International Journal of Advanced Engineering Research and Science (IJAERS)
Peer-Reviewed Journal
ISSN: 2349-6495(P) | 2456-1908(O)
Vol-9, Issue-4; Apr, 2022
Journal Home Page Available: https://ijaers.com/
Article DOI: https://dx.doi.org/10.22161/ijaers.94.21

Study Comparison of the Efficiency of a Photovoltaic System with Fixed Panels and with Solar Tracker in the Northwest of Brazil

Rodrigo Machado Cavalcanti[1], Elissandro Monteiro do Sacramento[2], Lutero Carmo de Lima[3], Natasha Esteves Batista[4]

[1]Centro de Ciências e Tecnologia Universidade Estadual do Ceara´ Fortaleza, CE, Brazil
E-mail: rodrigo.cavalcanti@aluno.uece.br
[2]Instituto Federal de, Educação Ciência e Tecnologia-IFCE Fortaleza, CE, Brazil
E-mail: elissandro.monteiro@ifce.edu.br
[3]Centro de Ciências e Tecnologia
Universidade Estadual do Ceara´ Fortaleza, CE, Brazil
E-mail: lutero.lima@uece.br
[4]Departamento de Engenharia Elétrica Universidade Federal do Ceara Fortaleza, CE, Brazil
E-mail: natashaestevesbatista@gmail.com

Received: 16 Mar 2022,

Received in revised form: 10 Apr 2022,

Accepted: 16 Apr 2022,

Available online: 26 Apr 2022

©2022 The Author(s). Published by AI Publication. This is an open access article under the CC BY license (https://creativecommons.org/licenses/by/4.0/).

***Keywords*— Photovoltaic System, Angle, Solar tracker, Return on Investment.**

***Abstract*— The performance of small photovoltaic (PV) systems connected to the grid in the state of Ceará is analyzed in this study. Three systems were developed, two of them with fixed angles of 18 and 22 degrees and one with a variable angle (solar tracker), which provided different results of generation efficiency, all of them have the same power of 2310 kW installed and are located on a building slab in the city of Fortaleza, in this configuration the systems have the same inputs to compare. The variation in generation efficiency be-tween systems is quite significant, reaching 19% between fixed and 27% when compared the worse fixed system and solar tracker, the higher costs for these types of system with tracker can increase the rate of return on investment turning into 2.9 years, higher than that of the fixed system with an angle of 22, which was 2.38 years.*

I. INTRODUCTION

The source of energy is divided into non-renewable energy or known as conventional energy and renewable energy. Non-renewable energy is defined as an energy source that cannot be recreated in a short period of time, such is coal, natural gas and oil. Renewable energy is another type of energy that has unlimited sources, such as hydropower, solar energy, biomass energy. etc.

The capacity to generate renewable energy is intensified each year through global warming. The trends in the use of this type of energy only tend to increase, with this the Government of the State of Ceará in 2019, launched the first and only hybrid atlas (wind and solar) in Brazil, this document has technical information aimed at professionals in the sector, identifying the best regions in the state to invest. Having a better idea of the best areas of solar and wind generation, with the numerical potentials such as wind speeds and solar radiation indices throughout the state of Ceará. [1]

The solar energy produced by the sun as call solar photovoltaics energy, this type of energy is divided in two categories. The first one is centered energy (solar power farms) the state of Ceará occupied the fifth place on country raking of state in 2021 with the production of 2951.6 MW. The second category is distributed energy (residential, rural, industry and commercial places), that is characterized by possibility to produce your own energy. The state has tenth place on country state ranking on 2021 with the production of 239.3 MW. As we know this amount is far way from the state potential. [2]

Taking this in consideration, this paper has focus in category distributed energy to increase the efficiency in around 15% reducing the payback time to less than three years. [3]

Justification

Due to the high capacity of the solar energy generation farms in state of Ceará and only a few places in the country have this solar irradiation. It is expected that with the use of small sized solar trackers, solar farms will have a large generation capacity per hectare, with this characteristic the generation curve would be more stable throughout the day. This work is justified by the prediction of reduced damage to

the environment, in addition to increasing the efficiency of solar photovoltaic generation, making applications in small distributed generation more viable.

Objectives

The general objective of this work is to compare the efficiency between a fixed photovoltaic system and one with a horizontal tracker, taking into account the gain in generationper area and costs.

The specific objectives of this study are:

1. Analyze the data of the Fortaleza resources stations (Fuceme and Solcast);
2. Develop an automatic control system for solar tracker;
3. Compare performance of the solar tracker system withthe fixed system;
4. Calculate the systems(tracker and fixed) paybacks.

II. EFFICIENCY STUDIES ABOUT PHOTOVOLTAICS SYSTEMS

The studies of PV systems have increase each year by academics and companies that aim to improve higher capac ity systems. The most compared set-ups are shown in the options below:

1. Between angles of each PV.
2. Direction of then PV.
3. Location on the Earth.
4. Compare between tracker and fixed system efficiency.

This article approach is related to the topic fourth. To improve both systems finding the best fixed angle and also compare what is the best system from a financial point of view.

In [4] a comparison between a fixed system of 38 degree inclination and a tracker, is made in Greece. The results yearly production was significant, 24.68% more efficiency on the tracker system. [4]

A experiment in Indonesia compare 2 systems one fixed solar panels in a angle of 15 degrees with a solar tracker. The results showed the power output of solar trackers does not in-crease compare with the fixed system. The conclusion was that have some loss with the power in the actuator and the average capacity factor was 9.6% and the final yield percentagewas 2.37%. [5]

Empirical studies were made too reviewing various methods of solar tracking, with gains in energy due to tracking and different MPPT algorithms. Results found that the active trackers were more commonly used when compared to passive trackers. Among the active trackers it was found that, the maintenance issues related to dual axes active trackers is irrelevant to maximize the efficiency of the PV system and allows controlled and competent collection and distribution of energy. The review further concludes that the increase in gain due to active tracking is approximately 30% with respect to the fixed system. [6]

One of the primary reasons of PV tracking systems is to improve the low efficiency of PV modules and consequently, the lower generation of electrical energy. Improvement in photovoltaic tracking systems can be made by using PV systems with concentrating mirrors (CPV) and photovoltaic/thermal hybrid systems (PV/T). Each of these systems has the potential to increase the yield of electrical en ergy. A fixed system compare to a system that has tracker and mirrors can have efficiency improved up to 22-56%. [7]

Some studies compare fixed PV and double axis tracker in the same latitude have an improvement of 30.79% yearly. Using crystalline silicon PV, the differences between single and doubles axis were estimated and varied around 5%. [8]

In the University of Ceará a study was developed regarding the calculus of the potential of generation in the state. The results showed that the total energy production during the measured period was 3708.2 kWh and the nominal energy production was 1685.5 kWh / kWp, showing a great potential of energy production that can be explored. [9]

III. MATERIALS AND METHOD

Material

The system will have the following items installed:

1. Two systems with seven solar panels in each of the fixed

generation system. The panels are from Canadian Solar brand model: 6S6U-330P and two solar inverters Ecosolys Ecos 2000 Plus.

2. One photovoltaic system with solar tracker (linear shifter), that has linear movement seeking greater performance (500 mm x 750 N linear actuator). This sys- tem has a inverter Ecosolys Ecos 3000 and 7 Canadian Solar panels model: 6S6U-330P.
3. One electrical panel for the system solar tracker movement (own manufacturing). Is a electronics PCB was made with the following components LM7805,LM393N, LDR, Transistor BC327.

Data irradiation collection

The irradiation data use on the project was collect on the Fuceme PCD installed on the University of Ceará that is 14 km from the FV system and the temperatures were use the data from the station of Fuceme in Praia do Futuro that is 4 km from the PV system. In the Figure 1 are the values collected on the PCDs from Fuceme and also include the in- formation from Solcast website to validate the results. The method use from the is type meteorological year and the results were very similar to the collecting stations.

Method

Many studies have develop renewable energy andgive effort in finding the optimum method to harness the energy, one of the discussing is tilt angle on PV panels. The ability of solar farms to produce energy is very dependent on the intensity of irradiance and duration of sun exposal onthe PV panel [10]. The current technology for a PV system is installing actuators on the panel so can follow the direction of the sunlight, this is the system mentioned on topic 3.1subtopic 2.

Month/Year	Temperature (C°) Fuceme Praia do futuro	Fuceme Uece irradiation kw/m2	Solcast irradiation kw/m2
Dec-20	28.27	180.56	184.02
Jan-21	25.41	165.73	168.50
Feb-21	28.15	153.03	153.80
Mar-21	27.57	141.30	141.83
Apr-21	28.14	163.39	163.38
May-21	27.44	142.78	146.03
Jun-21	27.82	156.36	159.82
Jul-21	27.38	168.88	172.71
Aug-21	27.13	197.67	194.63
Sep-21	27.46	198.03	195.169

Fig. 1. Irradiation and temperature data.

There is a fixed angle solar generation system shown in Figure 2 which is connected to 2 kw ecosolys inverters, these data are compared with each other and with the other system, the solar tracker showns in Figure 3 (this movement is done through a mobile system with linear shifter) is connected to a 3 kW Ecosolys inverter, the system has the samepanels power as the others.

Fig. 2. Fixed systems of the roof of the building.

The inverters manufacturer has its own application, to which one of the inverters connects via the internet to the manufacturer's server keep the records of generation daily, monthly and annually. This provides accurate information on the system's generation data.

Fig. 3. System with Tracker.

IV. MAIN EQUATIONS

Energy output

The total energy output is given by the total generation of power by the system over a given period of time. The monthly energy produced can be determined by the Equation1:

$$E_{AC,m} = \sum_{h=1}^{N} E_{AC,h} \qquad (1)$$

System efficiencies

The system efficiency can be PV array efficiency and system efficiency. Depending of the time resolution it can be hourly, daily, monthly or annually, in the project case was used monthly. The array efficiency is η_{PV} , is giv ing by the formula 2, where P_{PV} is the power of each so-lar panel has the power of 330 watts each (330*7 panels) / 1000, Y_{PV} is the monthly read values of radiation readied in (KWh/m^2/month), [11] Y_R is the power generated of the sys-tem and A_{PV} is the area of this system in square meter. As can be seen in Figure 4. [12]

3.3.1 Payback

In the figure 10 has the payback data table with the values of the three systems. To convert the values of money in

$$\eta_{PV} = \frac{100.P_{PV}.Y_{PV}}{Y_R.A_{PV}} \qquad (2)$$

dollars was used the exchange rate of one dollar to R$ 5,60 reais. The interest rate of the energy values was 10% per year in the first 4 years gave the U$0,17 per kilowatt. This value

The performance of all system installed is given by theformula number 3.

was multiply per total yearly production and divided by theinvestment in each system giving the payback in years.

$$\eta_{sys} = \frac{100.E_{CA}}{H.A_{PV}} \qquad (3)$$

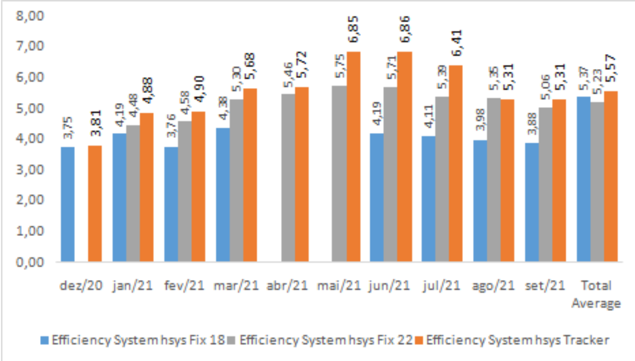

Fig. 4. Efficiency of the System.

Performance ratio

The performance ratio (PR) is showed in Figure 5 the calculus of this system indicates a overall effect of losses on a PV array´s normal power output. The PR values show how close the value is to the optimal performance during real operation and allows a comparison of PV systems independent of location, tilt angle, orientation and their nominal rated capacity. The PV system efficiency is compared with the nominal efficiency of the photovoltaic generator under standard conditions. Performance ratio is defined as the ratio of the final energy yield of the PV system Y_F to the reference yield Y_R: [13]

Month/Year	Performance Ratio - Fix 18	Performance Ratio - Fix 22	Performance Ratio - Tracker
dez/20	50,99	0,00	51,88
jan/21	56,96	61,04	66,47
fev/21	51,23	62,40	66,71
mar/21	59,60	72,20	77,28
abr/21	0,00	74,32	77,87
mai/21	0,00	78,22	93,17
jun/21	57,04	77,77	93,39
jul/21	55,87	73,29	87,25
ago/21	54,13	72,79	72,21
set/21	52,80	68,85	72,24
Anual average	73,10	71,21	75,85

Fig. 5. Performance Ratio.

V. CHANGES AND PRESENTED DIFFICULTIES

There were some problems in the inverters of this manufacturer's line. Because they are in process of guaranteed, the factory requires that the equipment has to be sent for re-pair on site, which is 4815 km away from where the system is installed. For this reason, there were two months that fixedangle system was unread, decreasing the history of collecteddata. In this process, the Ecososys 2 K brand Inverters endedup having their versions updated, to the Ecos 2 K+ version, with electronic improvements.

It is noteworthy that the inverter that was connected to the solar tracker system did not show any damage during themonths of data collection (from December 2020 to September 2021).

VI. RESULTS AND DISCUSSION

Taking into account the efficiencies of fixed solar gener ation systems have a loss of 15 to 25% of power, the objective is to reduce this loss and also reduce the investment requiredto purchase a solar generation system.

Three systems were assembled, two fixed with differentangles and one with a tracker. The data collection prove thereal efficiency percentage of the system.

The project's goal is a maximum payback of 4.0 years, taking into account the KW value of 0.17 dollars/KW. As show in the Figure 10 the systems had values with less the 3years payback.

Results obtained

The fixed system 01 has an angle of 18 degrees, the fixed system 02 has an angle of 22 degrees and one tracking system has a horizontal movement of 1 axis as shown in Figure 3, allfacing north.

4.1 Capacity Factor

$$PR = \frac{100.Y_F}{Y_R} \qquad (4)$$

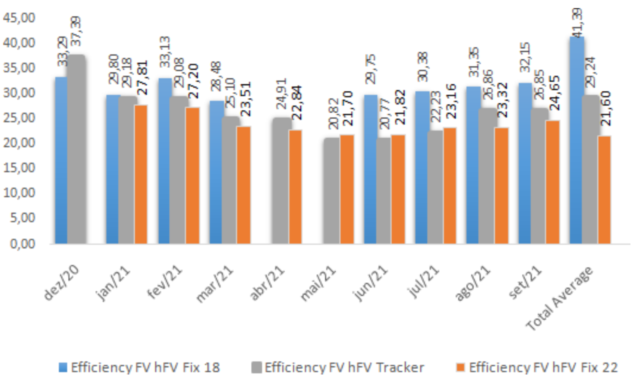

Fig. 6. Efficiency of the arrangement.

The capacity factor is used to present the energy delivered by an electric power generating system is defined as theratio of AC energy produced by the PV system over a period of time, to the energy output that would have been generatedif the entire period. [14]

Tracking generation system data was collected from December 2020 to September 2021, also inside the rainy sea- son, this was considered for the percentage analysis because both are in the same location. The system with a tracker in compared to the fixed system of 18 degree produces 27% and

$$CF = \frac{EAC}{P_{PV}.8760} \qquad (5)$$

between tracker and system with 22 degree produces 10%more as shown in Figure 10.

This shows that the direction angle at which the panels are mounted is essential for the system's energy result, as this small monthly difference is crucial for the medium-termreturn of the investment.

The Figure 7 shows the average monthly of radiation of the three systems in KWh/m^2/month , from December 2020 to September 2021. The irradiation varied between 180,56 kWh/m^2 in December 2020 to 198,03 kWh/m^2 in September 2021. The lowest month of radiation was May 2021.

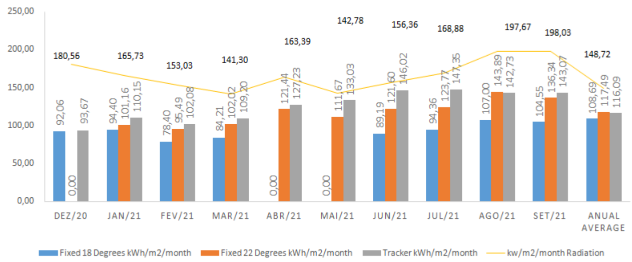

Fig. 7. Monthly energy production of each system and in-plane irradiation.

VII. CONCLUSIONS

Regarding the production of each system the fixed with 18 degrees was 2904 kwh/year, fixed with 22 degrees was 3576 kwh/year and the system with tracker was 3953 kwh/year, is a good producing average to the systems com- paring to the radiation level on the same period.

Figure 8 represent the efficiency of the PV module and also the efficiency of the systems, this values vary between each system, the fixed 18 degree has values between 29,75% to 33,29 % for PV efficiency and the system efficiency varybetween 3,75% to 4,38%, the fixed 22 degree has values be-tween 21,70% to 27,81% for PV efficiency and the system efficiency vary between 4,48% to 5,75 %, the tracker PV efficiency has values between 20,77% to 37,39% for PV efficiency and the system efficiency vary between 3,81% to 6,86%. This values represent the result of the energy produced in each system considering the climate of the region showing the months between December to March the worseones because is the raining season on Ceará. Figure 9 shows capacity factor of all system shows the result of position andthe angle of each system can have different results for the so- lar power generation. Figure 1 fixed system has 22 degrees produces 19% more energy compared to fixed system 18 degrees, this shows that with a simple study, a better earning results can be obtained simply by better calibrating the angle of incidence, it is clear that this is not a simple reality for the majority, of the distributed generation installations that we have installed in the state of Ceará. The vast majority of them are roof installations and not on slabs or ground, thus making the adjustment of angle difficult, but at the same timeit leaves the gap for analysis in places that they have space for installation on the ground, like farms in the interior of the state, that have distributed generation, which they end up supplying through discounted credits on the bills of customers residences who live in cities, making better use of theland in the interior of the state.

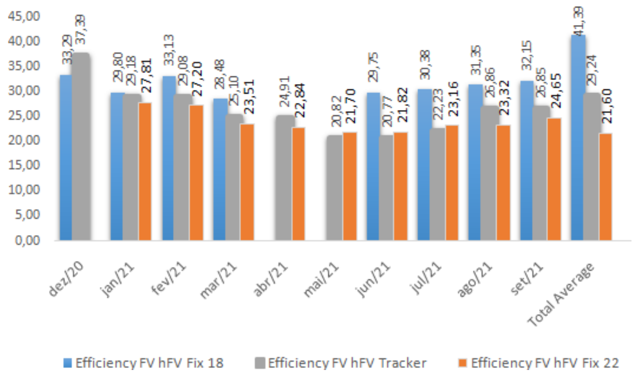

Fig. 8. Efficiency of the systems.

Month/Year	Capacity factor fixed 18	Capacity factor fixed 22	Capacity factor Tracker
dez/20	40%	0%	41%
jan/21	41%	44%	48%
fev/21	34%	41%	44%
mar/21	36%	44%	47%
abr/21	0%	53%	55%
mai/21	0%	48%	58%
jun/21	39%	53%	63%
jul/21	41%	54%	64%
ago/21	46%	62%	62%
set/21	45%	59%	62%
Anual average	27%	51%	54%

Fig. 9. Capacity Factor.

Opens the discussion regarding developing projects of new structures that can be install in roofs with the possibilityof adjusting the angle.

Also was installed a trackers system with a additional cost of 350 dollars that has a solar follower, as seen in figure 2, with 2 kw peak power system, but which generates an extra 10% compare to the system of 22 degree is best fixed angle system. So we can make the following calculations seen in figure 10.

Based on the results presented in figure 10, it can be seen that the additional cost to install a system with a solar tracker ended up generating an additional value in this case that was not higher then financial value generated for energy in the scale of 10%, thus the system with the follower endedup having a payback time superior to the 22 degree system, being economically more profitable only after 2.90 years, a new system that requires less maintenance. It is worth high- lighting the search for the perfect fixed angle and position of the panels that best adapt for each region, it can bring great results without raising costs, reducing the return on investment in up to 6 months.

All the three proposed systems have a good performance, but they have different prices of installation and power generation, as was seen on the results, with the numbers the more profitable project for short scale is the one with less payback in years, is the one with fixed angle of 22 degree, but also open the door to analyze structures the can have a little adjustment of angle and be install in roofs to getbetter results with lower investments.

Description	Fixed (18°)	Fixed (22°)	Tracker
	KW/Year	**KW/Year**	**KW/Year**
Anual Generation	2904.2	3576.8	3953.04
Annual interest rate	10.0%	10.0%	10.0%
Value of the Kw	$0.17	$0.17	$0.17
Savings in a yead	$487.49	$600.39	$663.55
Costs of each system	$1,428.57	$1,428.57	$1,571.43
Aditional cost	$0.00	$0.00	$350.00
Total cost system	$1,428.57	$1,428.57	$1,921.43
Payback investment in years	2.93	2.38	2.90

Fig. 10. Pay back of the systems

REFERENCES

[1] CEARA, G. E., 2020. Atlas do Eolico Solar do estado do Ceara. See also URL https://www.ceara.gov.br/.

[2] ABSOLAR,2021. Associacao Brasileira de Energia Solar Fotovoltaica. See also URL https://www.absolar.org.br/mercado/.

[3] GURGEL VIEIRA, R.", 2014.". In Tese Analise comparative do desempenho entre um painel solar estatico e com rastreamento no municıpio de Mossoro-RN.

[4] V.Perraki, and Megas, L., 2016. Single axis tracker versus fixed tilt pv: Experimental and simulated results, Department of Electrical and Computer Engineering, Greece.

[5] Herdian Wibowo, Yohandri Bow, C. R. S., 2021. Performance comparison analysis of fixed and solar- tracker installed panel at pv system, Departament of Renewable Energy Engineering, Politeknik Negeri Sri-wijaya.

[6] Sumathi, V., and Jayapragasha, R., 2019. Solar tracking methods to maximize pv system output – a review of the

methods adopted in recent decade, School of Electrical Engineering, VIT University, Chennai Campus, India.

[7] Seme, S., and Štumberger, B., 2020. Solar photovoltaic tracking systems for electricity generation, Faculty of Energy Technology, University of Maribor, Slovenia.

[8] Eke, R., and Senturk, A., 2012. Performance com- parison of a double-axis sun tracking versus fixed pv system, Mugla Sıtkı Kocman University, Clean Energy Research Development Centre, Turkey.

[9] De Lima, L. C., and de Araújo Ferreira, L., 2017. Performance analysis of a grid connected photovoltaic sys tem in northeastern brazil, Mestrado Acadêmico em Ciências Físicas Aplicadas, Universidade Estadual do Ceará, Brazil.

[10] Kurniawan. A., Taqwa A., 2019. PLC Aplication as an Automatic Transfer Switch for on-grid PV System. See also URL https://doi.org/10.1088/.

[11] Adaramola MS, V. E., 2016. Preliminary assessment of a small-scale rooftop pv-grid tied in norwegian climatic conditions., Climate and Average Weather Year Round in Fortaleza.

[12] Sharma V, C. S., 2013. Performance analysis of a 190 kwp grid interactive solar photovoltaic power plant in india, Centre for Energy and Environment, National In- stitute of Technology.

[13] Ozden T, Akinoglu BG, T. R., 2016. Long termout- door performance of three different on-grid pv arrays in central anatolia, Electrical and Electronics Engineering, Gümüşhane University, Turkey.

[14] Elhadj Sidi CEB, Ndiaye ML, B. M., 2016. Performance analysis of the first large-scale (15 mwp) grid- connected photovoltaic plant in mauritania, Unite´ Energies Renouvelables, Departement physique, Universite des Sciences, de Technologie et de Médecine (USTM), Mauritania.