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Comparative analysis of tracking mechanism benefit on the performances of flat PV technologies in the context of Burkina Faso operating environment

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Abstract

In this study, we seek to establish practical reference frames of comparison allowing to evaluate the potential and limit of production of the photovoltaic panels considering the used of sun tracking mechanism as a way to improve the harvesting energy. The objective is to identify the performances which various photovoltaic technologies can reach under the case of real weather conditions, in one hand, and under idealistic ultimate suitable case of 25°C cell temperature and the best radiation level provided through a clear sky at the specific altitude, in other hand. The study, starting from a predictive mathematical model of PV system integrating the effect of climatic conditions in the investigation of the performances at Ouagadougou (12.36° North, 5.41° East). The comparative analysis is done on annual energy output vs the tracking mechanism and on time series energy output vs the tracking mechanism. The study reveals that full tracking operated with BP 585F mono-Si solar cell is the most efficient case. Full tracking improved the harvesting energy by 14% compared to fixed approach whatever the used technology. Indicators have been highlighted that allows the yearly or real time estimation of each PV technology benefit.

Keywords: Predictive approach; Tracking mechanism; Flat PV; Temperature effect; Reference statement

1. Introduction

Solar energy is a form of energy that contributes to development while having a low environmental impact. It is very abundant in Burkina Faso, and its exploitation can help to improve the living conditions of the population. To study solar energy, System simulation is necessary to investigate the feasibility of Solar PV system at a given location [1] [2]. In fact, solar PV energy output is multi parametric dependency and climatic conditions are part of these parametric effects on the performances. Sun-tracking systems play an important role in the development of solar concentrating applications [3]. But is this importance transposable to flat PV technology. For many suppositions solar trackers worth the additional investment, by raising the level of solar radiation over the flat PV. So, they can contribute to improve PV systems performances depending to the tracking mode applied, to the location, to the hour and to the period of the year.

Previous works, has showed that the raising is more or less significant depending on the region, and [5] because of climatic parameters which vary to the nearest kilometers of earth. Although, tracking lead to increase level of solar radiation, it also led to increase cells temperatures, which can drop the PV efficiency. Besides, Tansu FİLİK et al. [6] studies show that tracking and fixed systems performances are more or less similar during cloudy days, as the global

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radiation is mainly composed of diffuse irradiation which is less sensitive to the receiver orientation. Takes into account a tracking mechanism suggests the consideration of the energy consumed by the moving fixtures. This amount of energy is mostly around 2‑5% of the collected energy but this could be higher if no optimization is performed [3]. In fact, when the slope of the surface varies continuously the driver need more energy to move the system. When the angular speed of motion is not appropriate with the demanded torque the efficiency of the motor decrease. Furthermore, the investment and installation cost on tracking systems is hard to recover because of the energy needed for driving the tracking system, if it is applied on small scale system. Therefore, the tracking mode winning a good power output with the simple and reliable mechanism of control and operation is more suitable.

The main question of today is to know if with such correlation solar trackers are worth the additional investment and if so for which PV technologies. Since the performance of solar system is subject to the alignment of the collector normal with the sun direction, many scientists have studied sun tracking systems with different applications to improve the efficiency of solar systems. Recently, Senpinar et al. (A. Senpinar, 2012) studied the effect of tracker on the performance of PV panel in Turkey, as Moshen et al. (Mohsen Mirzaei, 2018) did the same study for the case of Iran. Masakazu et al. (Masakazu Ito) found that tracking systems applied on large scale PV system earn 2 USD/W PV in world deserts.

Best benefits in power generation are generally made for full-tracking mode, but it is the most complicated one to be managed. These experimental studies bring information about the outcomes with the actual state of the art of solar technology field.

This paper aims to evaluate the performances of 5 solar cells technology according to 5 most commonly used solar tracking mechanism in a specific area of Burkina Faso at the latitude of 12°36 North 5.41° East. This work gets rid of multiple-choice purpose in real conditions based on onsite data and also the perspectives of idealistic improved conditions of clear sky, PV system operating at STC temperature 25°C.

2. Material and methods

2.1. Solar energy evaluation

2.1.1. The used database

Surface radiation measured data (hourly timestep) is taken from MeteoNorm. These data give a stair-step pattern. In this study we generated minute timestep series based on an algorithm that preserves the hourly sums from the weather data files and produces a smoother shape with no discontinuities [7]. This algorithm is the one incorporated in version 18 of the TRNSYS software package.

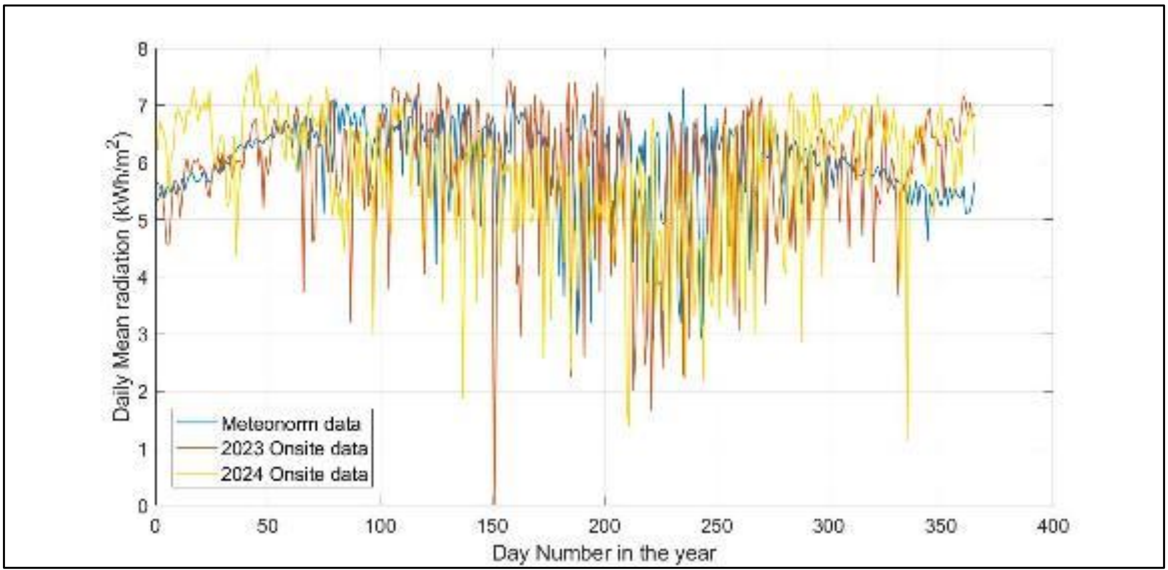

Figure 1 Daily radiation sample from the used databased

From figure 1 it can be observed that for the same daynumber the daily mean radiation changes from year to year, but Meteonorm data is a good match to be considered. as the same maximum level shows to be reached.

2.2. The studied tracking mechanisms

There are different approaches for PV tracking system [2] [3]. The sun tracker to achieve a full tracking were the sun is continuously track through two-axis closed loop (W.A. Lynch, 1990) and two-axis open-loop (K. Park, 1996) tracker. The sun can be track through one-axis open-loop (Kalogirou S. , 1996). We consider the case of fixed frame as the normal condition and are going to referee to this case in order to find out more improvement bring by tracking mechanism. Track2 is a partial tracking approach. Among one-axis approach we consider track 2 and track 3 and among two-axis model we consider track 4 and track 5, as followed.

2.2.1. Fixed frame

Our reference is a fixed system with latitude-tilted-axis in North-South direction. In this case we consider an inclination of 12,36° in south direction, which is the most common way to install solar PV panel in Burkina Faso.

$$\beta = \phi \quad (1)$$

$$\alpha = 0 \quad (2)$$

$$cos\,\theta_I = sin(\phi \pm \beta)\,sin\,\delta_S + cos(\phi \pm \beta)\,cos\,\delta_S\,cos\,\omega \quad (3)$$

2.2.2. Track 1

A one-axis sun tracker, the tracking axis is tilted from the horizon by an angle oriented along North-South direction, and tilted so that the normal surface is aligned with the sun each noon.

$$\beta = \phi - \delta_S \quad (4)$$

$$\alpha = 0 \quad (5)$$

The incidence angle is equal to (Meinel and Meinel, 1976; Duffie and Beckman, 1991)

$$cos\,\theta_I = sin^2\,\delta_S + cos^2\,\delta_S\,cos\,\omega \quad (6)$$

2.2.3. Track 2

A one-axis sun tracker, the tracking axis is to remain parallel to the surface of the earth and it is always oriented along North-South direction; the tracking is operated from East to West.

$$tan\,\beta = tan\,z\,|cos(\alpha - a)| \quad (7)$$

$$\alpha = \begin{cases} 90° & if\ a > 0° \\ -90° & otherwise \end{cases} \quad (8)$$

The angle of incidence can be obtained from (Kreith and Kreider, 1978; Duffie and Beckman, 1991)

$$cos\,\theta_I = \sqrt{sin^2\,h + cos^2\,\delta_S\,sin^2\,\omega} \quad (9)$$

2.2.4. Track 3

A one-axis sun tracker, the tracking is operated from North to South about and horizontal east-west axis

$$tan\,\beta = tan\,z\,|cos(a)| \quad (10)$$

$$\alpha = \begin{cases} 0° & if\ |a| \le 90° \\ 180° & if\ |a| > 90° \end{cases} \quad (11)$$

The angle of incidence can be obtained from (Kreith and Kreider, 1978; Duffie and Beckman, 1991)

$$cos\,\theta_I = \sqrt{1 - cos^2\,\delta_S\,sin^2\,\omega} \quad (12)$$

2.2.5. Track 4

This is the full tracking mode which is define as the Two-axis azimuth-elevation tracking.

$$\beta = z \quad 13$$

$$\alpha = a \quad 14$$

$$\cos\theta_I = 1 \quad 15$$

2.2.6. Track 5

A two-axis sun tracker, the tracking axis is to remain parallel to polar axis and the tracking is operated from North to South.

$$\tan\beta = \tan\phi / \cos\alpha \quad 16$$

$$\alpha = \tan^{-1}\left(\frac{\sin z \sin a}{\cos\theta' \sin\phi}\right) + 180 C_1 C_2 \quad 17$$

Where $C_1 = \begin{cases} 1 & si \ \left(\tan^{-1}\left(\frac{\sin z \sin a}{\cos\theta_I \sin\phi}\right)\right) a \geq 0 \\ 0 & otherwise \end{cases}$

$C_2 = \begin{cases} 1 & if\ a \geq 0° \\ -1 & otherwise \end{cases}$

$\cos\theta' = \cos z \cos\phi + \sin z \sin\phi \cos a$

The incidence angle is given by

$$\cos\theta = \cos\delta_S \quad 18$$

2.2.7. Estimation of solar radiation

For a given sun tracker, the theorical irradiation is approximated by Bernard [12, 13], and Daguenet [14]:

$$\psi_{th,gl0} = \psi_0\left[1 + 0.033\cos\left(\frac{360}{365}N_{jr}\right)\right] \times f_{atm}\cos\theta_I \quad 24$$

with

$$f_{atm} = A\exp(-B \times m_h) \text{ and } m_h = \frac{p_{atm}}{1000 \sin h}$$

In line with M. Daguenet [14], we consider a clear sky, while taking A = 0.87 and B = 0.17 as constants for determining the atmospheric attenuation of irradiation f_{atm}.

2.3. The conversion of solar radiation into electricity

Generally, the power delivered by a module is calculated by the equation [15]:

$$P(t) = \eta_{PV}(t) A \psi(t) \quad 195$$

Where

- A is the PV working area,
- $\eta_{PV}(t)$ is the efficiency of conversion of solar energy into electricity.
- $\psi(t)$ is the amount of energy considered at this time

We estimate the amount of energy collected in tracking mode on the basis of the amount of energy in horizontal plane by the correcting equation:

$$\psi(t) = \psi_{dif}(t) + \alpha(t) \times \psi_{dir}(t) \quad 26$$

The temperature at a given time $T_C(t)$ is determined based on the following equation:

$$T_C(t) = T_a(t) + h \times \psi(t) \quad 27$$

Where

$T_a(t)$ ambient temperature at the given time,
h is a coefficient given in table 1.

Many studies showed that the efficiency is in general is a function of the cell temperature T, the relative air mass AM and the global irradiation G (i.e. $\eta = \eta(\psi, T, AM)$). Wilhelm Durisch and al. [15] proposed a general model to predict the efficiency of many modules under varying climatic conditions, which is :

$$\eta_{PV} = p\left[q\frac{\psi}{\psi_0} + \left(\frac{\psi}{\psi_0}\right)^m\right]\left[1 + r\frac{T}{T_0} + s\frac{AM}{AM_0} + \left(\frac{AM}{AM_0}\right)^u\right] \qquad 208$$

The open parameters p, q, m, r, s and u have been determined by Wilhelm Durisch and al. [15] for five different modules fabricated with mono-crystalline, poly-crystalline and amorphous silicon as well as with copper–indium-diselenide, CuInSe2.

Table 1 Production variation rate in comparison to the best generation in fixed mode

Module	Producer	*p*	*q*	*m*	*r*	*s*	*u*	*h*
BP 585F mono-Si	BP Solar	23.62	-0.2983	0.1912	-0.09307	-0.9795	0.9865	0.028
LA361K51S poly-Si	Kyocera	15.39	-0.1770	0.794	-0.09736	-0.8998	0.9324	0.026
UPM US-30 a-Si	UniSolar	36.02	-0.7576	0.6601	-0.02863	-1.1432	1.0322	0.022
CIS ST40 $CuInSe_2$	Siemens	18.55	-0.3288	0.2612	-0.10039	-0.9678	0.9864	0.032
WS11003 $CuInSe_2$	Wuerth	12.33	-0.0685	0.0618	-0.0673	-0.9172	0.9701	0.030

3. Results and discussion

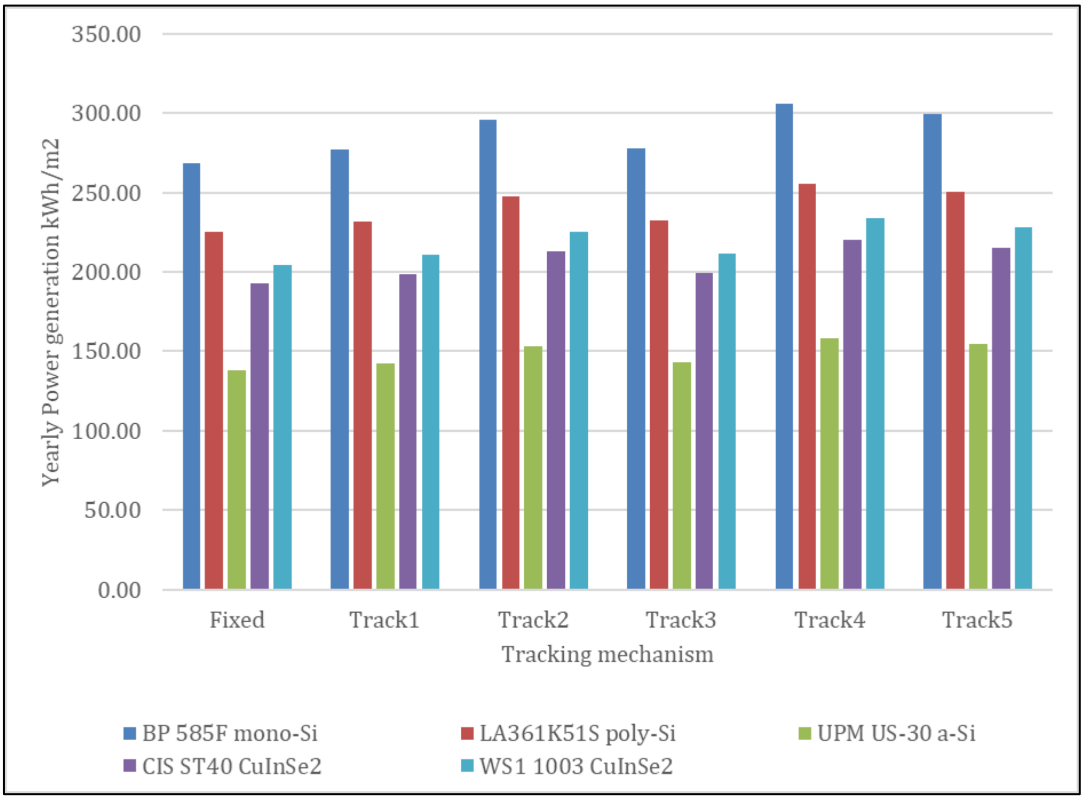

Figure 2 Yearly power generation of different solar cells for different tracking mechanism

From the results, one notes that the technology which produces best in fixed position is the LP 585F mono-If.Mono-Si (LP 585F) gives good basic performances and presents an excellent profit with tracking. It would be ideal for installations desired with high output. Poly-If (IA365K15) is less powerful than mono-If. A-If (UPM 215) has a weak basic production, but greatest relative profit with tracking while CuInSe2 (CIS ST40 & MSX 103B) present the lowest outputs.

It is noticed that no technology applied in tracking motion manages to produce better than the LP 585F mono-Si in a fixed position. The productions which exceed the case of this reference are obtained for same technology mainly with Track4, the track5 and the track2 which give in this order 14.46%, 11.76% and 10.42% of more energy. The partial alignment Track2, brings the same degree of optimization as the track3, which are around 3.22% to 3.57%.

The Table 2 presents the comparison of the energy productions within the same technology according to the tracking mechanism by considering the fixed condition as a reference in each technology type. It is noticed that each type of tracking mode conducts approximately to the same improvement rate independently to the PV technology type. Track4 is systematically most powerful, with profits growing almost about +13.49% to +14.65% compared to the fixed configuration of the same technology.Track2 and Track5 offer also good compromises, often close to the maximum as their relative profits with alignment are similar.

Table 2 Comparison of energy output improvement within the same technology regarding the fixed mode and according to the tracking mode

Module	***Track1 (%)***	***Track2 (%)***	***Track3 (%)***	***Track4 (%)***	***Track5 (%)***
BP 585F mono-Si	2.99	10.11	3.35	13.77	11.32
LA361K51S poly-Si	2.94	9.87	3.30	13.49	11.07
UPM US-30 a-Si	3.23	10.67	3.57	14.65	12.00
CIS ST40 $CuInSe_2$	3.10	10.42	3.47	14.23	11.68
WS11003 $CuInSe_2$	3.16	10.27	3.52	14.24	11.58
Average (%)	3.09	10.27	3.44	14.08	11.53
	0.095	0.222	0.094	0.358	0.268

Table 3 shows the results of comparison within the same technology, and the same mode of alignment, when the conditions of operating temperatures alone are improved and considered with 25°C. These results show that each technology would roughly undergo the same rate of optimization independently of the tracking mode. With this better condition of temperature, the increase in the output is made higher in this order CIS ST40 CuInSe2 between 11.72% and 12.38%; the LP 585F mono-If between 9.81% and 10.36%; the LA361K51S poly-If between 8.98% and 9.48%; the WS11003 CuInSe2 between 6.83% and 7.22% and finally the UPM Custom-30 A-If between 2.86% and 3.01%.

Table 3 Comparison for each technology and each tracking mechanism with better working temperature

PV technology	**Fixed (%)**	***Track1 (%)***	***Track2 (%)***	***Track3 (%)***	***Track4 (%)***	***Track5 (%)***	***Average (%)***	***Mean Ecart***
BP 585F mono-Si	9.81	10.00	10.09	10.00	10.36	10.18	10.07	0.14
LA361K51S poly-Si	8.98	9.15	9.24	9.14	9.48	9.32	9.22	0.13
UPM US-30 a-Si	2.86	2.91	2.94	2.91	3.01	2.96	2.93	0.04
CIS ST40 $CuInSe_2$	11.72	11.96	12.05	11.95	12.38	12.16	12.04	0.16
WS11003 $CuInSe_2$	6.83	6.96	7.02	6.96	7.22	7.09	7.01	0.10

Figure 3.a to c present different solar diagram with iso-contours of photovoltaic production for the same PV technology with concern to Fixed approach, Track2 and Track4. Each diagram combines time lines (in blue full lines); day-number lines (in red discontinuous lines); trajectories of the sun with rise in vertical axis and azimuth in horizontal axis; iso-contours of energy production (in melts colored of blue for weakest to yellow for highest), spread out from 0 to 120

W/m2. So photovoltaic energy production according to sun's rise and azimuth, the hour and the day in the year can be observed.

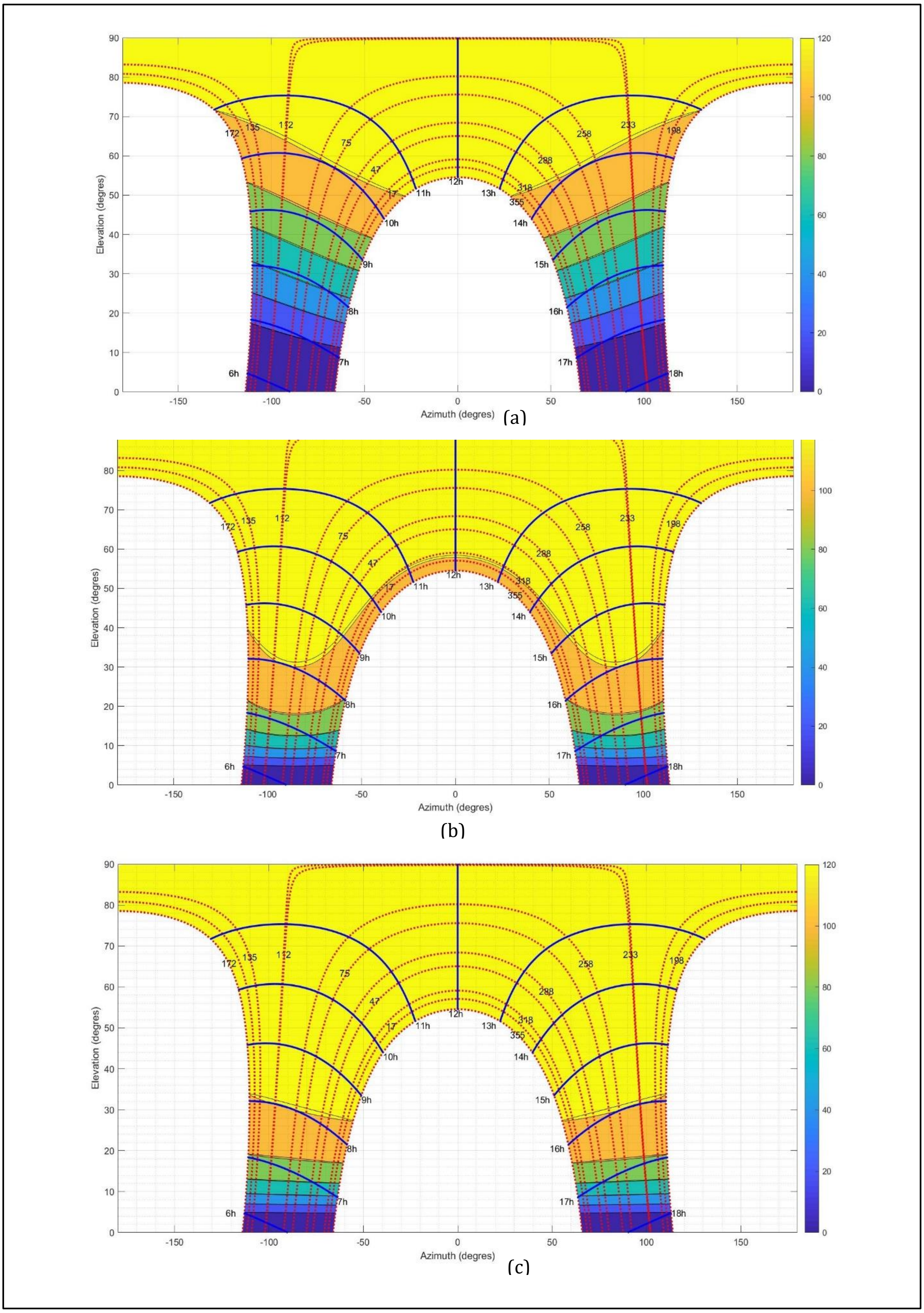

Figure 3 Different solar diagrams with iso-contours of photovoltaic production according to 3 tracking mechanism a) Fixed approach b) Track 2 c)Track 4

For these estimations we considered a fixed cell temperature of 25°C and a simulated solar radiation considering a clear sky at the altitude 12,36° North. The presented iso-contours show that each tracking mechanism increases the generating energy with a notable improve compare to fixed approach mainly at sun rise and sun set. More progressive profits are seen from one axis to two axis tracking approach. The advanced configurations of Track4 and Track5 offer a better distribution of the radiation on the whole of the solar diagram. They can contribute significantly to a project where solar generation stability is needed.

So, the biaxial tracking mechanism are better adapted to the seasonal and time variations. Based on these results the engineer choice will depends on the compromise between cost, maintenance, and energetic efficiency, motor consumption.

4. Conclusion

This paper aims to present the results about the impact of sun tracking on the performances of different PV technologies by using a predictive model, onsite meteorological data and simulation of tracking effect on radiation level. The results show that among the studied technology the LP 585F mono-If.Mono-Si (LP 585F) has the better output in all conditions.

Considering an equal sun tracking mechanism all technologies show more or less similar improvement rate, thus defining the gap in optimization by means of tracking approach independently to the used technology. But this study doesn't take into account the energy consumed by the motor driver which can decreased the energy improvement rate according to the number of tracking axis and the motor characteristics. In this way of analysis, the tracking methods are distinguished from each to other in terms of average performances in this order track4 with 14.46%; track5 11.76%; track2 with 10.42%; track 3 with 3.57%.

This prediction relates to configurations deprived of any device of solar concentration, but takes account of an option of optimization based on the follow-up of the apparent trajectory of the Sun, in order to evaluate the potential difference between fixed operation, operation with continuation alone. This work aims at providing a solid comparative base then making it possible to judge interest or not to introduce mechanisms of optimization (alignment, cooling, variable orientation, solar concentration).

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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