PHOTOVOLTAIC ENERGY GENERATION WITH MANUAL TRACKING APPLIED IN IRRIGATION SYSTEMS

V.F.Grah2, I.M. Ponciano3, D.G. Alves4, C.A. Salvador5, T.A. Botrel6

SUMMARY: Despite of advances, Brazil still has a part of population living in rural areas without supply of electric energy. Photovoltaic solar energy (PV) is an alternative to diversify the Brazilian Energetic Matrix and expand the use of irrigation systems in isolated areas. The goal of this work was evaluate the increment of pumping time; volume of water pumped and irrigated area; using one axis tracking system. In this way two PV modules have been installed, one static and another with solar tracking system, at Biosystems Engineering Department – ESALQ/USP, São Paulo State, Brazil. Both, static and tracking modules were coupled in a simulated irrigation system. The solar three steps manual tracking system shows more efficiency in the energy harvesting, compared to static generator; which resulted in significant increment of pumping time (40 - 160 min day\(^{-1}\)), volume of water pumped (884 - 3479 L day\(^{-1}\)) and irrigated area (196 – 773 m\(^2\) day\(^{-1}\) for a irrigation depth equal to 4.5 mm). Therewith, the tracking system shows a viable alternative technique to improve solar energy harvesting and increase the irrigated area with same area of PV generator.

KEYWORDS: renewable energy, solar energy, simulated irrigation system

GERAÇÃO DE ENERGIA FOTOVOLTAICA COM RASTREADOR MANUAL APLICADO EM SISTEMAS DE IRRIGAÇÃO

RESUMO: Apesar dos avanços, o Brasil possui uma parte da população na área rural sem abastecimento de energia elétrica. A energia solar fotovoltaica (FV) é uma alternativa para
diversificar a matriz energética brasileira e ampliar o uso de sistemas de irrigação em locais isolados. O objetivo do trabalho foi avaliar o incremento no tempo de bombeamento, volume de água bombeado e área irrigada; utilizando um sistema rastreador de um eixo. Para isso foram instalados dois módulos FV, um estático e outro com o sistema de rastreamento no Departamento de Engenharia de Biossistemas – ESALQ/USP. Para cada módulo FV, estático e móvel, foi acoplado um sistema simulado de irrigação. O sistema rastreador solar manual de três passos apresentou maior eficiência na captação de energia, quando comparado com geradores fixos; o que refletiu no incremento significativo do tempo de bombeamento (40 - 160 min d⁻¹), volume de água bombeada (884 - 3479 L d⁻¹) e área irrigada (196 – 773 m² d⁻¹ para uma lâmina de irrigação de 4,5 mm). Com isso, o rastreador mostrou uma alternativa técnica viável para melhorar a captação de energia solar e aumentar a área irrigada com a mesma área de gerador FV.

PALAVRAS-CHAVE: energia renovável, energia solar, sistema simulado de irrigação

INTRODUCTION

The PV technology have being the widest and promising available technology used in a current days, considering the need of environmental restoration (Moussi et al., 2003) and because it is a suitable energy for rural households which frequently are marginalized from supply network due the high involved cost (ONU, 2010). The current photovoltaic cell has low efficiency in transform solar in electric energy and there are no technologies that can improve this performance (Demain et. al, 2013). An alternative to improve the photovoltaic generation is optimizing the tilted angle with a solar tracking, in this way solar rays can achieve the PV generator perpendicularly throughout the day, obtaining a constant power in the PV cells (Kaldellis et. al, 2012). The PV modules cost has increased over the decades, in the end of 2012 the cost of PV generator increased 74% from 1998 to 2011 (Feldman et al., 2012). The reducing cost of the PV systems will make this technology the most attractive to rural electrification and water projects (Catoni, 2014), contributing to the spread of PV option applied in water pumping (Fedrizzi & Sauer, 2002).

The Brazil has propitious natural features to the development of the photovoltaic energy. Moreover, the Northeast of the Brazil has the lowest seasonal variations, thus that region has great technical and financial advantages to PV power plants. In the Development Countries the main PV energy users are those that living far from public supply, mainly in rural areas, and the pumping water is the usual application (Kordzadeh, 2010). Many of water
pumping projects in isolated rural areas in the North and Northeast of the Brazil are important to the social and financial development, and the use of this water can be divided in three categories: domestic supply, fish-farming and irrigation systems (ANEEL, 2002). According to Glasnovic & Margeta (2007), the irrigation is a very appropriate consumer of photovoltaic energy because the irrigation systems are often located considerably far from the power network, and their demands for power (crop water requirements) are consistent with the available solar energy. The irrigated agriculture allows such benefits to the farmers by providing: productivity improvements, high quality of products and ensure the crop during whole year. Hence, it is important to develop technologies that can provide the installation of irrigation systems in rural areas with drought problems, for instance, in arid regions (Qoiader & Steinbrecht, 2010). The goal of this work was evaluate the increment of pumping time; volume of water pumped and irrigated area; using one axis tracking system in PV generators.

MATERIAL AND METHODS
In order to evaluate the performance of PV generators with manual three steps solar tracking system (partial segment) applied to simulated irrigation system, it was made a comparative evaluation of the energy production in static and tracking PV generators. The modules were installed in the experimental area of the Department of Biosystems Engineering, Luiz de Queiroz College of Agriculture, São Paulo University, located in Piracicaba - SP (22° 42’ 30” S, 47° 38’ 00” W, 546 m). The PV generator inclination (β) which was optimized to irrigation season, the angle (ρ) and hour (h) of rotation were determined according study made by Grah & Botrel (2014) to the same experimental area.

Each both tracking PV system module as static were compound by following equipments: 1) one centrifugal pumps with 367.5 W power, BCR-2010 model from Schneider Industries, pump operating pressure and flow equal a 1.30 m³ h⁻¹ and 22.5 mca, respectively; 2) ten PV generators fromKyocera Industries, KD 140 model, with generators connected in series and parallel totaling a tense of 24 Vcc and current of 39.55 A; 3) one inverter from Xantrex Industries, Prosine 1000 model; 4) one charge controller from the Xantrex Industries, C40 model; 5) two batteries in series, to provide 24 Vcc, from Helias Industries, Freedom model of 45 Ah; 6) one pyranometers from Kipp & Zonen Industries, SP-lite. The support metallic structure of the PV generators was made in laboratory of the Department of Biosystems Engineering, where the metals were cut, welded, painted and installed in the experimental area. In Figure 1 is observed the three positions of the tracking system, to make those movements were used two steel cables each one attached at the opposite edge of
metallic structure. Each cable has three steel loops (each loop represented one step of the tracking system) which were enlaced in a hook located in the base of the pole that supported the metallic structure.

In order to achieve the proposed experimental evaluation and preserve water resources was not used a conventional irrigation system, nevertheless, it was built a simulated irrigation system which could simulated/controlled the operating water pressure (Figure 2). A compressor injected compressed air into a hermetic tank simulating the operating water pressure of irrigation systems. A pressure controller was used to maintain constant and simulate different operating pressure, it was composed by: pressure controller (developed by technician from Department of Biosystems Engineering); pressure transducer (MPX 5700DP, Freescale, until 0.686 MPa); two solenoid valves that regulated the input and output of air from compressor to the tank and other from the tank to the atmosphere.

A datalogger (CR10X, Campbell Scientific) was used to storage readings of: static and tracking solar irradiance (W m\(^{-2}\)); inside pressure of the hermetic tank (mca); pulse number from hydrometers installed in the pumping system to static and tracking solar generation structure. Additionally, in order to evaluate the simulated irrigation system was used three increment parameters: pumping time, volume of water pumped and irrigated area. In the analysis of the increment of irrigated area was used the simulated irrigation depth between 1.5 to 9 mm (range equal 1.5 mm). Throughout the period was made a summation of pumping time, volume of water pumped, irrigated area and generation energy for static and tracking PV modules.

RESULTS AND DISCUSSION

The average daily increment of PV energy was 3.95 MJ m\(^{-2}\) and the major energy increment was in the clear sky days (Kt >= 0.65). With the purpose to investigate the sky condition in the reading days of solar radiation, it was calculated the daily Kt which is the ratio of solar radiation in the ground level divided by the extraterrestrial solar radiation. Thus, the average daily increment of PV energy using tracking system was 15%, while for clear sky day this increment reached 19% (Figure 3). In the regions where clear sky days prevail, positives impact of using the tracking system is suppose to be major. Caton (2014), also emphasizes that there are many studies in the literature of various array orientations and tracking strategies, but little agreement as to the relative benefits. For single-axis tracking systems, reported benefits are dependent on re-adjustment frequency, for instance, for a polar axis (Vilela et. al, 2003; Gordon & Wenger, 1991) improvements in insolation are reported
between 11% and 32%. Lave & Kleissl (2011) illustrated that some of this variation is likely due to latitude and local weather pattern. Fraidenraich & Barbosa (1999) comparing the solar tracking to fixed slope PV generators installed in the Recife city, PE-Brazil (latitude de 8°S), they observed an annual benefit of 26%. Also in the Recife city, Vilela et al. (2003) comparing the PV generators with single-axis solar tracking system (east-west) to fixed generators, they observed an annual insolation increment of 20%.

The average daily flow and pumping head of the simulated irrigation system was 1.30 m³ h⁻¹ and 22.5 mca, the choose of this gross pumping head was made in order to simulate a sprinkler irrigation system operating with low water pressure sprinklers. Using a high head pressure it was possible to expand the results to a large range of irrigation system, since microirrigation to low water pressure sprinkler irrigation. The simulated irrigation system works during 34 days which in 12 was completely cloudless (Figure 4). It was observed a median of time increment near to 95 min d⁻¹, comparing tracking PV module to static PV module. In the morning the median increment was 75 min and in the afternoon 20 min. This difference in the time increment during the day was attributed to the use of the batteries. At sunrise the batteries were discharged while the tracking module was capable to generate additional energy getting more stability to batteries and consequently to pumping system. Nevertheless, it does not occur in the static module, which allowed an expressive increment of pumping time in the morning. How the batteries in both static and tracking modules were charged in the afternoon, the increment in this period was not so expressive.

The volume of water’s data from pumping system as tracking PV module as static PV module are presented in Figure 5. The average increment of pumped water volume by tracking PV system compared to static PV system was 16% (1.945 L d⁻¹) higher. Vilela et al. (2003) states that the volume of water pumped, to many tracking system strategies, can exceed the increment of the insolation in the generators. In Figure 6 is presented the increment of irrigated area accounting, the variation of irrigation depth. In the Table 1, it can be observed the quantitative increment of: energy generation, pumping time, volume of water pumped and irrigated area; using the tracking PV module with a manual three steps solar tracking system compared to the static PV module, to the Piracicaba, São Paulo State.

CONCLUSIONS
The manual three steps solar tracking system shows easy installation and operation, its uses is recommended to short farmers that does not have public energy supply and that need electricity, among other, pump water to low water pressure irrigation system. The tracking
system proposed showed more efficiency in the energy harvesting, with an increment of insolation on the generator about 1.46 to 6.01 MJ m\(^2\) dia\(^{-1}\), when compared to static PV generators; what reflected in a significant increment of pumping time (40 - 160 min d\(^{-1}\)), volume of water pumped (884 - 3479 L d\(^{-1}\)) and irrigated area (196 – 773 m\(^2\) d\(^{-1}\) to a 4.5 mm of irrigation depth). Thus, the tracking solar system proposed show itself a technical alternative to improve the solar energy harvesting. The use of the solar tracking developed, when compared to fixed slope generators, provides an energy increment of 19%. This increment was achieved in clear sky condition which demonstrates a great potential in Brazilian Regions that have well defined rain station like Center-West Region, and for regions with high insolation all year like Northeast Region.

ACKNOWLEDGEMENTS

The authors acknowledge with thanks the financial support of Foundation for Research Support of the State of Goiás (FAPEG), Foundation for Research Support of the State of São Paulo (FAPESP) and the financial support of Coordination for the Improvement of Higher Education Personnel (CAPES). Also we acknowledge the laboratory technician Ezequiel Saretta for he supports throw the installation process.

REFERENCES


Figure 1. The left figure shows the metallic structure in the first step of the tracking system, at morning (from sunrise to 10 AM). The center figure shows the metallic structure in the second step of the tracking system, at noon (from 10 AM to 14 PM). The right figure shows the metallic structure in third step of the tracking system, at afternoon (from 14 PM to sunset).

Figure 2. The Simulated irrigation system. The left figure shows the water reservoir and the hermetic tank. The right figure shows the centrifugal pumps moved by tracking (right pump) and static (left pump) modules, datalogger, hydrometers and air compressor.
Figure 3. Increment of the photovoltaic energy generation using manual three steps tracking systems compared to static photovoltaic generators (bars). The Clearness Index show how cloudy was the day (circles).

Figure 4. Increment of pumping time by using tracking PV module. It shows the difference between morning and afternoon, which at morning there was more increment compared to the afternoon because the stability of the batteries.
Figure 5. Volume of water pumped from pumping system in both tracking and static PV modules. The difference in height between the black and grey bars is the daily increment of the volume of water pumped.

Figure 6. Increment of irrigated area of using tracking PV module compared to the static PV module. To a lower irrigation depth the increment of irrigated area was bigger.

Table 1. Value of the evaluated parameters to while period.

<table>
<thead>
<tr>
<th></th>
<th>Insolation in the modules (MJ m²)</th>
<th>Pumping time (h)</th>
<th>Volume of water pumped (L)</th>
<th>Irrigated area* (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking PV module</td>
<td>1.182</td>
<td>262.48</td>
<td>407.359</td>
<td>2.662</td>
</tr>
<tr>
<td>Static PV module</td>
<td>1.005</td>
<td>313.35</td>
<td>341.224</td>
<td>2.230</td>
</tr>
<tr>
<td>Increment</td>
<td>177</td>
<td>50.87</td>
<td>66.135</td>
<td>432</td>
</tr>
</tbody>
</table>

* Average value to the period, considering an irrigation depth equal 4.5 mm to short-cycle culture (FAO, 2002)