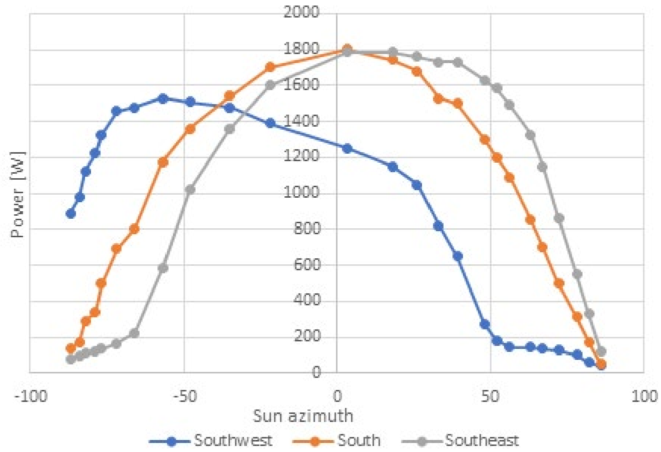

Fig. 6. Electrical power produced by each package of PV panel (Late March and early April, 2024)

As expected, the figure 6 shows that the Eastern PV package produces more electrical power in the morning (right hand side of the diagram), and Western PV package does it in the afternoon (left hand side of the diagram). The South PV package has symmetrical figure due to symmetrical movement of the sunrays.

The Eastern and Western PV panels packages have asymmetrical figures. This is more obvious for the Western PV panels package due to its bigger difference of azimuth angle related to south.

The Eastern and Southern PV panels have similar maximum value (due to smaller difference in their azimuth angle), but Western PV panels have smaller maximum value. This can be explained by the fact that when the sunrays have perpendicular direction in horizontal plane to the Western PV panels, the vertical angle (altitude) of the sunrays has already declined, and by that, increasing the angle between the normal to the PV panels and the sunrays.

One important aspect of the positioning of the PV panels is the increasing and decreasing of the whole efficiency of the system (figure 7). In that context, the line illustrating correlation between the actual system and the same system in which all PV panels are south, in percent, is interesting for analysis. The diagram shows significant achievements in efficiency in early and late stages of the daylight period. During the peak period (around noon) there is reduction in cumulative efficiency around 5-15%. In this context it is important to note that the cumulative power produced in the morning, and in the afternoon is much less than in the peak period (around noon). Therefore, significant improvements (in percent) in the morning and the afternoon should be carefully considered.

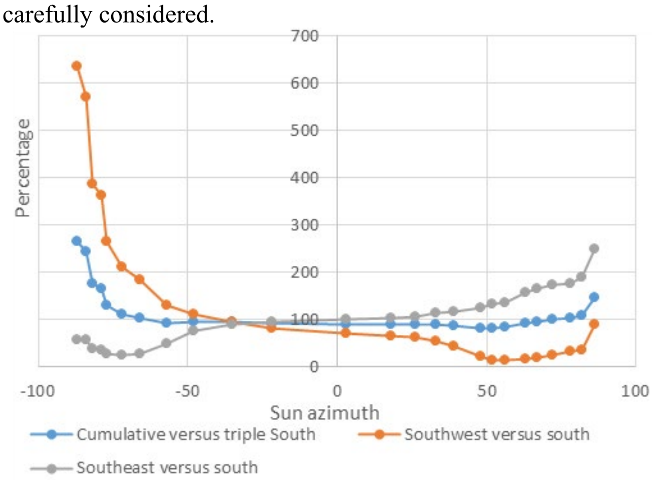

Fig. 7. Relative percentage of electric power produced by PV panels in comparison to south oriented panels (Late March an early April, 2024)

The other results (not shown due to space restriction) which relates to the summer and winter period when duration of sunshine period changes from maximum to minimum show similar characters like those shown on figure 6 and figure 7, but there are still noticeable differences. Namely, due to the fact that in summer period solar azimuth angles are much bigger during sunrise and sunset, the differences in power generation of southeast and southwest PV panels are bigger and the total period of the day when there is significant power production is much longer. That means that there is a logic to orient some PV panels further on east and west related to those oriented to south. This is especially important for those applications where it is valuable to have prolonged power production versus higher pick production in the middle of the sunshine period. In other hand, during the winter period, solar azimuth angles during sunrise and sunset are significantly lower, and there is no use of big differences of the azimuth angle of PV voltaic panels related to the south.

One should not forget that everything said above is very much related to the geographical coordinates of the place where the PV panels are to be installed. The employed methodology of research, and results achieved allow to optimize the position and orientation of the PV panels. This should be done in the context of the needs for any specific application and will probably lead to sharing the PV panels in several modules with different orientation and connecting them into integrated system, as figure 3 shows.

CONCLUSION

Photovoltaic systems are confirming that they are environmentally friendly sources for electric energy, even for specific applications, like agrivoltaics, or rural household.

The one who is to decide about if, and which PV system correspond to specific needs, should be familiar with the basics of this technics, and be able to choose not only the system components, but also orientation of the PV panels.

With careful analysis, there is a possibility to use the advantages, and to mitigate downsides of PV systems, and to tune the system towards the specific needs.

Such analysis starts with review of the electric power needs at specific application. Such needs should be analyzed as “bigger picture” in the context of a number of factors: availability and price of grid energy; availability of other power sources, geographical position, number of sunshine days in the year, terrain condition, agricultural needs, PV systems availability and prices, etc. In that process there is a need of sufficient level of expertise of PV systems.

Since agrivoltaic applications may cover significant area, there is a possibility to make a system of packages of PV modules with different orientation. This possibility, if cleverly used, might adopt some of the advantages of the geographical position, terrain conditions and PV system advantages to the needs for power in any specific application.

This research results and analysis offers some useful information when deciding the way of mounting and orientating of photovoltaic panels, especially discussing possible benefits in share of photovoltaic panels in several groups according to their orientation.

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