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Performance Analysis of A 3.6 MW Solar Photo-Voltaic (PV) Plant with Single-Axis Tracking and Fixed Tilt Type of PV Array in a Single Site: A Comparative Study

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Abstract-This work is focused on techno-commercial feasibility of a single-axis solar tracking system compared to fixed tilt system based on real energy yield data. For this purpose, an existing solar PV plant situated in Infosys SEZ Campus, Hyderabad, India of cumulative capacity 3.6 MW (DC) has been considered. The Plant constitutes 3.6 MW capacity with an installation of 1.8 MW as Fixed Tilt (FT) system and 1.8 MW as Single-axis Tracking (SAT) system. The analysis shows that the SAT system is technically effective in terms of Energy Gain, Performance Ratio (PR) & Capacity Utilisation Factor (CUF) compared to the fixed tilt system. It also prevails that the SAT system is cost effective compared to the FT system. Therefore, the use of tracking system, either be it single-axis or dual-axis may be done in those regions where land acquisition is a serious issue and thus proper utilisation of precious land may be done.

Keywords- Photo-voltaic System, Single-axis Tracking System, Fixed Tilt System, Tilt Angle, Azimuth Angle, Solar Radiation, Techno-commercial Analysis, PR, CUF, SEP, Energy Gain, GCR, SPR, PBP, IRR, NPV, Solstice, Carbon Credit, Hyderabad, India.

INTRODUCTION

PV panels are the efficient source of renewable energy compared to the other sources and is the only energy source that can supply the additional energy that the world will need over the next several decades in a manner that will protect the environment and be sustainable [1]. From the Current and Voltage output (I-V) curve of PV Module, it can be observed that there is an impact of incident solar radiation on the Current(I) output thus in Power (P) output also as P=VI. The major constraints in case of implementation of Solar PV Plants are limited efficiency of the Solar PV cells and limited land area available, especially in a densely populated country like India. Since, the power generation capability of such systems is dependent on the sun radiation received by the panels and at low radiation level when the array does not provide enough output power, reactive power is drawn from distribution transformer and fed into inverter and loads [2], introduction of tracking system that momentarily positions solar panels according to the direction of the sun is very helpful in maximizing energy yield [3]. Solar PV Plants with sun tracker may become more cost-effective solution than the purchase of additional Solar PV Modules [4]. Also, the orientation of Solar PV Module has an impact on the generation profile. South orientated Module with an optimum tilt angle has the highest degree of autarky, whereas, the east/west orientation has the positive impact of smoothing electricity generation, although incorporating lower electricity generation and lower degree of autarky [5].

Solar PV Module will have maximum radiation when incident light is perpendicular to the panel [6], but with the change of the position of the sun, a fixed mounted solar module can only get maximum radiation for certain duration of a day. The maximum & minimum declination of sun occurs in summer and winter solstice with the angle of 23.45° & -23.45° in the north-south direction respectively and travels from east (morning) to west (evening) direction as shown in **Fig. 1**[3, 7]. To get higher radiation levels, tracking systems is needed to be introduced. It uses axis to fix the solar panel and allows the panels to adjust the tilt (north to south direction) and azimuth angle (east to west direction) according to the current position of the sun.

Based on the Degree of freedom of Module Mounting Structure movement direction, photovoltaic systems may be divided into three

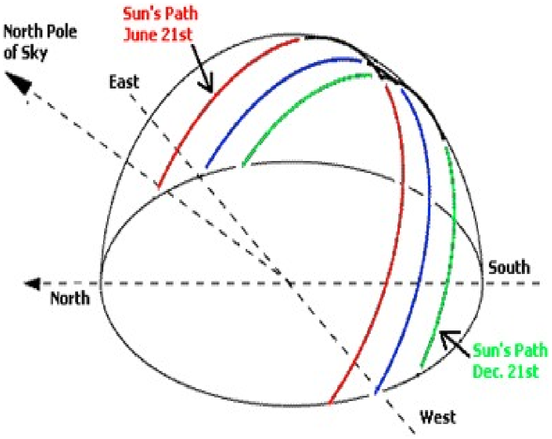


Fig. 1: Sun-path during different seasons.

types, viz, (a) Fixed Tilt System; systems in which the panels are positioned with a certain tilt angle that in the northern hemisphere is oriented southward and their position cannot be changed during the day, (b) Single-axis Tracking System; where it is possible to move the panels on a single path which is usually an east-west direction to adjust azimuth angle or it may be in north-south direction to adjust tilt angle in some cases and (c) Double-Axis Tracking System; in such systems, the panels are able to move along both east-west and north-south directions. Therefore, they are always perpendicular to the sun radiation's direction and receive the maximum amount of radiation [3, 8, 14].

Solar tracking system maximizes the collection of direct beam solar radiation on sunny days, which is the predominant component of the incoming global or total solar radiation, as well as the solar energy capture on cloudy days, when almost all of the solar energy is in the form of diffuse solar radiation [9] and double-axis tracking can increase the amount of solar energy captured by 50% compared to PV modules with a fixed tilt [10]. Single-axis tracking gives approximately 90% as much solar energy as double-axis tracking [11]. Even though single-axis tracking systems can bring additional gain of energy of around 33% over fixed system, there are several challenges linked to factors such as land used, resources, electricity rates, etc. Therefore, the use of tracking configuration for a specific application should be carefully analysed to find out if the acquired surplus energy prevails on the techno-economical disadvantages of the tracking systems [12].

To account for techno-commercial feasibility of a single-axis solar tracking system compared to fixed tilt system, in this paper, the impact of east-west tracking enabled Module Mounting Structure (MMS) on the generation profile of a ground mounted Solar PV plant is analysed for a specific location (Hyderabad, India), focusing on some important technical, financial and land use effectiveness parameters. In case of technical analysis, PVSYST software simulations for Fixed Tilt and Single-axis Tracking are made and compared to actual energy yield data from the plant site of these systems. The technical analysis study consists of two different comparisons, more specifically, comparisons are performed between:

a) Fixed Tilt and Single-axis Tracking systems, PVSYST simulation data.

b) Fixed Tilt and Single-axis Tracking systems, real (measured) data.

Whereas, the financial and land use effectiveness analysis study are performed based on the real field data.

PLANT OVERVIEW

The solar PV plant located at Infosys SEZ Campus in Hyderabad, India is studied and evaluated here. The Plant consists of cumulative solar PV array capacity with fixed tilt configuration of 1.841 MW (1.62 MW AC) and with single-axis tracker of 1.804 MW (1.62 MW AC).

The single-axis tracking array has been designed to move from East to West direction throughout the day according to the sun position with a broad turn range of 120° i.e., 60° towards both the east and west direction w.r.t. south. The fixed tilt array configuration has been designed orienting towards south with an azimuth of 180° w.r.t. north and a tilt angle of 14° for optimum annual generation. The configuration of each installed array is shown below in **Fig. 2**.

A. Site Location & Weather Data:

Solar irradiation is the main parameter in designinga solar PV system and in order to obtain the maximum power output from the PV arrays, the optimized tilt must be determined through simulation taking Latitude angle as reference in case of fixed tilt system. **Table-I** shows Local weather data of the site situated in Hyderabad and **Fig. 3** shows the site location.

Fig. 2: Solar PV array configuration and SAT

TABLE-I
LOACAL WEATHER DATA

Item Description	Value
Latitude	17.26° N
Longitude	78.37° E
Elevation	540 m
Average Temperature	27°C
Relative Humidity	60%
Avg. Wind Speed	2.8 m/s
Annual Precipitation	817 mm

Fig. 3: Geographical location of the Solar PV Plant.

The PVSYST software & Meteonorm weather database was used to obtain the monthly solar irradiation data for the site location, as sun radiation varies largely in a given year. **Fig. 4** shows comparison of the month-wise incident solar radiation (KWh/m2/day) on fixed tilt (14°) PV array & PV array with single-axis tracker and temperature for the site situated in Hyderabad.

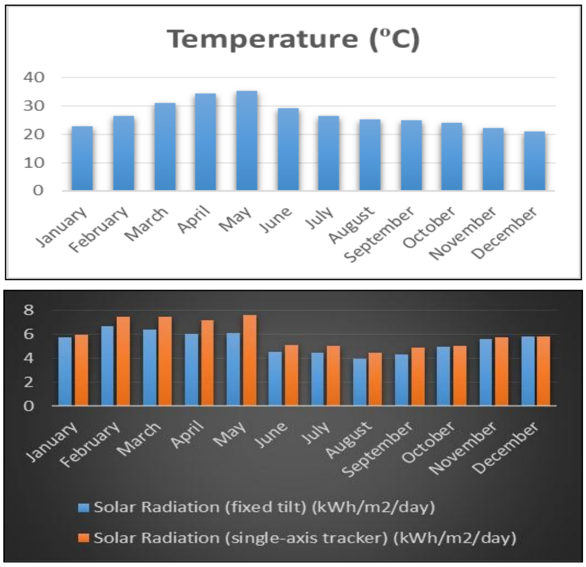


Fig. 4: Simulated incident solar irradiation and temperature of site.

B. Module Specification:

In this plant, BenQ Solar make Green Triplex PM072P00 of 310 Wp rating Solar PV Modules have been used. Each Module has 72 (12x6) poly-crystalline 156mm X156mm solar cells connected in series and is of 1956 x 992 x 40mm dimension. I- V curve of the module at various irradiance (W/m^2) and temperature (ºC) levels is shown below in **Fig.5**. Also, the electrical specifications [30] of the module under Standard Test Condition (STC) are furnished in

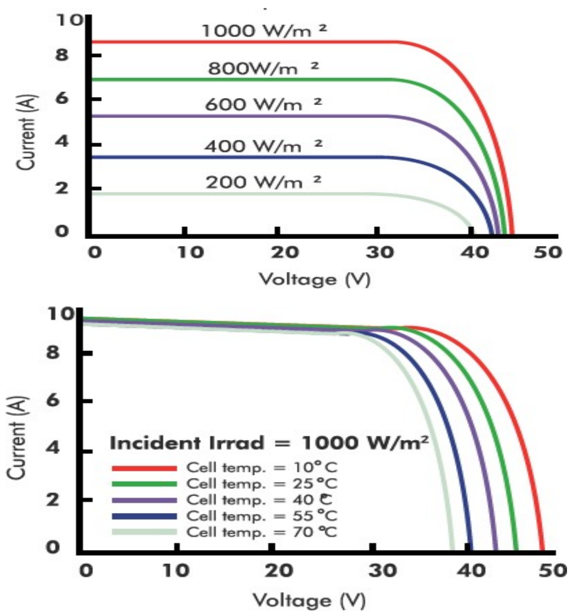


Fig. 5: I-V characteristics of the module at various irradiance (W/m^2) and temperature (°C) level

TABLE II
PV MODULE ELECTRICAL SPECIFICATIONS

Parameters	Value
Nominal Power (P_{max})	310 W
Maximum Voltage (V_{mp})	37.12 V
Maximum Current (I_{mp})	8.33 A
Open Circuit Voltage (V_{oc})	45.75 V
Short Circuit Current (I_{sc})	8.77 A
Module Efficiency(η_m)	15.98 %
Temp. coefficient of Power (δ)	-0.42%/°C

TABLE III
INVERTER ELECTRICAL SPECIFICATIONS

Parameters	Value (XC 540)
Nominal Real Power (at PF=1)	540 kW
DC MPPT Range	440-885 V
Max Open Ckt. Voltage	1000 V
DC Input Current	1280 A
AC Output Voltage	300 V
Nominal AC Output Current	1040 A
Maximum Efficiency (η)	98.5%

C. Inverter Specification:

In this plant, 6 Nos. Schneider Electric make ConextCore XC series grid-tied Central Inverters of rating 540 kW have been used. Each Inverter is of indoor type with IP 20 level of protection and 208.5 x 240.0 x 66.0 cm dimension. Important technical specifications [31] are furnished in **Table III** above.

D. Energy Yield Simulation:

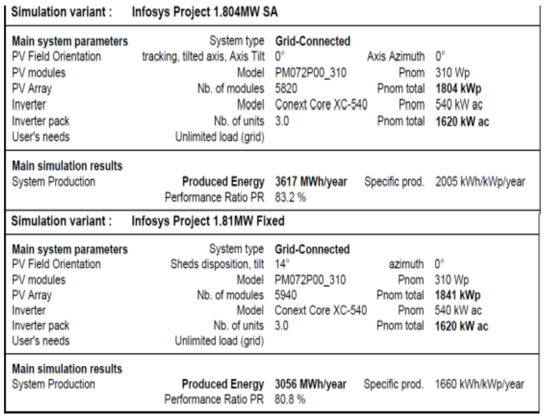
The annual energy yield is computed for a solar PV Plant using the basic designs and indicative layout by considering specific environmental conditions, downtime losses, AC ohmic losses, module degradation, transformation, transmission line losses etc. that reflect twenty-five-year plant life. Various losses that a Solar PV Plant might experience due have significant effect on the system performance efficiency, which results in reduction of energy yield.

Shading losses generally come from trees or nearby buildings or any other structure or even due to self-shading from its Module Mounting Structure and back-to-back PV rows.

This site was understood to be fairly flat and therefore horizon shading was considered negligible as no major landmass was observed. Additionally, the site does not have any large nearby structures such as buildings or trees that may shade it. Thus, 1% shading loss was considered during system modeling.

Other losses such as soiling losses, module mismatch, Light Induced Degradation (LID) and DC wiring were considered 3%, 1.4%, 2% and 1.4% respectively during system modeling. Equipment conversion losses were considered as per manufacturer specifications. Also, AC wiring losses which comes from the electrical output of the inverter was considered 0.3%.

Upon simulation of the entire Plant using the PVSyst simulation software and feeding various losses externally as described above, a predicted energy yield of 1.66 MU/MW/Year for 14º fixed-tilt systems and 2.0 MU/MW/Year for single-axis tilt system was found.


Simulation variant : Infosys Project 1.804MW SA

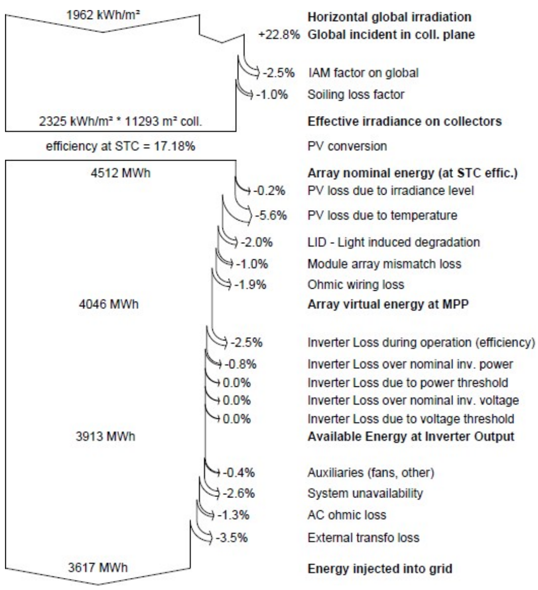
Main system parameters — System type: Grid-Connected
PV Field Orientation — tracking, tilted axis, Axis Tilt 0° — Axis Azimuth 0°
PV modules — Model PM072P00_310 — Pnom 310 Wp
PV Array — Nb. of modules 5820 — Pnom total 1804 kWp
Inverter — Model Conext Core XC-540 — Pnom 540 kW ac
Inverter pack — Nb. of units 3.0 — Pnom total 1620 kW ac
User's needs — Unlimited load (grid)

Main simulation results
System Production — Produced Energy 3617 MWh/year — Specific prod. 2005 kWh/kWp/year
Performance Ratio PR 83.2 %

Simulation variant : Infosys Project 1.81MW Fixed

Main system parameters — System type: Grid-Connected
PV Field Orientation — Sheds disposition, tilt 14° — azimuth 0°
PV modules — Model PM072P00_310 — Pnom 310 Wp
PV Array — Nb. of modules 5940 — Pnom total 1841 kWp
Inverter — Model Conext Core XC-540 — Pnom 540 kW ac
Inverter pack — Nb. of units 3.0 — Pnom total 1620 kW ac
User's needs — Unlimited load (grid)

Main simulation results
System Production — Produced Energy 3056 MWh/year — Specific prod. 1660 kWh/kWp/year
Performance Ratio PR 80.8 %



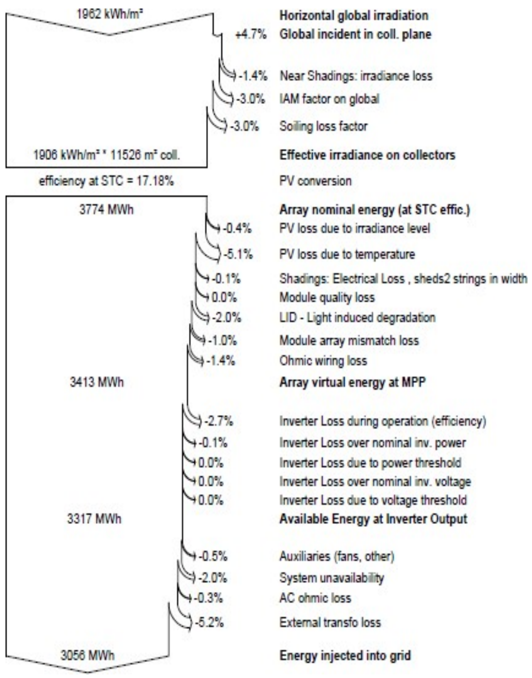


Fig. 6: PVSyst Design Simulation Output for (a) Single Axis Tracking System; (b) Fixed Tilt System

E. Single Line Diagram (SLD):

The overall plant layout along with individual rating of all the plant equipment has been shown in the **Fig. 7** below as a single line diagram. Total two number step up transformers have been used with cumulative capacity of 3.6 MVA. Both the transformers are of 4 winding, 1.8 MVA, 33kV/300- 300-300V rating with YNd11d11d11 configuration.

METHODOLOGY

The aim of this study is to analyse the Techno-economical effectiveness of single-axis solar tracking system over a fixed-tilt system. To investigate the effect of sun tracking mechanism, real solar energy generation data for both single-axis tracking and fixed-tilt system are collected for a period of 3 years (2016-2018) along with the weather data from Weather Monitoring System (WMS) installed at the site. The following analyses have been done based on the collected data.

A. Technical Analysis

To analyse technical effectiveness of both the system, the following parameters have been considered;

Specific Energy Production (*SEP*): It is the indicator which shows, how much energy (kWh) has been generated per kWp Solar PV Plant [14]. Unit of the indicator is kWh/kWp.

Energy Gain: It is the extra energy generation achieved due to single axis sun tracker compared to fixed tilt system and has been calculated using the following equation:

Energy Gain (%) = $[(E_{SAT} - E_{FT}) / E_{FT}] \times 100$ (i)

Where:

E_{SAT} (kWh/kWp): Specific Energy produced from SAT Solar PV array.

E_{FT} (kWh/kWp): Specific Energy produced from FT Solar PV array.

Performance Ratio (PR): The performance ratio is a measure of the quality of a PV plant that is independent of location and it therefore often described as a quality factor.

The performance ratio (PR) is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant. It thus shows the proportion of energy that is actually available for export to the grid after deduction of energy loss (e.g., due to thermal losses and conduction losses) and of energy consumption for operation. The closer the PR value determined for a PV plant approaches 100 %, the more efficiently the respective PV plant is operating. PR is calculated using the formula provided in IEC 61724 considering the weather data of the site and may be termed as weather-corrected PR (PR_{corr}) [13].

$$PR_{corr} = \Sigma_i EN_{AC}\_i / [\Sigma_i P_{STC} (G_{POA}\_i / G_{STC}) \times (1 - \delta \times 0.01) \times (T_{cell\_typ\_avg} - T_{cell\_i})] \quad \text{(ii)}$$

Where:

The summations are over a defined period of time (days, weeks, months, years)

EN_{AC} = measured AC electrical generation (MW)

P_{STC} = summation of installed modules' power rating from flash test data (MW)

G_{POA} = measured plane of array (POA) irradiance (kW/m^2)

i = a given point in time

G_{STC} = irradiance at standard test conditions (STC)

T_{cell} = cell temperature computed from measured meteorological data (°C).

Tcell_typ_avg = average cell temperature computed from one year of weather data using the project weather file (°C).
δ = temperature coefficient for power (%/°C, negative in sign) that corresponds to the installed modules.

Capacity Utilization Factor (CUF): It is also known as Plant Load Factor (PLF) of a PV power plant (usually expressed as a percentage) is the ratio of the actual output over the period of a year and its output if it had operated at nominal power the entire year [33], as described in the formula below.
CUF=Annual Energy Generated/[8760(hours/year)x Installed Capacity(kWp)] (iii)

B. Land Use Analysis

To analyse whether the precious land has been used effectively or not, the following parameters have been considered:

Ground Cover Ratio (*GCR*): It is defined as the ratio of the PV array area to total ground area for the system. The higher value the *GCR* has, the better surface exploitation is done [14].

Surface Performance Ratio (SPR): It indicates the amount of solar energy (kWh) generated per m^2 area covered by a solar PV system. Unit of the indicator is kWh/m^2 [14].

This has been defined as the product of the Specific Energy Production (SEP) and the peak power installed per square meter land (P_{STC}/S), as it is shown in the following Equation;

$SPR = SEP x (P_{STC}/S) = (Em/ P_{STC}) x (P_{STC} /S)$
$= Em/S$ (iv)

The SPR takes into account not only the production improvement of the tracking system, but the larger area it needs for the installation. It is to be noted that the *SPR* value is independent of the power size of the installation.

C. Financial Analysis

A financial study includes calculation of the most commonly used financial parameters viz., Payback Period (PBP), Net Present Value (NPV) and Internal Rate of Return (IRR).

Carbon Credit Calculation: Carbon Credit is something that can be used to assign a commercial dollar value to one metric ton of greenhouse gas emissions (tCO_2) or its equivalent, so that they can measure, buy, sell, and trade it. It can be calculated using the following equation:

Carbon Credit (tCO_2) = Generation (MWh)/F_E (MWh/tCO_2) (v)

Where:

F_E= Emission Factor as calculated by Central Electricity Authority (CEA) [15].

Price of Carbon Credit depends upon the various market-based mechanisms available viz., Clean Development Mechanism (CDM), Verified Carbon Standard (VCS) and Gold Standard (GS). Here, VCS mechanism [16] has been used for calculation of price.

Payback Period (PBP): It is the length of time required to recover the initial cash outlay of a project through the successive cash inflows [14]. It is calculated using the following equation:

PBP = Initial Outlay/Net Cash Inflows

= I/(cxp-m) (vi)

Where:
I= real costs of the investment (INR)
c= retribution of the produced energy (INR/kWh)
p= yearly energy production (kWh/year)
m= maintenance and replacement costs (INR/year)

Net Present Value (NPV): NPV is how much return a project will make, accounting for the time value of money [14]. Factors such as opportunity cost, inflation and risk are all accounted for in NPV to give the overall value of the project in today's time. A positive value for NPV indicates that the project is set to make money or prove profitable to clients over the time period considered. Vice versa is the case for a negative NPV. It is calculated using the following formula:

NPV= [Net Cash Inflow x (1 + discount rate) ^-(time)] – I (vii)

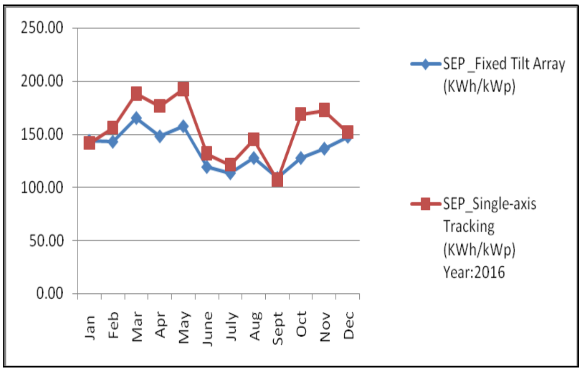
Internal Rate of Return (IRR): It is the discount rate at which the sum of Net Present Value (NPV) of the current investment and all future cash inflow is zero [14]. It is an indicator of the growth of the project is expected to generate. It is calculated using the following formula:

[Net Cash Inflow x (1 + IRR) ^-(time)] – I = 0 (viii)

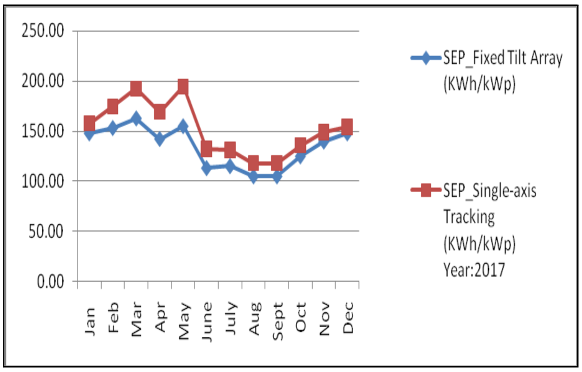
RESULT AND DISCUSSION

A. Technical Analysis Results

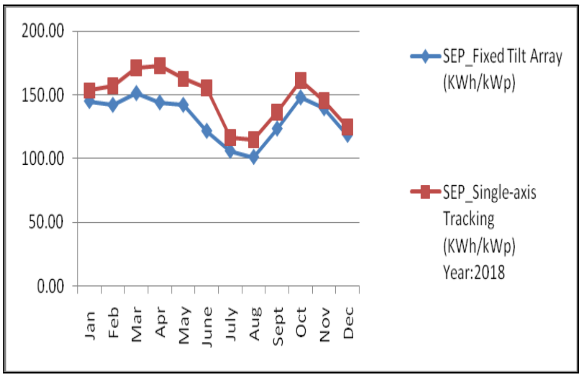
The calculated Specific Energy Production (SEP), Performance Ratio (PR) & Capacity Utilisation Factor (CUF) for both Single-axis Tracking (SAT) and Fixed Tilt (FT) are represented in **Fig. 8** below as graph for comparison and the real 3 years (2016-2018) generation data are furnished below in **Table IV**.



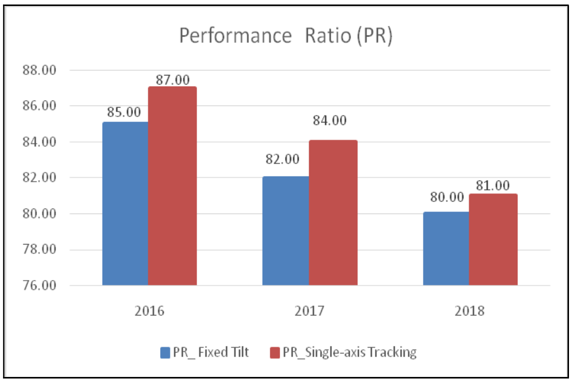
(a)



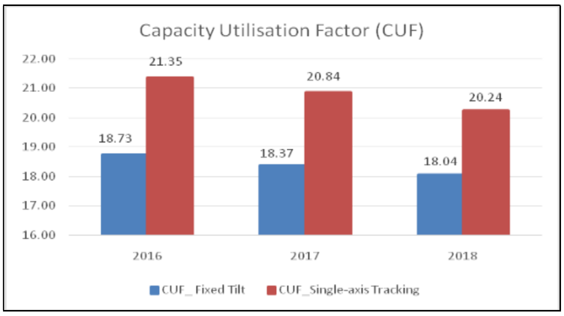
(b)



(c)



(d)



(e)

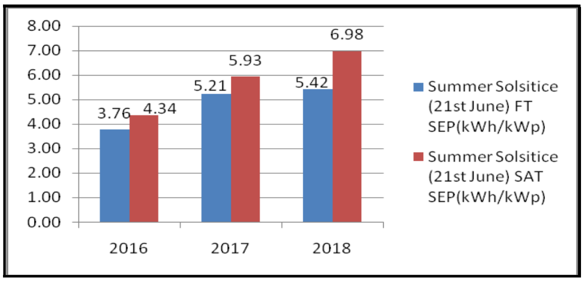
Fig 8: (a) SEP comparison in 2016; **(b)** SEP comparison in 2017; **(c)** SEP comparison in 2018; **(d)** PR comparison; **(e)** CUF comparison.

The above result clearly shows an energy gain of 14%, 13.4% & 12.2% have been achieved under the particular climate condition of the site in the year 2016, 2017 & 2018 respectively from the SAT system. The slight decline in the energy gain may be due to combined effect of the climate condition of those particular years and Solar PV Module generation degradation (normally around 1% per year).

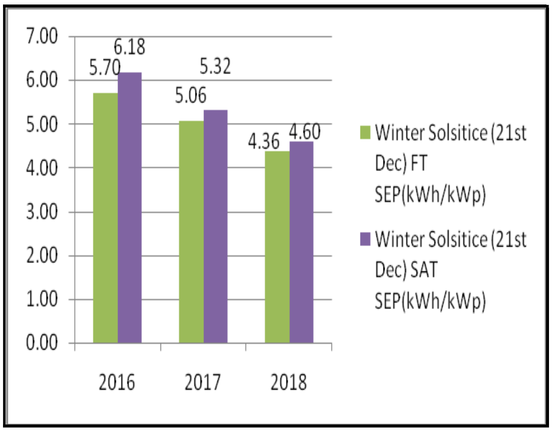
The calculated Specific Energy Production (SEP), Performance Ratio (PR) & Capacity Utilisation Factor (CUF) are also showing higher value in case of SAT system compared to the FT system with 14º tilt angle, which indicates better utilisation of the solar resources and plant equipments.

As the maximum & minimum declination of sun occurs in summer and winter solstice with the angle of 23.45° & -23.45° respectively, a comparison of generation achieved during both the scenario are represented in **Fig. 9** below as graph for both the Solar PV array system type.

From the following comparison also, it can be noticed that the SAT solar PV array system is more efficient in case of energy generation, compared to the FT system with 14° tilt angle.



(a)



(b)

Fig. 9: (a) SEP comparison in summer solstice; (b) SEP comparison in winter solstice.

B. Land Use Analysis Results

In order to determine, which system is effective in case of land use GCR & SPR are calculated as furnished in **Table V** below.

Description	FT	SAT
Installed DC Capacity	1.841 MW	1.804 MW
Module Area (m^2)	11403	11174
Total PV Yard Area (m^2)	17968	18341
Specific Land Area (m^2/kWp)	9.76	10.17
Ground Cover Ratio (GCR)	1.58	1.64
Average Energy Generated (kwh/yr)	2964435	3288799
SPR (kWh/m^2)	164.98	179.31

TABLE V: Calculated results of GCR & SPR.

Graphical representations of the calculated parameters are shown in Fig. 10 below.

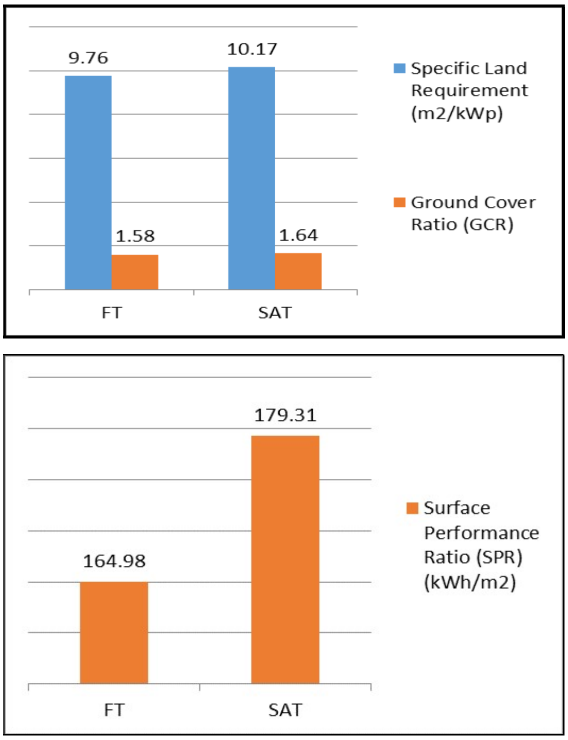


Fig. 10: Specific Land Area Requirement, GCR & SPR comparison.

The above calculated result shows, even though the Specific Land Area Requirement per kWp & Ground Cover Ratio i.e., (Land area/Module area) is little higher in case of SAT system, it produces higher energy (kWh) per m^2 of land area used i.e, SPR as compared to the FT system with 14° tilt angle.

C. Financial Analysis Results

Financial analysis has been done on the extra cost involvement for the SAT solar PV array compared to FT array and the energy gain due to installation of SAT system. The SAT system is slightly costlier than the FT system, cost of which varies with brand, covering angle, rotating motor quality etc. INR 1500000/ MW has been considered as the extra cost involvement for SAT array system and various other considerations are furnished in the **Table VI** below.

From the calculated result it can be seen that the additional investment made in order to install SAT system has a Payback Period of 1.57 years with a positive Net Present Value (NPV) of INR 1490207 and Internal Rate of Return (IRR) of 39.28 %. As, the calculated NPV and the IRR for the considered three years (2016-18) duration is positive & greater than the discount rate (9%) respectively, the additional investment for SAT system is financially viable.

CONCLUSION

From the above results, it can be concluded that the solar system with Single-axis Tracker (SAT) PV array has generated more energy throughout the whole period of three years (2016-18) and also during both summer & winter solstice. On an average, the SAT system had achieved an energy gain of 14%, 13.4% & 12.2% in 2016, 2017 & 2018 respectively as compared to Fixed Tilt (FT) system. Throughout the three years (2016-18) period, the SAT system had operated with higher Performance Ratio (PR) and Capacity Utilization Factor (CUF) value as compared to FT system, which means, the SAT system is able to collect more irradiance (W/m2) and utilise the installed capacity better as compared to FT system.

Though the Specific Land Area (m^2/kWp) requirement and Ground Cover Ratio (GCR) is little higher in case of SAT system, its Surface Performance Ratio (SPR) is higher (179 kWh/m^2) as compared to FT system (165 kWh/m^2).

The additional investment made for the SAT system had been paid back by the energy gain within 1.57 years with an IRR of 39.28 and NPV of INR 1490207 for the duration (2016-18) considered. The energy gain achieved throughout the plant life after the payback period will contribute to overall payback of the plant cost and reduce the overall payback period of the whole plant as compared to FT system.

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Nomenclature

PV	Photovoltaic
FT	Fixed Tilt
SAT	Single-axis Tracking
PR	Performance Ratio
PR_{corr}	Weather corrected PR
CUF	Capacity Utilisation Factor
PLF	Plant Load Factor
MMS	Module Mounting Structure
STC	Standard Test Condition, 25 °C, 1000W/m^2; A.M. = 1.5
IP	Ingress Protection
PF	Power Factor
MPPT	Maximum Power Point Tracker
LID	Light Induced Degradation
MU	Million Unit (10^6 kWh)
WMS	Weather Monitoring System
SEP	Specific Energy Production
GCR	Ground Cover Ratio
SPR	Surface Performance Ratio
Em	Energy Generated (kWh)
S	Area of PV Module Installation (m^2)
I	Real costs of the investment (INR)
c	Retribution of the produced energy (INR/kWh)
m	Maintenance and replacement costs (INR/year)
Pmax	Nominal Power (W)
Vmp	Maximum Voltage (V)
Imp	Maximum Current (A)
V_{oc}	Open Circuit Voltage (V)
I_{sc}	Short Circuit Current (A)
η_m	Module Efficiency
δ	Temperature coefficient of Power (%/°C)
E_{SAT}	SEP from SAT Solar PV array (kWh/kWp)
E_{FT}	SEP from FT Solar PV array (kWh/kWp)
E_{NAC}	Generated AC electrical Power (MW)
P_{STC}	Summation of installed modules' power rating from flash test data (MW)
i	A given point in time
G_{POA}	Measured plane of array (POA) irradiance (kW/m^2)
GSTC	Irradiance at STC
Tcell	Cell temperature computed from measured meteorological data (°C).
$T_{cell\_typ\_avg}$	Average cell temperature computed from one year of weather data using the project weather file (°C).
PBP	Payback Period
NPV	Net Present Value
IRR	Internal Rate of Return
F_E	Emission Factor as calculated by Central Electricity Authority (CEA)
tCO2	Equivalent to one Carbon Credit unit
p	Yearly energy production (kWh/year)

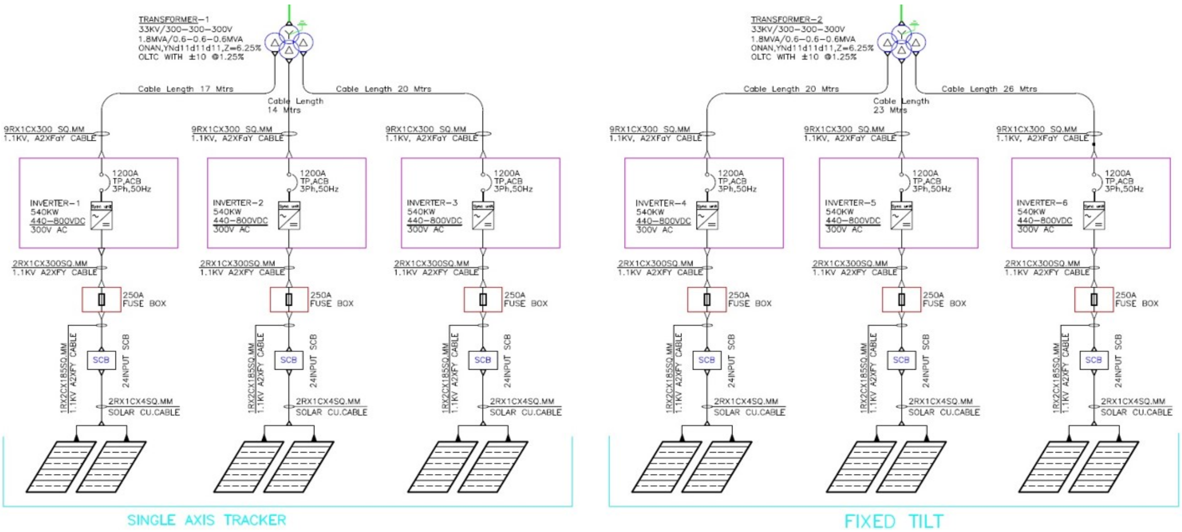

Fig. 7: DC Single Line Diagram of the Plan

Year	Generation	Installed Capacity (kW)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total	Generation Gain	CUF	PR
2016	Fixed Tilt Array (KWh)	1841	265094.5	263437.6	304473.49	272826.7	290205.74	219805.9	209164.92	235417.58	200995.06	235417.58	251534.873	271943.02	3020317	In Unit (Kwh)	Fixed Tilt Array	Fixed Tilt Array
	Single-axis Tracking (KWh) Year:2016	1804	273840.916	281336.71	339070.529	317760.052	346635.69	237508.24	218118.148	260968.97	201823.72	304038.013	310608.065	282599.277	3374308	353991.36	18.73	85
	SEP _Fixed Tilt Array (KWh/kWp)	1841	143.99	143.09	165.38	148.19	157.63	119.39	113.61	127.87	109.18	127.87	136.63	147.71	1641	In Percentage (%)	Single-axis Tracking Year:2016	Single-axis Tracking Year:2016
	SEP_Single-axis Tracking (KWh/kWp) Year:2016	1804	151.80	155.95	187.95	176.14	192.15	131.66	120.91	144.66	111.88	168.54	172.18	156.65	1870	14.01	21.35	87
2017	Fixed Tilt Array (KWh)	1841	271994.34	281813.31	299386.24	261537.83	284958.52	207930.48	211585.73	192810.68	192720.06	229582.09	256732.60	271886.08	2962938	In Unit (Kwh)	Fixed Tilt Array	Fixed Tilt Array
	Single-axis Tracking (kWh) Year:2017	1804	284339.50	315359.57	347171.07	305033.12	350773.25	238299.67	236137.78	212767.25	212755.61	244872.63	268176.24	277722.89	3293409	330470.62	18.37	82
	SEP_Fixed Tilt Array (KWh/kWp)	1841	147.74	153.08	162.62	142.06	154.78	112.94	114.93	104.73	104.68	124.71	139.45	147.68	1609	In Percentage (%)	Single-axis Tracking Year:2017	Single-axis Tracking Year:2017
	SEP_Single-axis Tracking (KWh/kWp) Year:2017	1804	157.62	174.81	192.45	169.09	194.44	132.10	130.90	117.94	117.94	135.74	148.66	153.95	1826	13.43	20.84	84
2018	Fixed Tilt Array (KWh)	1841	266792.59	261206.21	278234.06	264790.35	261251.94	223655.96	194793.04	186052.45	227041.43	272018.78	256334.58	217878.27	2910050	In Unit (Kwh)	Fixed Tilt Array	Fixed Tilt Array
	Single-axis Tracking (KWh) Year:2018	1804	277086.91	283672.72	308962.93	312052.21	293405.99	280623.33	210670.29	207407.25	245920.67	290488.33	262804.08	225586.10	3198681	288631.13	18.04	80
	SEP_Fixed Tilt Array (KWh/kWp)	1841	144.92	141.88	151.13	143.83	141.91	121.49	105.81	101.06	123.33	147.76	139.24	118.35	1581	In Percentage (%)	Single-axis Tracking Year:2018	Single-axis Tracking Year:2018
	SEP_Single-axis Tracking (KWh/kWp) Year:2018	1804	153.60	157.25	171.27	172.98	162.64	155.56	116.78	114.97	136.32	161.02	145.68	125.05	1773	12.17	20.24	81

TABLE IV: Real three years (2016-2018) generation data and calculated SEP, Energy Gain, CUF & PR.

Extra Cost of SAT Array Installation/MW (INR)				2700000		Emmission factor		0.9645	Carbon Credit Value (VCS)			0.3 USD
Electricity tariff inflation per annum				5%		Discount Rate		9%	O & M Cost	1.5% of the Installation cost		
Sl. No.	Year	Energy Gain (kWh)	Power Purchase Tariff/ kWh (INR)	Price of Energy Gain (INR)	Cumulat-ive Price (INR)	Carbon Credit Trading Value (INR)	Total Saving (INR)	O & M Cost (INR)	Net Saving (INR)	Payback Period (Years)	NPV (INR)	IRR (%)
1	2016	353991	5.0	1769955	1769955	7170	1777125	40500	1736625	1.55	1490207	30.7
2	2017	330471	5.3	1734973	3504928	6694	1741666	40500	1701166			
3	2018	288631	5.5	1591078	5096006	5846	1596924	40500	1556424			

TABLE VI: Calculated results of PBP, NPV & IRR

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