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Aiming at Optimization of Tracking Technology through Seasonally Tilted Sun Trackers: An Indian Perspective

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***Abstract*—**Discussions on concepts of Single Axis Tracker (SAT) are becoming more and more apt for developing countries like India not just as an advancement in racking technology but due to the utmost necessity of reaching at the lowest Levelized Cost of Energy (LCOE) targets. With this increasing competition and significant fall in feed-in tariffs of solar PV projects, developers are under constant pressure to secure investment for their projects and eventually earn profits from them. Moreover, being the second largest populated country, India suffers from scarcity of land because of higher average population density. So, to mitigate the risk of this dual edged sword with reducing trend of unit (kWh) cost at one side and utilization of land on the other, tracking evolved as the call of the hour. Therefore, the prime objectives of this paper are not only to showcase how STT proves to be an effective mechanism to get more gain in Global Incidence in collector plane (G_{inc}) with respect to traditional mounting systems but also to introduce Seasonally Tilted Tracker (STT) technology as a possible option for high latitude locations.

***Keywords*—**Tracking system, grid-connected PV systems, cost reduction.

I. Introduction: The Concept

THE ideal mechanism through which maximum generation can be produced in a PV plant is to orient the solar PV modules towards sun in such a manner that the incident rays are perpendicular to the module surface. But our earth not only revolves around the Sun but also rotates on its own axes. So, two particular aspects need to be kept in mind that

a) during rotation of the earth, it experiences a respective movement of sun from east to west via south (called as sun-path).
b) this sun-path of a location gets periodically changed due to revolution of earth.

Both these changes occur daily, but the former is much more detectable as it happens every, day whereas the latter is distributed throughout the year, getting detectable during the change of seasons (Fig. 1 [1]).

So, talking about traditional mounting systems, both fixed tilted (FT) structures (i.e., facing towards south at a fixed tilt) and seasonally tilted fixed (STF) structures (i.e.; facing towards south with a fixed tilt with seasonal tilt adjustment facilities twice or thrice a year) had limitations of not having the capability of adjusting themselves as per the daily shift in sun-path. Thus, the thought process of trackers came into existence. While studying about trackers from the work of several other scientists, we came across few observations about them (Fig. 2):

- Applicability of SAT-Vertical is only limited to very high latitude locations, like Europe and thus its applicability and acceptability is not in India.
- SAT-Horizontal is applicable all over India, especially South India.
- During literature review, it was already studied from several previous research works done by eminent scientists that trackers are location specific in nature, and if comparison is drawn in between single and dual axis trackers, though dual-axis trackers are more accurate in pointing directly at the sun which is usually the brightest spot in the sky [2], single axis will win the race with flying colors due to lower engineering complexity, higher ground coverage ratio (GCR), and last but not the least, price. Thus, this analysis on Single Axis tracking technology became more appropriate for a price sensitive market, like India.

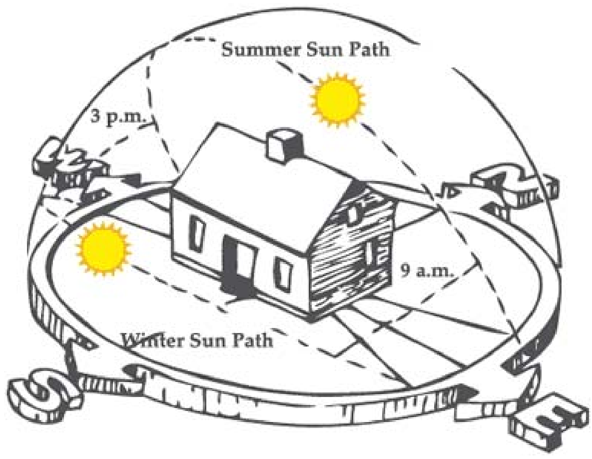

Fig. 1 Varying Sun-Path

Apart from increment in generation, few other firm observations came up from our study and the above analysis and they were:

- Since trackers are highly location sensitive, for different location (higher and lower latitude areas) we should have different options of tracker.

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- Trackers occupy higher space with respect to FT and STF structures of same DC capacity.
- With the advent of trackers, module mounting system design remained no more just a structural activity but since gears, motors & control elements got involved in it, the system became more sophisticated and complex resulting into increment in cost.
- Trackers will increase plant's Operation and Maintenance (O&M) cost to certain extent due to more number of serviceable parts and
- Trackers need more land leveling than other traditional structures as the different rows and strings are tied together to form a table which gets driven by a single actuator.

From the above knowhow gathered from our study, there were some dark spots in front of us where we wanted to work upon. Broadly, they were two;

a) Developing such a tracker that can be universally used in all locations.
b) Finding out a mechanism through which we can enhance the GCR and at the same time do not compromise much on the generation with respect to a dual axis tracker.

Thus, the target was to club together the benefits of a SAT-Horizontal and STF structure. This will purge the issue of low GCR of dual axis tracker and even increase the generation of a SAT- Horizontal by another 5-8% (depending on location) giving it a semi-dual configuration. That is Seasonally Tilted Tracker (STT).

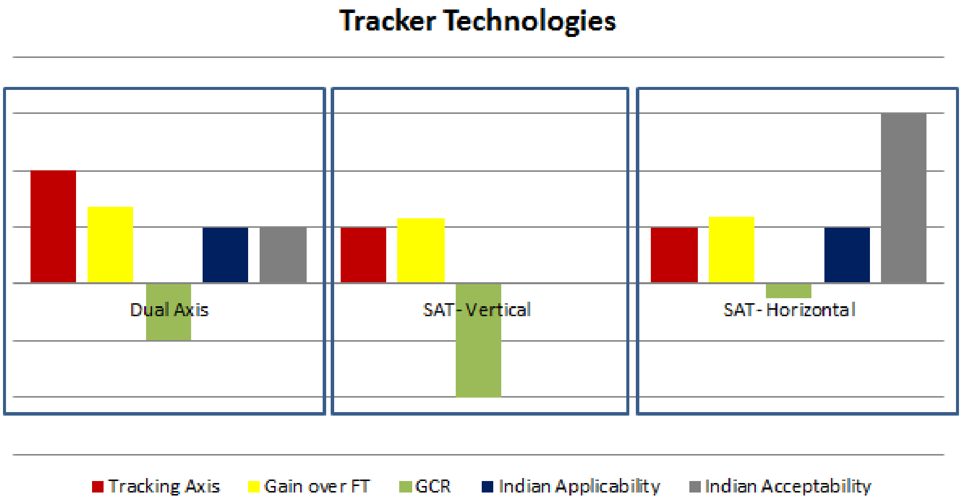

Fig. 2 Tracker Comparison

II. Background and Motivation

A. Market Conditions

With this decreasing benchmark cost (see Fig. 3) of energy companies started analyzing several alternatives to achieve the same. But, majority of the analysis came out explaining measures of CAPEX reduction, like replacement of RCC control rooms with prefabricated ones, usage of five winding transformers (as done by Schneider, Electrotherm, GE Energy and few more) in place of three windings, using large megawatt scale central inverters above 1 MW size (as manufactured by TBEA, L&T, Power Electronics and some more) in place of medium size central inverters, to name a few of them. However, these alterations and reengineering only brought an effect of around 1% - 1.5% reduction in material cost for a project. Therefore, gradually large EPC companies and developers started realizing that just bringing reduction in Balance of System (BOS) cost will not be going to help them in long run. A holistic approach is required for cost optimization which must include:

a) Design optimization and bringing better control on the top three cost components (constituting almost 70% - 75% of the total material cost) in a Solar PV power plant, i.e. Solar Module, Module mounting structure, and Solar Inverters.
b) Increasing generation from each power plant that gets designed so that we extract the maximum possible output from our investment.
c) Enhance usage of those products and processes that assure quicker installation, and also easier operation and maintenance (O&M).
d) Loss minimization at each step of a project to ensure better control on allied expenses of a project.

Since controlling the first two above mentioned aspects would be the most important, thus our focus of work was towards the same. Through our research, we not only concentrated on generation but also tried to find out the most effective tracking system which takes care of generation increment without compromising much upon:

✓ Ground Coverage Ratio (GCR),
✓ Generation,
✓ Can be manufactured at an affordable cost.

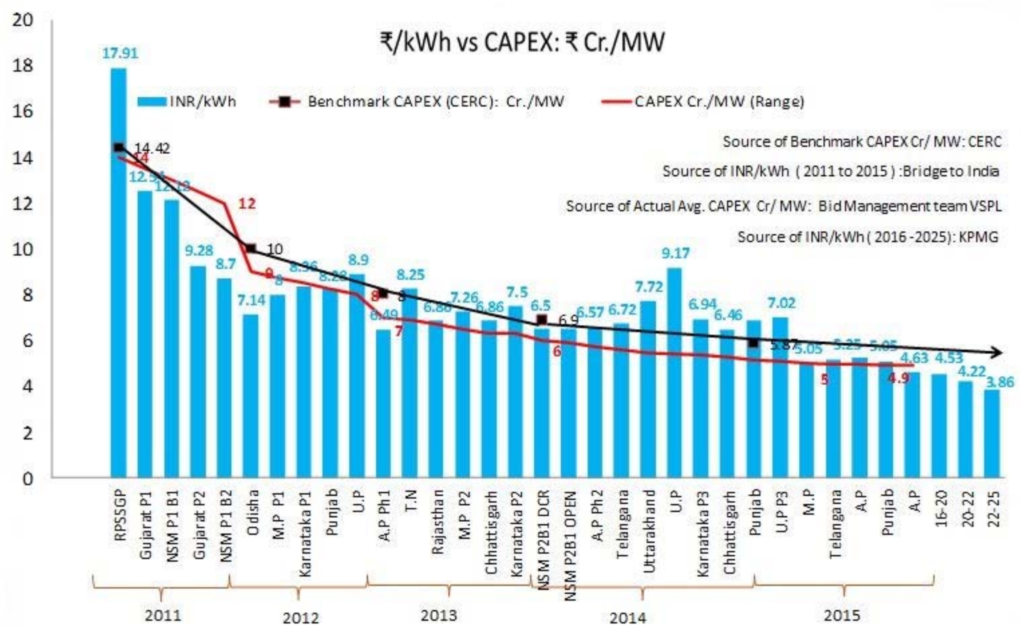

Fig. 3 Unit Cost (INR/kWh) vs. CAPEX

B. Hindrance

During our interaction with some of the Indian and foreign tracker manufacturers, it has been found that each of them promises different percentage of gain over traditional mounting systems (FT or STF), whereas the analysis through simulation software for the same set of manufacturers gives no such difference. Thus, there was no means through which we can verify their stated gain percentages against a real-time data for a particular location.

Since it is the responsibility of the all prominent EPC players and reputed developers to guide the development of the PV market and introduce technically superior products, performance and reliability of a technology must be tested mandatorily during its very entry stage. That was also the motivation for us behind the deployment of the real time test bench (in process) for analysis of different trackers and modules.

III. The Test Bed

A. Necessity

As we discussed above, the primary requirement of this test bench was to come up with an installation through which we can establish the utility of STT in providing us with the lowest LCOE. Going into details, the various other touch points of this test bench will be

a) To have real time data which will help us to take strategic decisions for different module and mounting technologies.
b) Comparative analysis between different module mounting technologies to calculate variations in stability, flexibility, and ease of installation.
c) To validate the design of Seasonal Tilted Tracker (STT-Technology Demonstration Model-2).
d) To analyze the ground reality of the gain in usage of Bifacial Modules, as simulation software like PVsyst, cannot calculate the same.
e) To analyze the gain through the application of Micro-inverters/ Optimizer (Sine/ Smart modules respectively) and establish the same in comparison with traditional string inverters.

But, through this paper, we will only be focusing on STT showcasing our trials to establish the generation gain and the LCOE aspects for that.

B. Test Bed Mix

In this test bench, we planned to analyze three vital materials of a PV plant:

a) PV Module,
b) Module mounting structure,
c) Inverter.

Except the variation of the above three components, we tried to keep almost all aspects of these PV plants constant:

- Geographical Location
  - Latitude: 28°37′42″N
  - Longitude: 75°37′07″E
- Global Horizontal Irradiance.

In the test bench, we designed to analyze three types of PV module. They are:

- Polycrystalline PV Module with PERC (Passive Emitter Rear Contact) Cell,
- Polycrystalline AC Modules- PV modules with Micro Inverters,
- Mono-crystalline (N-type) Bifacial Module.

For the second costliest element of a PV Plant (module mounting structures), we analyzed four of their types-

- Fixed Tilted (FT) structure,
- Seasonal fixed tilted (SFT) structure,

- Single Axis Tracker (SAT)-Horizontal,
- Seasonal Tilted Tracker (STT).

The manufacturing of these structures is done with hot dip galvanized (HDG) sections following IS-2062 [3] and Galvalume sections following IS-15961:2012 [4] with wind speed consideration of Zone 5 (50 m/s).

Now, when talking about inverters, we installed 10 different ground mounted PV plant of same DC Capacity with string inverters, three with microinverters and one combined set of bifacial module with microinverters. The scheme is shown in below (Fig. 4)

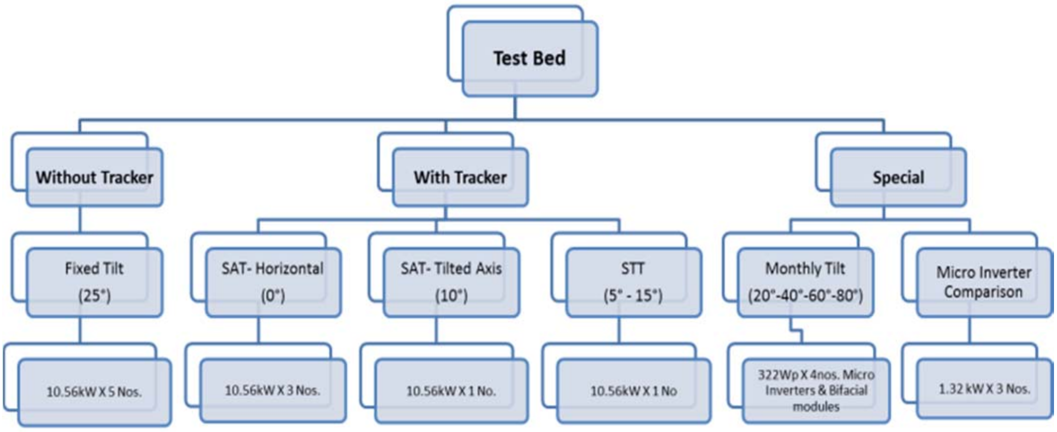

Fig. 4 Test Bed Plant Scheme

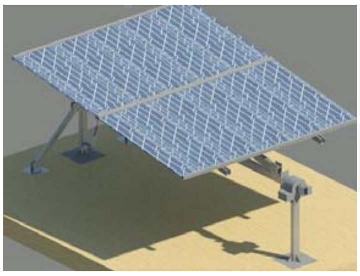

Fig. 5 Frontal view of STT

C. Focusing on STT

Different manufacturers of tracker promise different percentage of gain on Global Inclined Irradiance (G_{inc}) over traditional mounting systems (FT or SFT), whereas the analysis through simulation software for the same set of manufacturers gives no such difference. During our due diligence process for different trackers, we started realizing that the gain in G_{inc} will always be same if

- Location is same;
- Time of year is same;
- Tracking angle and accuracy is same.

Thus, the only controllable factor out of the above-mentioned factors for creating difference amongst competitors is precision of tracking. Except that, few major factors contributing in creating an edge are:

- Adaptability to land terrain,
- Auxiliary consumption,
- Weight,
- No. of foundations required per block,
- Ease of handling of tracker parts,
- Robustness (torque, friction etc. handling capacity),
- Life Expectancy of material,
- Per unit (mostly measured in per Wp) cost.

So, that is the reason why along with innovative solution every manufacturer needs to focus on continuous improvement on sourcing of material and also design of structural parts of a tracker to maintain its position in market.

Since in this paper we will be restricting our discussion to the aspect of Tracking angle and accuracy in STT, let us dive down into the design and analysis for the incremental gain in G_{inc} that can be achieved by this technology.

Broadly four types of single axis tracker (SAT) came into our discussion. In all the cases the tracker rotates from East to West -

- SAT- Horizontal- The solar module will be mounted parallel (at 0 degrees) to ground;
- SAT- Vertical- The solar module will be mounted perpendicularly (at 90 degrees) to ground;
- SAT- Tilted Axis- The solar module will be mounted at a fixed angle towards South (within 8-10 degrees, depending on location);
- SAT- Seasonal Tilt (STT)- The solar module will be mounted at a fixed angle towards South (within 5-15 degrees, depending on location) for a particular season and then gets changed to another angle.

So, for the last type of SAT mentioned, the concept resembles Dual Axis tracking but avoids the complexity in changing both the axis at all instance through the year, on every day.

The technology demonstration design of STT has been simplified by using slew gear for rotating the tracker from East to West direction and linear actuator for changing the tilt seasonally (Figs. 5 and 6).

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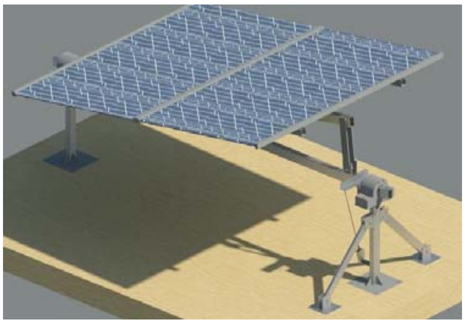

Fig. 6 Rear view of STT

Design Considerations	Non Tracker	
Technology	Fixed Tilt	Seasonal Tilt
Tilt angle (°)- Jan, Feb, Mar, Oct, Nov, Dec	25	34
Tilt angle (°)- Apr, Sep	25	18
Tilt angle (°)- May, Jun, Jul, Aug	25	8
Azimuth angle (°)	0	0
Pitch on East-West side (m)	7	8
Pitch on North-South side (m)	0	0
Parameters		
PV loss due to Irradiance level (%):	-0.1	-0.1
Soiling loss (%):	2	2
Global Incidence in collector plane (kWh/m2):	2104.7	2174.8
Jan	153.0	162.2
Feb	172.7	180.1
Mar	205.2	207.0
Apr	205.8	204.2
May	197.6	206.8
Jun	172.5	184.3
Jul	153.9	162.9
Aug	164.4	167.5
Sep	173.1	167.0
Oct	188.1	193.5
Nov	162.9	172.6
Dec	155.5	166.7
Gain in Ginc w.r.t. Fixed Tilt (%):	0	3.3%

Fig. 7 Gain in Global Incidence in collector plane: SFT w.r.t FT

Design Considerations	Tracker		
Technology	SAT- Horizontal	SAT- Tilted Axis	SAT- Seasonal Tilt (STT)
Tilt angle (°)- Jan, Feb, Mar, Oct, Nov, Dec	0	10	15
Tilt angle (°)- Apr, Sep	0	10	10
Tilt angle (°)- May, Jun, Jul, Aug	0	10	5
Azimuth angle (°)	NA	0	0
Pitch on East-West side (m)	5	7	7
Pitch on North-South side (m)	0	2.5	3
Parameters			
PV loss due to Irradiance level (%):	-0.3	-0.3	-0.4
Soiling loss (%):	1.5	1.5	1.5
Global Incidence in collector plane (kWh/m2):	2350	2497.6	2546.7
Jan	142.9	162.4	185.1
Feb	175.5	196.3	209.0
Mar	232	249.8	248.3
Apr	251.5	261.8	249.0
May	250.8	252.5	239.1
Jun	218	216.4	208.7
Jul	188.2	187.5	186.2
Aug	198.6	203.2	198.9
Sep	198.6	209.6	209.5
Oct	197.3	216.9	227.6
Nov	155.8	178.2	197.1
Dec	140.8	163.0	188.2
Gain in Ginc w.r.t. Fixed Tilt (%):	11.7%	18.7%	21.0%

Fig. 8 Gain in Global Incidence in collector plane: SATs w.r.t FT

In the test bed mentioned above, we tried to analyze the gain in G_{inc} by shifting from fixed tilted structure to trackers in Figs. 7 and 8.

From Fig. 9, we can clearly state that STT has definite enhanced performance over traditional SAT- Horizontal and Tilted Axis. Since this site is located in North India, thus gain in G_{inc} has been limited to 21%, and it is ensured that, for South Indian sites, it will definitely provide more gain. But, analysis needs to be done whether that incremental gain is comparable with increase in cost per Wp. Thus, from this experiment, we can clearly state that the concept of STT is very much applicable in Indian context for north Indian locations.

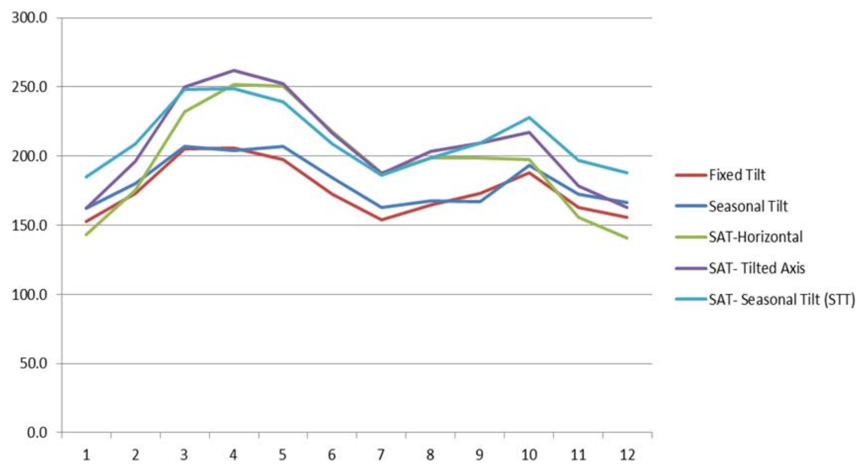

Fig. 9 Comparison of Yearly Global Incidence in collector plane

IV. Work in Progress

Though, from our analysis, we have established that STT is much better in comparison with conventional SATs, but still right now, we are working on aspects like:

- Levelized Cost of Energy (LCOE) analysis with STT,
- Continual improvement in STT design for ease of operation and maintenance,
- Structural analysis with respect to UL 3703 [5].

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