Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 7, No. 4, July : 2023

EFFECT OF AZIMUTH ANGLE ON THE PERFORMANCE OF INDUSTRIAL SCALE SOLAR PHOTOVOLTAIC POWER PLANT – A QUANTITATIVE APPROACH

Sachin Vrajlal Rajani, Assistant Professor, Electrical Engineering Department, VVP Engineering College, Rajkot, Gujarat, 360005, sachin.rajani.el@vvpedulink.ac.in

Abstract
The power generation by solar photovoltaic panels is affected by the orientation of the solar panels, the better the orientation, higher is the system yield. Here, in this paper, an attempt is made to analyze the effect of Azimuth Angle variation on the solar PV panel performance. Different Azimuth angles, i.e., 0^0, -15^0, -30^0, -45^0 are considered for a 260-kW industrial scale solar PV system and output yield of the 260-kW system over a complete year and month by month is analyzed. PVSyst® software is used to simulate and analyze the system. The results are presented with the four cases of Azimuth angle variation, and it is judged from the simulation results that the quantitative effect of variation in the yearly output is largely affected by installing the solar PV panels to the correct orientation. The variation of power output is observed from 1.16% to 5.66% which is considerable for a commercial scale PV system. This research will be helpful to the solar PV installers and consumers for their PV installations.

Key words: Azimuth Angle, Orientation, PVsyst, Solar PV Plant, Yearly Energy Yield

I. Introduction

Rising fuel prices, global economic indicators, global warming, and greenhouse effect issues has caused havoc in the overall environment of the world. Researchers and scientists are trying very hard to find a way to solve the problems. One of the solutions is to produce electricity with the resources available from nature. Solar thermal, Solar Photovoltaic (SPV) hydro, wind, and geothermal are some of the options.[1-4] Out of these options, solar PV panels being modular and the solar PV systems with so many government incentives have become highly popular in the last decade or so. Solar PV panels can be operated by incorporating Maximum Power Point Trackers (MPPT) to enhance output of the panels. These electronic trackers along with the single or dual axis physical trackers can enhance power output to a great deal. This available energy can be stored in the storage devices like batteries, supercapacitors and many more.[5-7] These panels are also useful to generate electricity in the remote areas where the power production by the conventional means that is thermal, hydro, or nuclear is either not possible or not economically viable. At present, these PV panels are used in remote areas for the applications of transportation, medical facilities like vaccine storage, uninterrupted power supplies, protective devices like dynamic voltage restorer and many others.[8-10] Solar PV panels when installed may have a fixed tilt, seasonal tilt, or a continuously variable tilt according to the system design. Normally, a fixed tilt according to the site latitude angle is a preferred structure owing to minimum maintenance requirements and cost. The current research in this field has shown a correlation between the Azimuth angle (orientation of a solar panel with respect to the true North direction) and output variation of a solar PV system but it is not quantified. This research gap is addressed here, and the research carried out in this paper helps reader understand quantification of variation in the output of a solar photovoltaic power plant with the variation in the Azimuth Angle that can be as high as 5 % or even more and when a commercial scale PV system or a large-scale industrial system is considered, the output energy in MWh per year makes a huge difference. This quantification of the relation between Azimuth Angle and Solar PV power plant output energy over a year is the novelty of the paper presented here.

II. Materials and Methods

Materials and methods employed for the research work carried out are highlighted in the subsequent sections.

2.1 Azimuth Angle

It is a well-known fact that the solar panels are oriented North-South to receive direct light throughout the day. These panels are not orientated flat but at some angle with respect to the horizontal line known as a tilt angle as shown in Figure 1. An Azimuth angle is an angle that is formed between a reference direction (North) and axis of solar panel. So, the North direction will have an azimuth 0^0. Moving clockwise will give a positive azimuth angle means direction East has an Azimuth $+90^0$ and moving anti-clockwise will lead to negative Azimuth means direction West will have an Azimuth equal to -90^0. These angular positions along with the solar panel are shown in Figure 1 [11,12,13,14]. Once, the Azimuth and tilt angles of the solar panels are fixed for the fixed tilt systems, the next task is to determine the effect of the Azimuth angle's variation or Tilt Angle's variation on the output of the solar PV system. It is going to change with reference to the selected angle, but by what percentage? For this very reason, this paper introduces a comparison between azimuth angles 0^0, -15^0, -30^0, -45^0 and the corresponding output over a year from the same solar PV system.

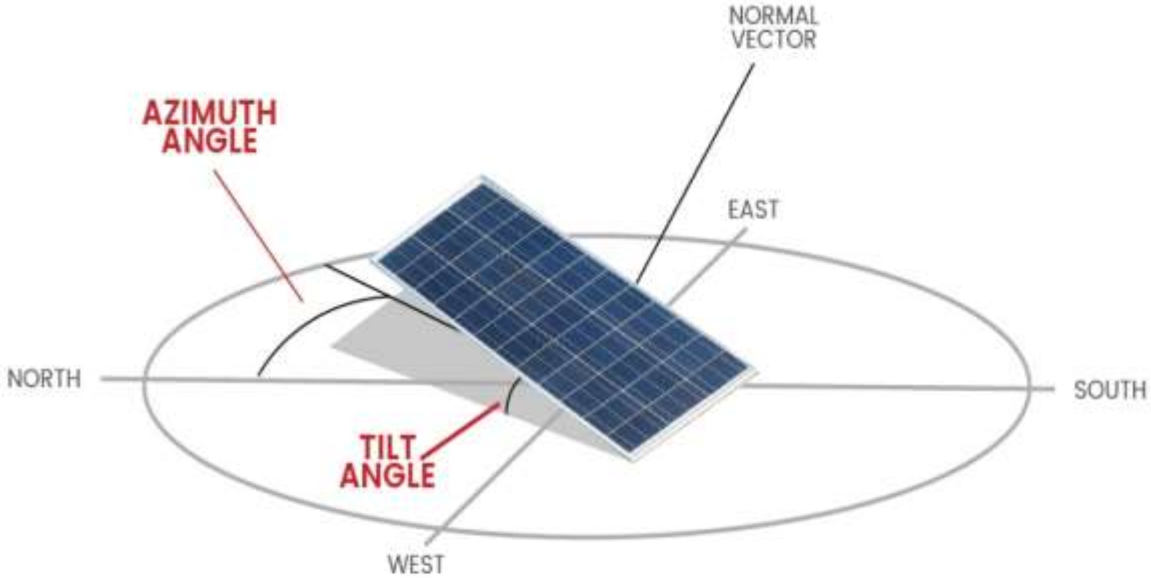

Figure 1. Tilt angle and Azimuth Angle for a Solar Panel

Table 1. Meteo data of the 260-kW industrial system at the selected site

Month	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb
January	144	40.3	20.50
February	150.9	42.8	22.60
March	193.5	60.5	28.00
April	201.8	73.2	31.40
May	208.7	81.9	33.00
June	173	93.7	31.40
July	126.7	85.6	29.10
August	126.9	84.9	28.20
September	150.3	70.1	28.70
October	158.2	61.1	28.10
November	136.5	41.1	24.10
December	123.5	39.7	20.45
For a Year	1894	774.9	27.16

2.2 Solar Photovoltaic Panels

The complete 260 kW system was designed with the solar panels of Mono 440 Wp Solar PV Panel (Twin 144 half-cells). The datasheet of Mono 440 Wp Solar PV Panel (Twin 144 half-cells) is presented in Table 2. For a system of 260 kW total number of panels used were 591 (that is 260040 W = 260.040 kW). 60 kW inverter in four numbers were used in the study. As inverters can take 10% overload the total system load can go up to 60*4 = 240 kW and 10% extra means 240+24 = 264 kW. Here, the system capacity was limited to 260-kW. The inverter data sheet is presented in Table 3.

Table 2. Datasheet of mono 440 Wp solar PV panel (twin 144 half-cells)

Parameter	Value
Pmpp	440.6 W
Impp	10.58 A
Isc	11.10 A
Vmpp	41.6 V
Voc	49.7 V
Cell Efficiency	22.21 %
Module Efficiency	19.80 %
Temperature Co-eff.	-0.36% per 0C
Length	2115 mm
Width	1052 mm
Thickness	35 mm
Weight	24 kg
Frame	Aluminium
Connections	MC-4
Maximum Voltage (IEC)	1500 V
Cells in series	72
Cells in parallel	2
Total cells	72*2 = 144
Module area	2.225 m^2
Cell area	1.984 m^2
Series Resistance Rse	0.224 Ohms

Table 3. Datasheet of a 60-kW inverter

Parameter	Value
Minimum MPP Voltage	500 V
Maximum MPP Voltage	1450 V
Power Threshold	297 W
Maximum PV current	88 A
Operating frequency	50 or 60 Hz
Maximum Efficiency	98.50%
Width	600 mm
Depth	300 mm
Height	1000 mm

III. Experimental details

A 260-kW industrial scale system is taken for the consideration at the industrial site at Sarkhej near Ahmedabad (Gujarat, India) location. The latitude and longitude of the selected site is 22.9733^0 N and 72.4847^0 E respectively. The site location is presented in Figure 2. The 260-kW solar PV plant was

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 7, No. 4, July : 2023

designed and analyzed in a widely used solar software PVsyst®. The Meteo data of the 260-kW industrial system at the selected site is presented in Table 1.

3.1 PVSYST® Software

PVsyst® is a highly renowned software in the field of study of solar photovoltaic systems. Both stand-alone and grid-connected systems can be simulated in the software. It is considered state-of-the-art software for solar PV system simulations. The software is quite versatile with the features of location, street map, large library and data sets of solar PV panels, inverters, and power optimizers. This software is used by many solar PV installers including residential, commercial, industrial, large-scale installations and professionals for carrying out the analysis before installation of solar PV plant. This software can give meteorological data for any location including temperature variations throughout the year, global horizontal irradiance, diffused horizontal irradiance and so many other parameters.

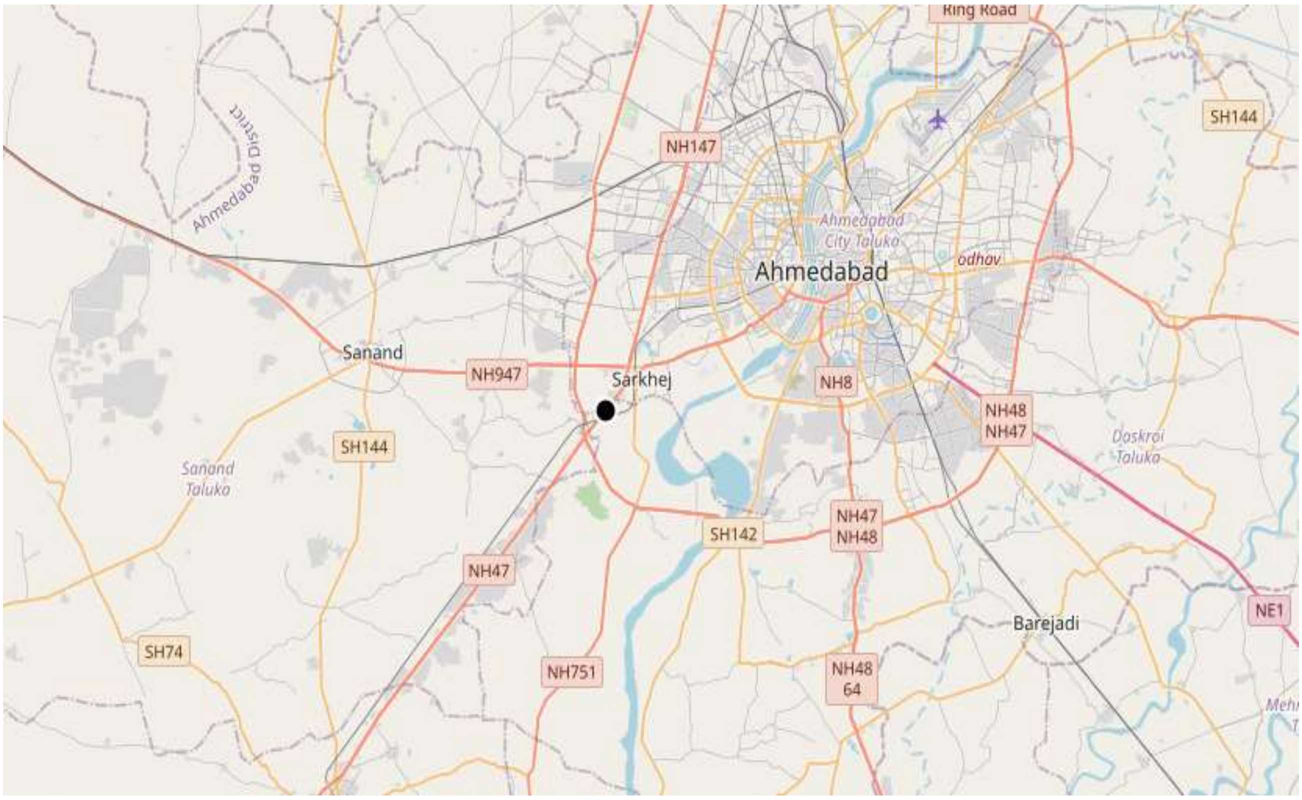

Figure 2. Industrial site near Ahmedabad, Gujarat, India

The parameters listed in Table 1 are Global horizontal irradiance in kWh/m^2, Diffused horizontal irradiance in kWh/m^2 and Ambient temperature in ^0C. For any solar PV plant the efficiency of a solar cell and performance ratio are also the important parameters to be considered. These parameters are defined as follows.

Efficiency: Efficiency of solar cell or a panel is given by an equation

$$\text{Efficiency } \eta = \frac{\text{Pmax}}{\text{Area} \times 1000\ \text{W/m\^{}2}} \times 100 \qquad \ldots(1)$$

Where, Pamx is the maximum power of the panel, and 1000 W/m^2 refers to the standard test condition. The performance ratio of the solar power plant is defined as,

$$PR = \frac{\text{Actual Energy Generated in kWh}}{A \times r \times H} \times 100 \qquad \ldots(2)$$

Where, A = Total solar panel area in m^2, r is solar panel yield or efficiency, and H is the solar insolation on the tilted plane in kWh/m^2. In the simplest of the terms, Performance Ratio (PR) is defined as

$$PR = \frac{\text{Actual Energy Generated in kWh}}{\textit{Theoretical output in kWh}} \qquad \ldots(3)$$

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 7, No. 4, July : 2023

IV. Results and discussion

The industrial scale 260-kW solar power plant was designed and developed using the widely used software PVsyst®. To observe the effect of Azimuth angle on the performance of the power plant, the azimuth angle was varied from 0^0 to -15^0 to -30^0 to -45^0 and all the results are presented herewith.

4.1 Azimuth Angle = 0^0

When Azimuth angle was kept 0^0 (true North orientation), the normalized production of a solar PV plant was observed to be 4.69 kWh/kWp/day, array losses were 0.93 kWh/kWp/day and system losses were 0.09 kWh/kWp/day. The system production over a year was 447 MWh/year and specific production was observed to be 1711 kWh/kWp/year. The performance ratio of the system was measured to be 0.822. The daily input-output diagram, performance ratio, system output power distribution and array temperature results are presented in figures 3 (a) to 3 (d) for the Azimuth angle = 0^0. The loss diagram is presented in figure 3 (e).

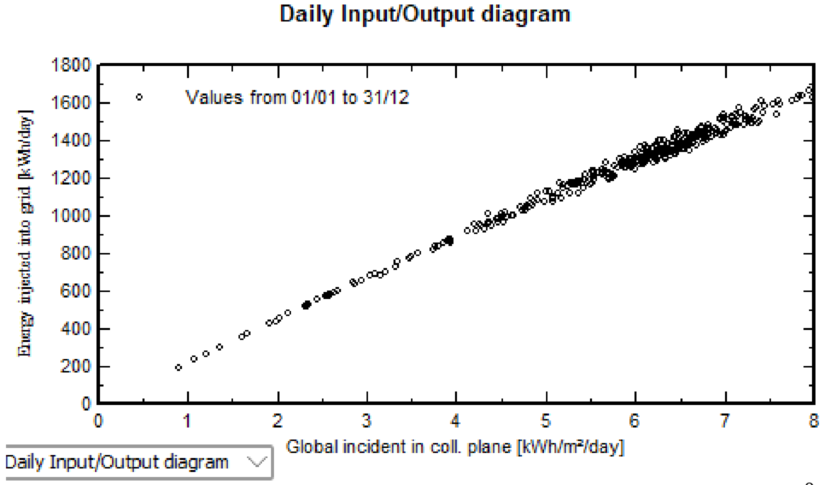

Figure 3 (a) Daily input output diagram for Azimuth Angle 0^0

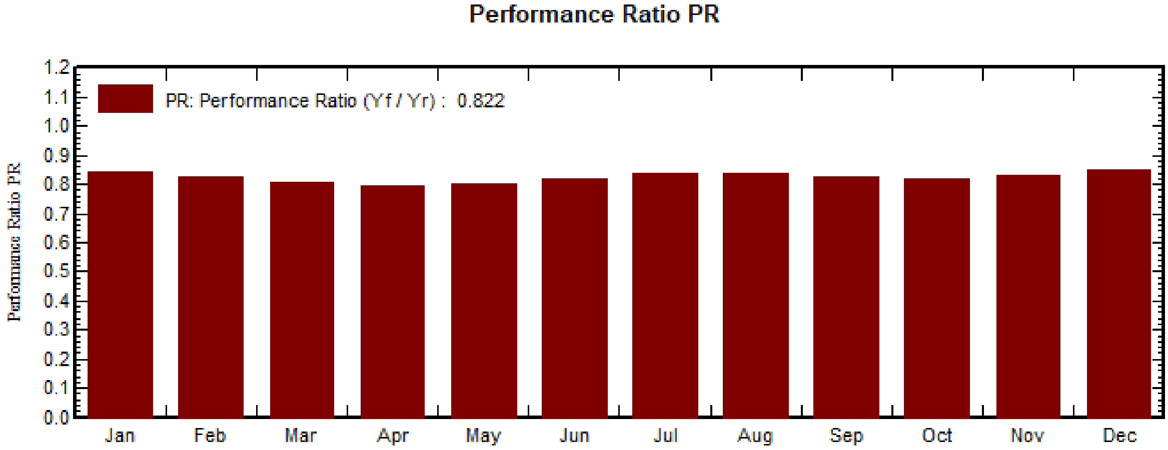

Figure 3 (b) Performance Ratio for Azimuth Angle 0^0

The daily input/output diagram in figure 3 (a) shows that global incident energy in kWh/m^2/day falls largely in the range of 4.5 to 7.2 kWh/m^2/day. Performance ratio variation in figure 3 (b) shows its variation from January to December and it is having a value ranging from 0.811 (81.1%) to 0.853 (85.3%) and an average value throughout the year 0.822 (82.2%). The system output power distribution in figure 3 (c) shows that the kW power injected into the grid has a large value for the output power range from 130 kW to 210 kW that means that the system can work in a satisfactory way. Array temperature variations range from 20^0 to 70^0 centigrade during the whole year as presented in figure 3 (d). Loss diagram in figure 3 (e) shows that the temperature losses and array mismatch losses are predominant and wiring losses are also considerable.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 7, No. 4, July : 2023

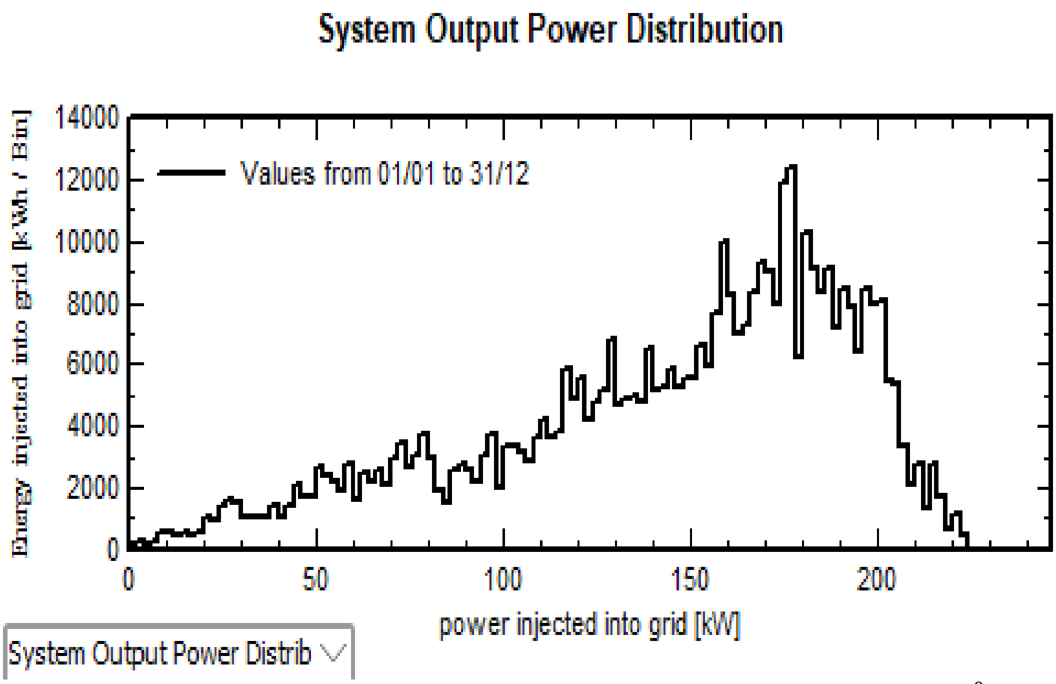

Figure 3 (c) System Output Power Distribution for Azimuth Angle 0^0

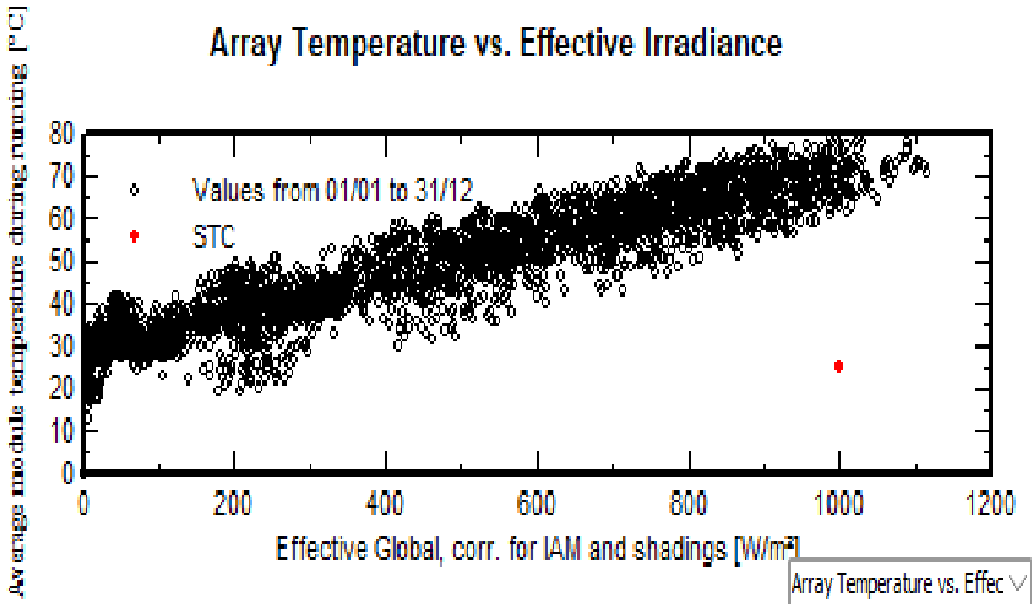

Figure 3 (d) Array Temperature and effective irradiance relation for Azimuth Angle 0^0

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 7, No. 4, July : 2023

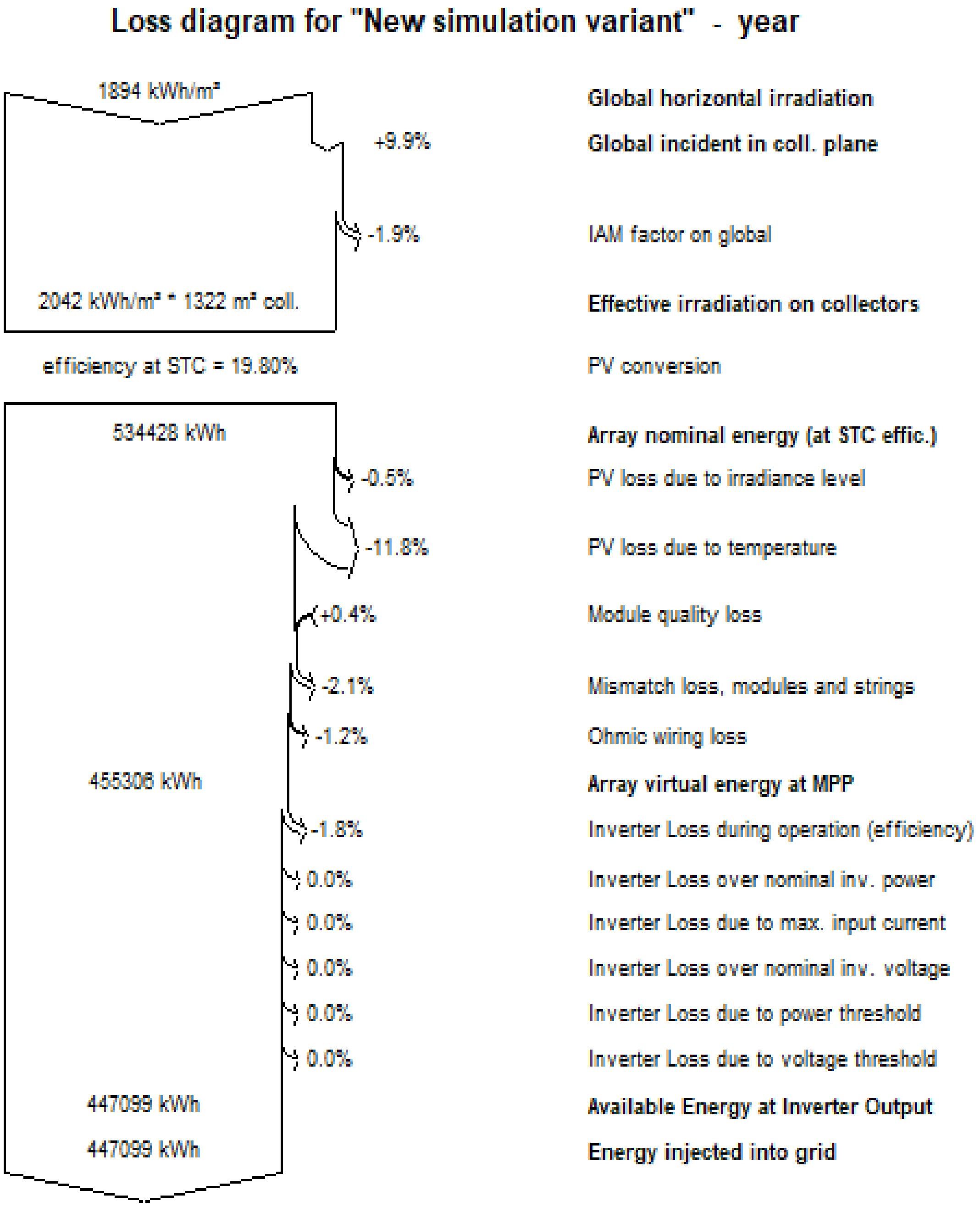

Figure 3 (e) Loss diagram for Azimuth Angle 0^0

4.2 Azimuth Angle = -15^0

The daily input-output diagram, performance ratio, system output power distribution and array temperature results are presented in figures 4 (a) to 4 (d) for the Azimuth angle = -15^0. When Azimuth angle was kept -15^0 (Towards West from the true North), the normalized production of a solar PV plant was observed to be 4.63 kWh/kWp/day, array losses were 0.91 kWh/kWp/day and system losses were 0.09 kWh/kWp/day. The system production over a year was 442 MWh/year and specific production was observed to be 1691 kWh/kWp/year. The performance ratio of the system was measured to be 0.823.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 7, No. 4, July : 2023

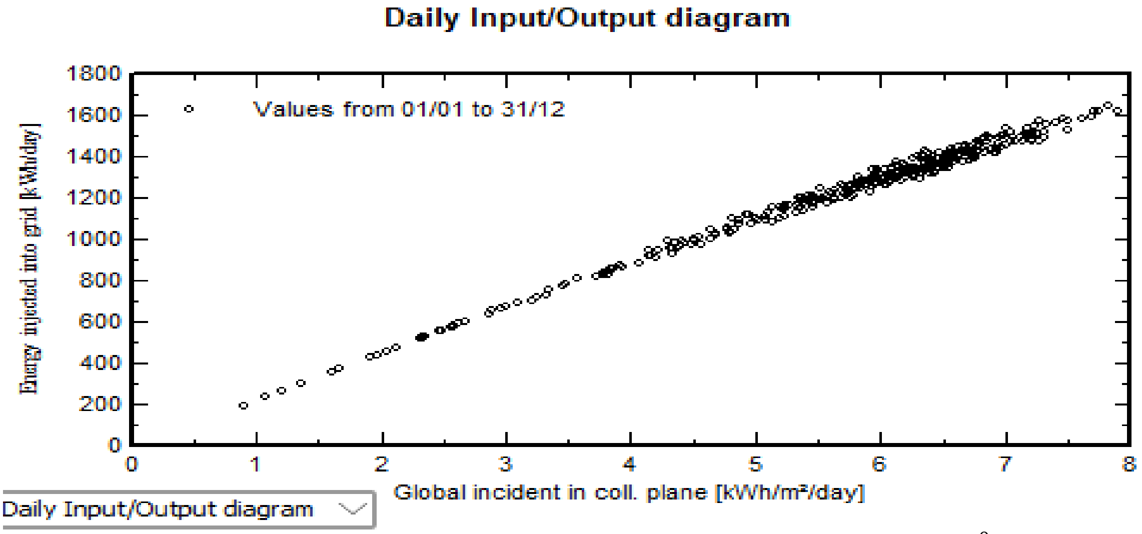

Figure 4 (a) Daily input output diagram for Azimuth Angle -15^0

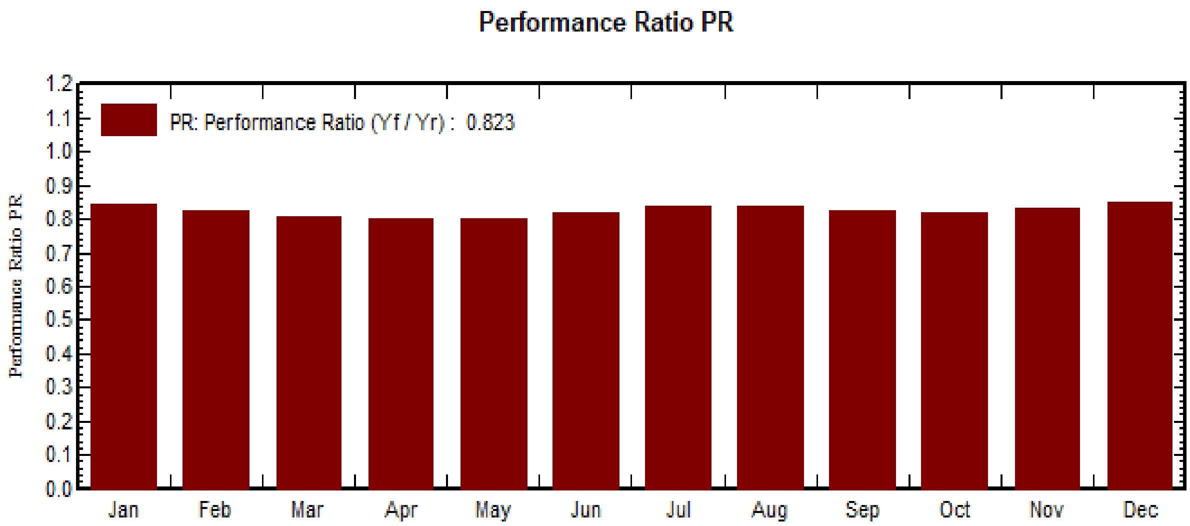

Figure 4 (b) Performance Ratio for Azimuth Angle -15^0

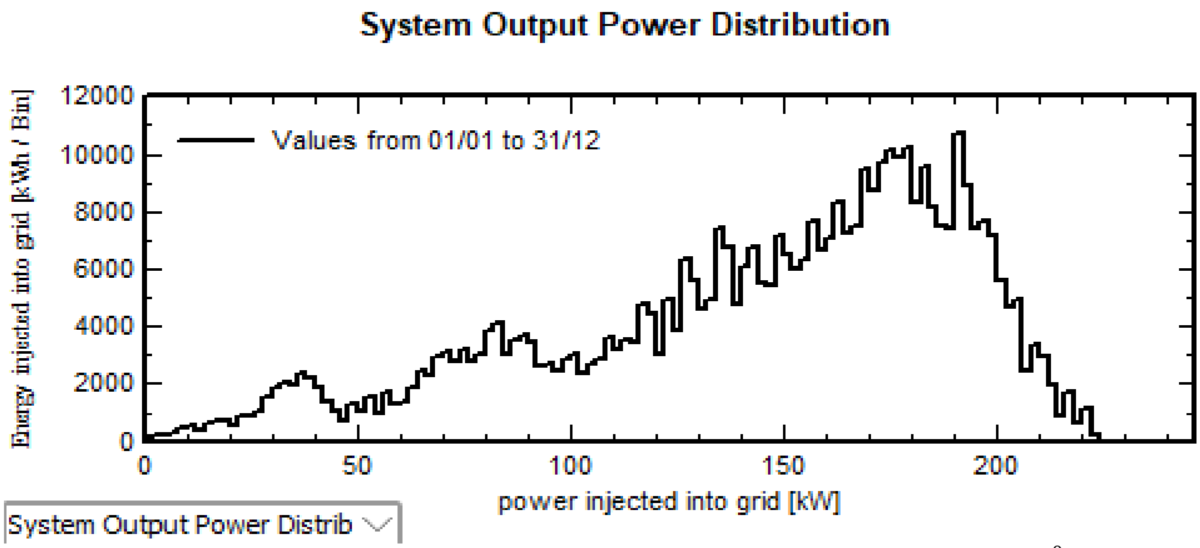

Figure 4 (c)System Output Power Distribution for Azimuth Angle -15^0

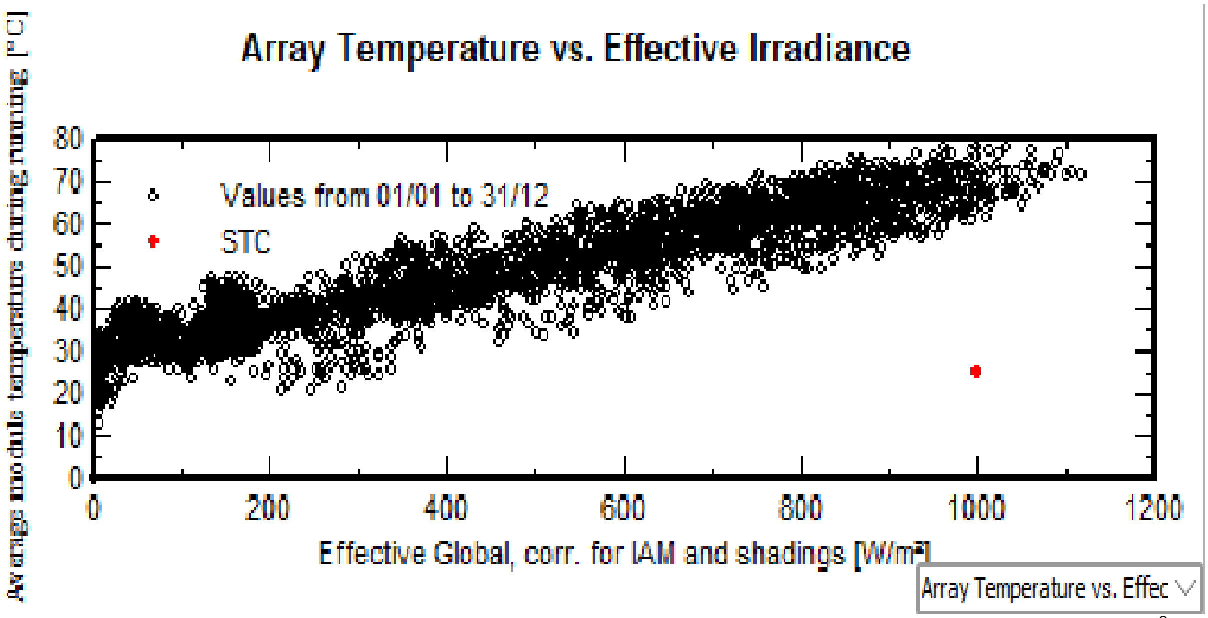

Figure 4 (d) Array Temperature and effective irradiance relation for Azimuth Angle -15^0

4.3 Azimuth Angle = -30^0

When Azimuth angle was kept -30^0 (Towards West from the true North), the normalized production of a solar PV plant was observed to be decreased to 4.54 kWh/kWp/day, array losses were 0.89 kWh/kWp/day and system losses were 0.08 kWh/kWp/day. The system production over a year was 433 MWh/year and specific production was observed to be 1657 kWh/kWp/year. The performance ratio of the system was measured to be 0.823. The performance ratio diagram is presented in figure 5 the Azimuth angle = -30^0.

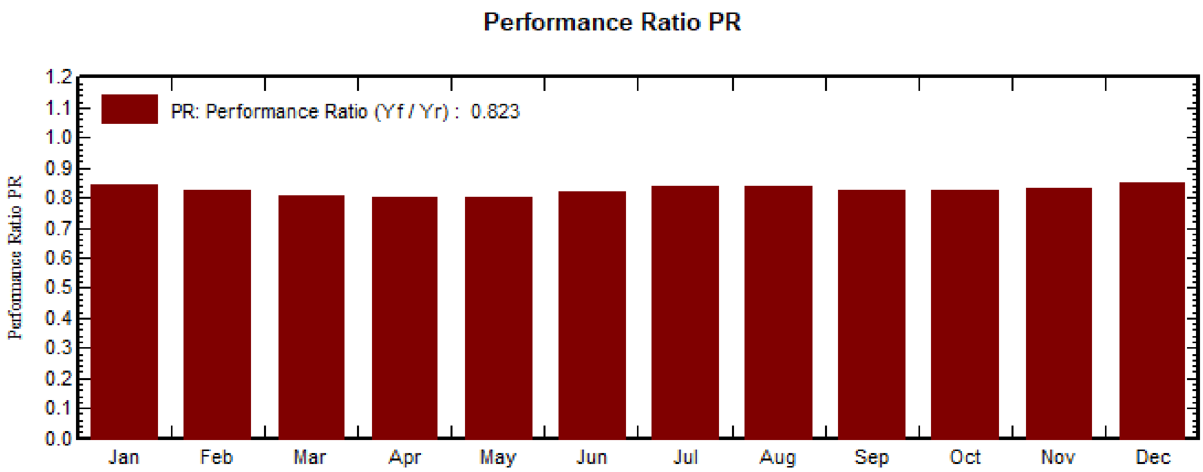

Figure 5. Performance Ratio for Azimuth Angle -30^0

4.4 Azimuth Angle = -45^0

When Azimuth angle was kept -45^0 (Towards West from the true North), the normalized production of a solar PV plant was observed to be further decreased to 4.42 kWh/kWp/day, array losses were 0.85 kWh/kWp/day and system losses were 0.08 kWh/kWp/day. The system production over a year was 422 MWh/year and specific production was observed to be 1614 kWh/kWp/year. The performance ratio of the system was measured to be 0.825. The performance ratio diagram is presented in figure 6 for the Azimuth angle = -45^0.

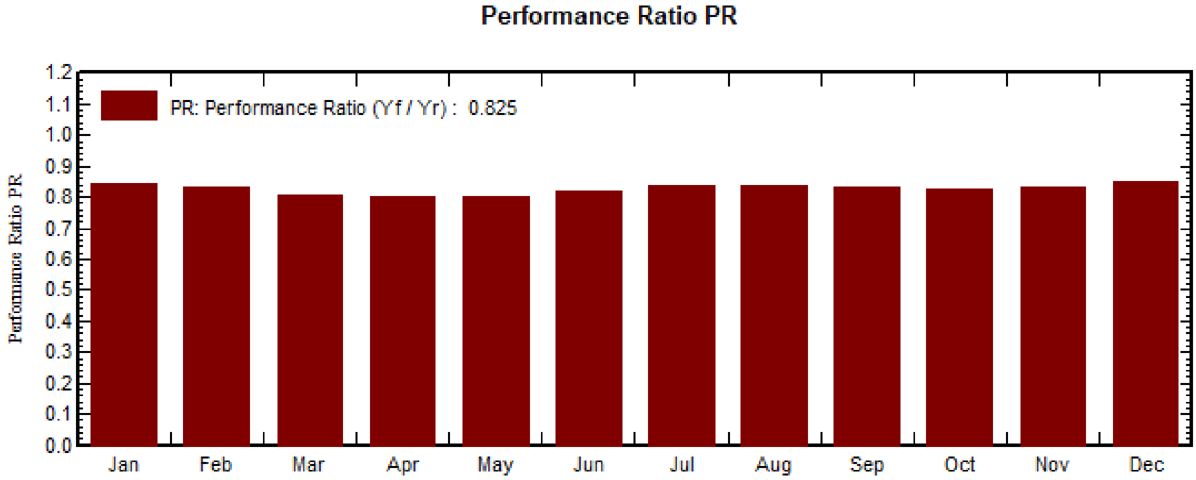

Figure 6. Performance Ratio for Azimuth Angle -45^0

Thus, varying the Azimuth angle from 0^0 to -45^0 in the steps of -15^0, make system production vary to a substantial value. These results are summarized in table 4.

Table 4. Summary of results for different azimuth angles

Azimuth Angle	Normalized Production in kWh/kWp /day	Specific Production in kWh/kWp/Year	Total Energy Produced in MWh/ Year
0	4.69	1711	447
-15	4.63	1691	442
-30	4.54	1657	433
-45	4.42	1614	422

As presented in table 5, the specific production per year was reduced from 1711 to 1691 to 1657 to 1614 kWh/kWp/Year when the azimuth angle was varied from 0^0 to -15^0 to -30^0 to -45^0 respectively. Calculation of the % reduction in production is presented in table 5.

Table 5. Calculation of the % reduction in production

Azimuth Angle Variation	Production Reduction in kWh/kWp/Year	% Production Reduction
0^0 to -15^0	1711 – 1691 = 20	20/1711 = 0.0116 = 1.16%
0^0 to -30^0	1711 – 1657 = 54	54/1711 = 0.0315 = 3.15%
0^0 to -45^0	1711 – 1614 = 97	97/1711 = 0.0566 = 5.66%

Industrial rate of energy in India is approximately Rs. 8/kWh. So, 1 MWh energy would cost Rs. 8*1000 = Rs. 8000. Based on MWh/Year total production of the system, the azimuth angle comparison is presented in Table 6.

Table 6. Calculation of cost of energy loss per year

Azimuth Angle Variation	Total Production in Loss MWh/Year	Cost of Energy Loss over a Year in Rs.
0^0 to -15^0	447 – 442 = 5	5 *8000 = 40,000
0^0 to -30^0	447 – 433 = 14	14*8000 = 1,12,000
0^0 to -45^0	447 – 422 = 25	25*8000 = 2,00,000

V. Conclusion

The paper presents the in-depth analysis for a 260-kW industrial scale solar PV system for varying Azimuth angle. The industrial site selected near Ahmedabad has been analyzed in many aspects. The variation in Azimuth angle from 0 to -45^0 results in the % production loss of 5.66% and the energy lost cost was observed to be Rs. 2,00,000 per annum. The calculations presented give a figurative idea regarding installing the panels apart from Azimuth angle 0^0 and the subsequent production loss. It is concluded that the solar panels when installed orienting true North results in better production. This research will be helpful to the solar PV installers and consumers for their PV installations in future.

VI. Conflict of interests: There is No conflict of interests for the author regarding this research work and a research paper.

VII. Acknowledgement

This work is sponsored by Gujarat Council on Science and Technology (GUJCOST), Gandhinagar, India. This work is supported by V.V.P. Engineering College, Rajkot.

References

[1] Manu PriyaDarshani, Ritu Shaw & Rishi Sharma (2023), “Investigation of the Trail Environment to Enhance the Efficiency of the Solar Cell, through Pre-Installation Study”, Journal of Scientific & Industrial Research, Vol. 82, 2023, pp. 307 – 315.

[2] Junvi Shen, Alireza Khaligh (2015), “A Supervisory Energy Management Control Strategy in a Battery/Ultracapacitor Hybrid Energy Storage System”, IEEE Transactions on Transportation Electrification, Vol. 1, 2015, pp.1–9.

[3] Sachin Vrajlal Rajani, Vivek J Pandya (2016), “Experimental verification of the rate of charge improvement using photovoltaic MPPT hardware for the battery and ultracapacitor storage devices”, Solar Energy, Vol. 139, 2016, pp. 142 – 148.

[4] Maurizio Acciarri, Alessia Le Donne, Stefano Marchionna (2018), CIGS thin films grown by hybrid sputtering-evaporation method: Properties and PV performance. Solar Energy, Vol. 175, 2018, pp. 16–24.

[5] Panel Stefano Pasini, Donato Spoltore, Antonella Parisini, Stefano Marchionna, Laura Fornasini, Danilo Bersani, Roberto Fornari, Alessio Bosio (2023), “Innovative back-contact for Sb2se3-based thin film solar cells”, Solar energy, Vol. 249, 2023, pp. 414–423.

[6] Savita Kashyap, Jaya Madan, Rahul Pandey, Jeyakumar Ramanujam (2022), “22.8% efficient ion implanted PERC solar cell with a roadmap to achieve 23.5% efficiency: A process and device simulation study”, Optical Materials, Vol. 128, 2022, pp. 112–121.

[7] Sachin Vrajlal Rajani, Dr. Vivek Pandya, Varsha A Shah (2016), “Experimental validation of the ultracapacitor parameters using the method of averaging for photovoltaic applications”, Journal of energy storage, Vol. 5, 2016, pp. 120–126.

[8] Sachin Vrajlal Rajani, Vivek J Pandya (2015), Simulation and comparison of perturb and observe and incremental conductance MPPT algorithms for solar energy system connected to grid, Sadhana, Vol. 40, 2015, pp. 139–153.

[9] P Kapil, C Vibhakar, S Rajani, K Bhayani (2013), Voltage Sag/Swell Compensation Using Dynamic Voltage Restorer (DVR), International Journal of Application or Innovation in Engineering & Management, Vol. 4, 2013, pp.1–6.

[10] L. Zhang, K. Sun,Y. Xing, L. Feng, and H.Ge (2011), “A modular grid-connected, photovoltaic generation system based on DC bus” IEEE Trans. Power Electron., Vol. 26, 2011, pp. 523–536.

[11] W. Derouich, M. Besbes, J.D. Olivencia (2014), “Prefeasibility Study of a Solar Power Plant Project and Optimization of a Meteorological Station Performance”, Journal of Applied Research and Technology, Vol. 12, 2014, pp. 72–79.

[12] Shih-Ming Chen; Tsorng-Juu Liang, Ke-Ren Hu, Design (2013), “Analysis, and Implementation of Solar Power Optimizer for DC Distribution System”, IEEE Transactions on Power Electronics Vol. 28, 2013, pp.1764–1772.

[13] F. L. Luo and H. Ye (2004), “Positive output multiple-lift push-pull switched capacitor Luo-converters”, IEEE Trans. Ind. Electron., Vol. 51, 2004, pp.594–601.

[14] Mohamed S. Emeara, Ahmed F. AbdelGawad, Ahmed El Abgay (2021), “Orientation-Optimization Simulation for Solar Photovoltaic Plant of Cairo International Airport”, The Egyptian International Journal of Engineering Sciences and Technology, Vol. 33, 2021, pp. 45–56.