PHOTOVOLTAIC PUMPING FOR DRIP IRRIGATION

Aleman, C.C.[1]; Paes, R.G.[2]; Ferreir A, T.S.[3]

ABSTRACT

The search for sustainable food production standards to meet the increasing demand of the population increase has led to discussions on the energy issue. The Brazil natural features are in favour of photovoltaic electricity generation. Solar radiation in Brazil varies from 8 to 24 MJ m^{-2} day^{-1}. In 2017, Brazil had 438.3 MW of installed capacity of solar generation. The installed power of approximately 9% is used by the rural sector. The State of Bahia stands out with the highest participation with 151 MW installed power, resulting from high values of solar radiation hitting 6.5 kWh m^{-2} day^{-1}. The objective of this work was to evaluate and compare the efficiency of drip irrigation operated by a photovoltaic system without energy storage (SB) and another that uses batteries to store energy (CB). The experiment was conducted in the Experimental area of Agricultural Engineering Department (DEA), the Federal University of Viçosa (UFV), Viçosa-MG, Brazil, during the period from October 24 to December 20, 2018. It used two sets of vibratory submerged pump photovoltaic solar-powered, Anauger model Solar spumping system, R100. The photovoltaic system without energy storage (SB) was used in accordance with the manufacturer's recommendations. The other system that uses batteries to store energy (CB) was adapted with three stationary batteries Heliar Freedom DF1000 70Ah 12V and a Viewstar VS3048AU 30A charge controller 36ValongwithAnauger model solar pumping system. There were two irrigation systems, a button-type emitters with Dripper iDrop Normal (Irritec), with flow rate of 4 L h^{-1} at 1 bar pressure. And another with button-type emitters Dripper iDrop PC (Irritec), 4 l/h flow, pressure-compensating, with approximately the same flow rate at 0.5 to 4.5 bar. The two irrigation systems were composed of seven laterals, spaced at 0.8 0.8 m. each Touchline with 22 issuers, spaced 0.5 in 0.5 m, totaling 154 transmitters per system. Irrigation systems, the assessment of uniformity of water distribution was conducted according to the methodology of DENÍCULI et al. (1980). In this way, the experiment was composed of 4 treatments, normal transmitter with pump without energy storage in batteries (NSB), self-compensating emitter with pump without energy storage in batteries (PCSB), normal transmitter with storage pump energy in batteries (NCB) and emitter self-compensating with pump with energy storage in batteries (PCCB). Photovoltaic drip irrigation systems with batteries were more effective due to greater uniformity of application of the irrigation with almost equal supply flow rate.

Keywords: Energy management; Sustainability; Water management; Water efficiency.

1. INTRODUCTION

In Brazil, the main source of electricity is hydroelectric plants, which require large flooded areas and generate large environmental impacts when compared to wind and solar sources, considered as clean and inexhaustible (MICHELS et al., 2009). Due to the increasing number of conflicts due to the water crisis caused by the annual volume of rainfall below the historical average, Brazil has used alternative sources to meet its demand, mainly derived from oil and coal.

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[1] Universidade Federal de ViÃ§osa, Brazil, catariny@ufv.br

[2] Universidade Federal de ViÃ§osa, Brazil, rafael.gpaes@gmail.com

[3] Universidade Federal de ViÃ§osa, Brazil, thallita.ferreira@ufv.br

However, in recent years the implementation of Renewable Energies (RE) has been growing rapidly, driven by government policies, by reducing the cost of some RE technologies, by the strong fluctuation of fossil fuel prices and electric energy tariffs, reduction of greenhouse gas (GHG) emissions (IPCC, 2011). Among the ER stands out the photovoltaic energy, which rightly converts solar energy into electricity through the solar panels.

Brazil has great potential for the installation of photovoltaic energy. On February 21, 2019, the country had a power granted of 1,987,719 kW, representing 1.21% of the energy generated (ANEEL, 2019).

Photovoltaic energy has been prominent in water pumping (WAZED et al., 2018). The great advantage of the use of photovoltaic systems for irrigation is that in the spring and summer period where the highest values of reference evapotranspiration (ET0) are observed, there is a greater pumping of water by the system due to the greater number of hours of sunshine (MICHELS et al., 2009).

There are two generations of photovoltaic pumping. The autonomous photovoltaic irrigation systems, without energy storage, work by oscillating the flow and pressure, since the solar radiation is not constant. To overcome this problem, energy storage mechanisms are used, in batteries or by pumping the water to a larger geometric height in relation to the irrigated area. However, these alternatives increase the cost. Another alternative that has emerged to solve this problem is the hybrid systems, which combine photovoltaic energy and other energy sources to provide security of the energy supply, in cases of low solar radiation conditions (LÓPEZ-LUQUE et al., 2015).

Carroquino et al. (2015) argue that the ideal economic solution for drip irrigation in the Mediterranean region is the hybrid photovoltaic and diesel pumping system. The presence of diesel generators eliminated the need to oversize the generation of photovoltaic energy to ensure energy security.

The objective of this work was to evaluate and compare the irrigation efficiency performed by local irrigation from a commercial standalone pumping kit (SB - without battery) with another one that uses batteries for energy storage (CB - with battery).

2. MATERIAL AND METHODS

The present work was carried out during the period from October 24 to December 20, 2018, spring season. The irrigation system was set up in the Experimental Irrigation Area, Department of Agricultural Engineering (DEA), Federal University of Viçosa (UFV), Viçosa - MG. The geographical coordinates are latitude 20º 46 'S and longitude 42º 52' W, being at 675 m of altitude in relation to sea level.

Two sets of submersible solar powered photovoltaic vibration pump were used, Anauger manufacturer, Anauger Solar R100 model. The pump works at the bottom of the tank, which simplifies the installation and allows the best use of the water level of the tank.

The photovoltaic system without energy storage (SB) was installed following the manufacturer's recommendations. The other system that uses batteries to store energy (CB) has been adapted to three stationary Heliar batteries Freedom DF1000 70Ah 12V, connected in series, and a Viewstar VS3048AU 30A 36V load controller , in addition to the use of another Anauger solar panel connected in series.

The two pumps were installed in a 1000-liter PVC water tank on the ground level next to the photovoltaic panels, however the systems did not work simultaneously. The water was then conveyed to the irrigation systems by a PVC pipe with nominal diameter of 32mm.

As the experiment was carried out in the Southern Hemisphere, the photovoltaic panels were positioned to geographical north, with slope similar to the local latitude (ALVARENGA et al., 2014). Such slope is important for maximizing power generation and for obtaining greater efficiency of the photovoltaic system due to the greater exposure to solar radiation.

The solar radiation measurements, in W m^{-2} were made by the Davis automatic weather station, through its pyranometer. The station was installed at the experiment site and programmed to collect data at intervals of five minutes.

The pressure readings were made with a Bronze Digital Manometer - VKP - 064, positioned before the hydrometer near the two irrigation systems. This device records maximum and minimum pressure values during each test. To do this, at the beginning of each repetition, the maximum and minimum pressure values were zeroed after the system was pressurized. The flow mediation in each test was calculated through the analog hydrometer and time relation. At the beginning and at the end of each test the volume readings were made in the apparatus, the difference between the final and initial volume divided by the duration time to find the average flow.

Two irrigation systems were used, one with iDrop Normal drip button emitters (Irritec), with a flow rate of 4 L h -1 at a pressure of 1 bar; and another with iDrop PC drip button emitters (Irritec), with a flow rate of 4 L h -1 , which is self- compensating , with approximately the same flow in the range of 0.5 to 4.5 bar. The two irrigation systems were composed of seven lateral lines, spaced 0.8 in 0.8 m, with each lateral line containing 22 emitters, spaced 0.5 in 0.5 m, totaling 154 emitters per system. The average service pressure of the emitters was 1.5 bar, considering the pump operating at maximum power, so that when the power supplied by the panel decreased, the emitters still worked above the lower service pressure limit.

This evaluation consisted of 4 irrigation systems, irrigation system with normal emitter with pump without storage of energy in batteries (NSB), irrigation system with self-compensating emitter with pump without storage of energy in batteries (PCSB), irrigation system with emitter normal with pump with energy storage in batteries (NCB) and irrigation system with self-compensating emitter with pump with energy storage in batteries (PCCB).

The evaluations were carried out between October 24 and November 30, 2018 (predominant season: spring). The NSB and PCSB tests were performed on random days and times, with cloud conditions varying between open, cloudy and cloudy days, in order to vary the solar radiation as much as possible, in order to perform the analyzes reliably.

A system was created to simulate the irrigation, returning to the water into the same reservoir in order to compare the volume pumped by each system for the same day. The pressure in the system was generated by the partial closure of the drawer register located at the end of the pipe, creating a pressure of 1.5 bar, using the CB system to regulate the register. The SB system worked all day while the CB system recharged the batteries, and at night the CB system works until the batteries are discharged. By making the readings in the hydrometer it was possible to calculate the volume pumped by each system for the same radiation condition. Six trials were performed between December 14 and 20, 2018.

For localized irrigation systems, the evaluation of water distribution uniformity was performed according to the methodology of Keller and Karmeli (1975), with modification proposed by Denícula et al. (1980). This methodology consists of the data collection in four lateral lines (first line, 1/3 line and 2/3 of the origin and last line), with a study of eight emitters per line (first emitter, emitters 1/7, 2 / 7, 3/7, 4/7, 5/7 and 6/7 of origin, and last issuer), totaling 32 collection points.

The coefficient of uniformity of distribution, the Christiansen uniformity coefficient (CUC - Equation 1), proposed by Christiansen (1942), and the distribution uniformity coefficient (CUD - Equation 2) proposed by Criddle et al . (1956).

$$CUC = \left(1 - \frac{\Sigma \; |L_i - L_m \;|}{n \,.L_m}\right).100$$

(Equation 1)

Where: CUC - Christiansen uniformity coefficient (%); L i - depth collected in emitter "i", mm; L m - average blade of all observations, mm; n - number of emitters collected.

$$CUD = \left(\frac{L_{25}}{L_m}\right).100$$

(Equation 2)

Where: CUD - distribution uniformity coefficient (%); L 25 - average of the lower quartile of the emitter depth (mm); Lm - mean depth of all observations.
To confirm the variation in the solar radiation conditions at the time of the NSB and PCSB tests, the hourly brightness index (K_T^h) for each evaluation by Equation 1, according to Duffie and Beckman (1980) (Equation 3).

$$K_T^h = \frac{Rs}{Ra}$$

(Equation 3)

Where: - hourly, non-dimensional clarity index; Rs - hourly solar radiation, W m^{-2}; Ra - radiation at the top of the hourly atmosphere, W m^{-2}.

For Rs, the mean value of solar radiation measured by the automatic meteorological station for each test was used and Ra was calculated according to FAO Bulletin 56 (1998). According to Escobedo et al. (2009), the hourly brightness index can be classified into four intervals,(K_T^h) ≤ 0.35 cloudy sky, 0.35 <(K_T^h) ≤ 0.55 partly cloudy with predominance of the diffuse component of solar radiation, 0.55 <(K_T^h) ≤ 0.65 partly cloudy with predominance of the direct component of solar radiation and(K_T^h) > 0.65 clear sky.

For localized irrigation systems, Kruskal- Walall's nonparametric test (CONOVER, 1980) was applied to verify if there was statistical difference between the calculated values of CUC and CUD of the 4 systems. The multiple comparison test used was the least significant Fisher difference (LSD) (CONOVER; IMAN, 1981), applied with the Bonferroni correction (SHINGALA; RAJYAGURU, 2015). Analyzes were performed in software R (R CORE TEAM, 2018), using the Agricolae package (DE MENDIBURU, 2019).

3. RESULTS AND DISCUSSION

Table 1 and Table 2 show the day and time at which each test was performed, the values of solar radiation and the hourly brightness index (K_T^h) for NSB and PCSB, respectively. According to Alvarenga et al. (2014), photovoltaic panels have good functioning from 9 to 15 o'clock, because in this period the Ra presents its highest values. Thus, (K_T^h) allows to characterize the solar radiation of a region, and it is possible to estimate the operation of the solar panels in the production of photovoltaic solar energy (GALDINO et al., 2016).

During daylight hours close to sunrise and sunset, even in clear sky conditions the Rs are low. Thus, to confirm the variation in the cloudiness conditions only the values of (K_T^h) comprised between 9 and 15 hours were classified.

Table 1. Date, time, solar radiation, and hourly brightness index for each NSB test

NSB					
Nº test	Date	H. Start	H.Final	Rad. solar (w/m²)	K_T^h
1	24/out	09:27:00	09:43:00	508.8	0.58
2	24/out	13:09:00	13:28:00	316.6	0.21
3	24/out	14:06:00	14:22:00	445.5	0.31
4*	24/out	15:05:00	15:22:00	415.4	0.32
5*	24/out	16:09:00	16:37:00	106.7	0.10
6*	25/out	08:34:00	08:56:00	345.0	0.63
7	25/out	10:10:00	10:28:00	418.0	0.36
8	25/out	14:11:00	14:27:00	372.3	0.26
9*	25/out	15:09:00	15:27:00	183.2	0.14
10	26/out	09:25:00	09:44:00	172.6	0.19
11	29/out	11:49:00	12:09:00	191.4	0.14
12	26/nov	10:00:00	10:15:00	795.5	0.57
13	26/nov	13:24:00	13:39:00	530.5	0.32
14	27/nov	09:09:00	09:24:00	684.3	0.60
15	27/nov	10:37:00	10:52:00	795.3	0.57
16	27/nov	12:24:00	12:39:00	956.3	0.58
17	27/nov	12:57:00	13:13:00	970.0	0.59
18	27/nov	13:30:00	13:45:00	1230.8	0.75
19	27/nov	14:16:00	14:31:00	430.7	0.28
20	27/nov	14:44:00	15:01:00	303.0	0.20
21*	27/nov	15:29:00	15:52:00	211.5	0.16
22	28/nov	10:09:00	10:26:00	412.8	0.29
23	28/nov	10:44:00	10:59:00	1032.8	0.73
24	28/nov	12:54:00	13:07:00	1164.3	0.70

*K_T^h values no classified

Table 2. Date, time, solar radiation, and hourly brightness index for each PCSB test

PCSB					
Nº teste	Date	H. Start	H. Final	Rad. solar (w/m²)	K_T^h
1	12/nov	12:29:00	12:47:00	639.8	0.40
2	12/nov	13:31:00	13:47:00	367.0	0.23
3*	12/nov	15:04:00	15:19:00	899.8	0.69
4	23/nov	10:57:00	11:12:00	552.0	0.35
5	23/nov	11:40:00	11:55:00	491.5	0.32
6	26/nov	09:03:00	09:18:00	286.0	0.25
7	26/nov	10:31:00	10:46:00	751.0	0.54
8	26/nov	12:00:00	12:16:00	782.5	0.47
9	26/nov	12:51:00	13:04:00	1285.3	0.78
10	27/nov	09:49:00	10:05:00	1101.5	0.97
11	28/nov	13:19:00	13:31:00	1106.7	0.67
12	28/nov	13:41:00	13:53:00	352.3	0.21
13	28/nov	14:03:00	14:15:00	735.0	0.48
14	28/nov	14:24:00	14:39:00	335.3	0.22
15	28/nov	14:46:00	15:01:00	732.0	0.48
16	29/nov	09:09:00	09:25:00	349.0	0.30
17	29/nov	09:37:00	09:55:00	338.5	0.29

* K_T^hvalues no classified

The NSB tests performed in 47.3% under cloudy conditions, 5.3% partially cloudy, with predominance of the diffuse component of the radiation, 31.6% partially cloudy, with a predominance of the direct radiation component and 15.8% clear sky. For the PCSB, the values were 43.7%, 37.5%, 0.0% and 18.8%, respectively. Thus, one can observe the variation of the solar radiation between the evaluations.

In Table 3, Figure 1 and Figure 2, it was observed that the tests that used the CB system presented statistically the highest values of CUC and CUD, in addition to exhibiting a lower degree of dispersion. This is due to the CB system working with constant pressure and flow, since the load controller provides a constant power to the pump. However, the SB system fluctuates the pressure and flow during the tests due to the variation of the solar radiation incident on the photovoltaic panel.

Table 3. Teste de média dos valores de CUC e CUD

System	CUC	Group	CUD	Group
PCCB	97,56	a	96,23	a
NCB	96,83	ab	95,19	ab
PCSB	96,68	b	94,64	b
NSB	95,88	b	93,31	b

a = higher average group and b = lower average group.

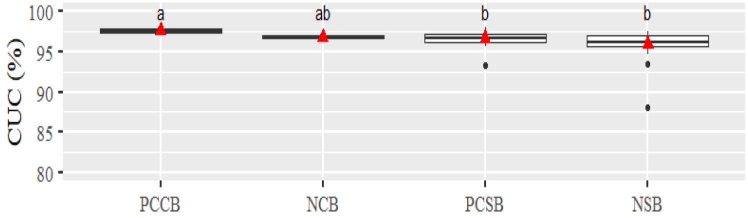

Figure 1. Multiple LSD comparison test for the observed CUC values for each system. Averages (red symbol) followed by the same letter do not present statistical difference.

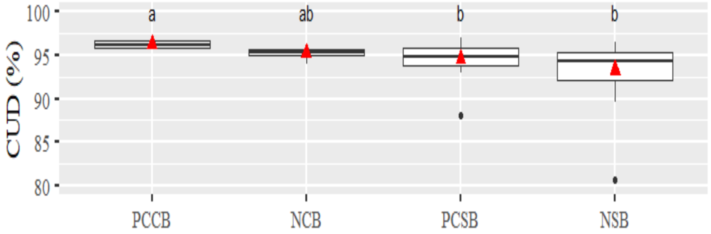

Figure 2. Multiple LSD comparison test for the CUD values observed for each system. Averages (red symbol) followed by the same letter do not present statistical difference.

Although the mean values of CUC and CUD are lower for the SB system, these values were classified as excellent according to Mantovani (2001). Only the NSB presented an evaluation in which the values of CUC and CUD were classified as good, 88.05% and 80.65%, which coincides with the lowest value of solar radiation among all the tests.

The other CUC and CUD values for all tests were classified as excellent. According to Zago (2017), in Cascavel - PR, using a small autonomous photovoltaic irrigation system with drip irrigation, similar results were obtained, none of the CUC and CUD values were classified as unacceptable, with most values obtained rated as excellent. Campana et al. (2015) found that the use of photovoltaic energy for pumping in an irrigation system is an alternative for the supply of water in a sustainable and economically viable way, mainly for arid and semi-arid regions.

Analysis of the type of emitter for the SB system the normal emitter (NSB) presented a greater dispersion of the calculated values and lower average value of CUC and CUD, although these were statistically equal. This is because in the normal emitter the flow varies due to pressure variation, while the self-compensating emitter has a mechanism to control the pressure above 0.5 bar, providing uniform flow rates and CUC and CUD values close.

The CUC values are always higher than the CUD values for the same test, since the latter is a more rigorous test, since in its methodology the 25% smaller volumes was used for its calculation. Figure 3 shows that the flow rate of the CB system is very small, with a standard deviation of 24.63 L h-1 for NCB and 7.71 L h-1 for PCCB. The SB system shows a very large variation in flow rates, following the solar radiation oscillation. The standard deviation for NSB and PCSB were, respectively, 158.52 and

119.37 L h-1.

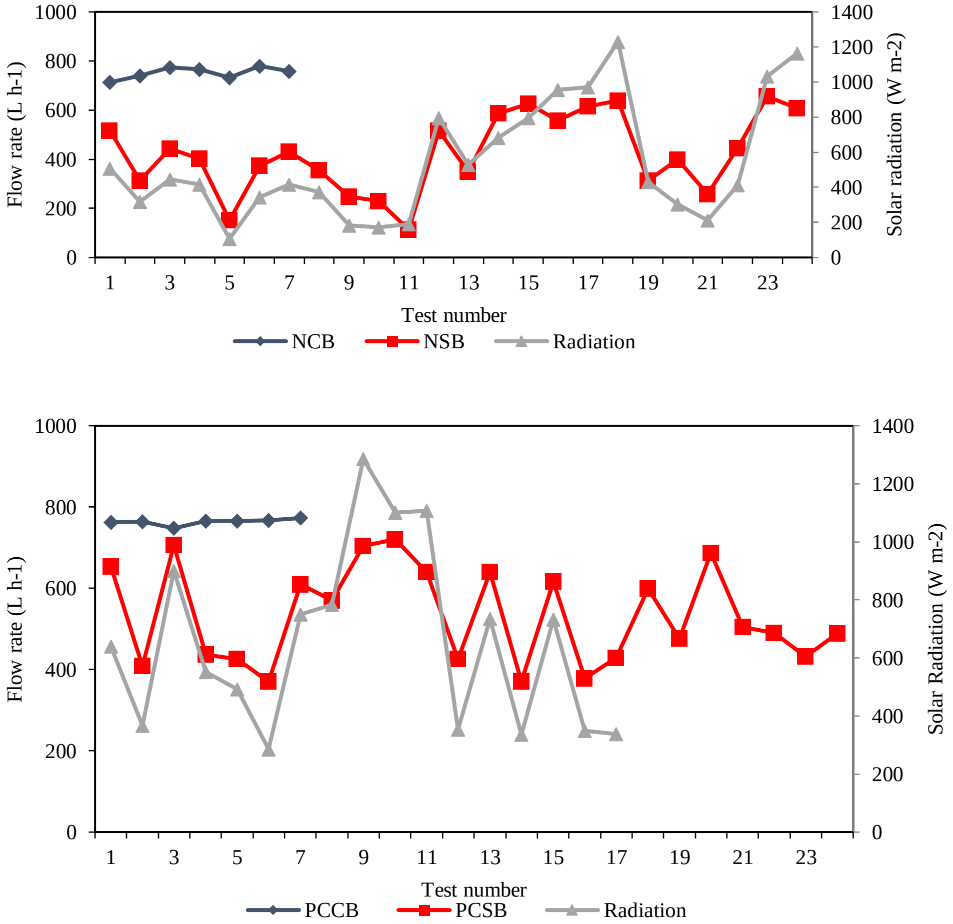

Figure 3. Variation of system flow and solar radiation observed for the NSB and PCSB evaluations.

4. CONCLUSIONS

Photovoltaic drip irrigation systems with batteries are more effective due to greater uniformity of application of the irrigation and flow rate.

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