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Econometric analysis of solar tracker systems in India, a case study

Seyed Samsamoddin Naghavi Chaleshtori[1], Adinath M. Funde[1*]

[1]School of Energy Studies, Savitribai Phule Pune University (formerly University of Pune), Ganeshkhind, Pune – 411007. India

Email: samsam.naghavi@gmail.com (SSNC) , * adinath@unipune.ac.in (AMF)

Abstract. Energy generation typically requires an investment in a technology that assures supply over many years. This paper deals with techno-economical study of solar tracker system employed in Photovoltaic (PV) energy conversion. The proposed single axis solar tracker device ensures the optimization of the conversion of solar energy into electricity by properly orienting the PV panel in accordance with actual position of the sun. Solar tracking system is one of the most direct approaches adopted to harvest more solar energy from PV system compared to static solar PV arrays. Hence, with the use of tracking system, the PV panels are able to receive maximum sunlight and thus generate more energy.

I. INTRODUCTION

The energy produced by any solar conversion system depends mainly on efficient collection of solar radiation. However, to be able to collect the maximum of solar energy, the most usually used scheme in solar applications is a solar PV surface oriented toward the equator and generally inclined according to the annual, seasonal or monthly optimum slope as those proposed in [1-5].But, in a fixed-tilt PV array, the normal or near normal incidence of solar radiation is limited in time i.e. at local solar noon. Therefore, to receive maximum solar insolation, one needs to orient the PV panels normal to beam radiation. In many cases the extra costs of the mechanical system and optical elements are significantly related to system performance. The optimized solution as proposed by several researchers to increase the yield of solar PV plant is the use of sun tracker systems. The use of sun tracking systems in solar PV systems applications enables the PV panel to constantly track the sun, hence to collect the maximum solar irradiance throughout the day. However, these systems can be economically profitable only if the extra cost related to the sun tracking mechanism is lower than the cost of the additional panels which will lead to the same power production with a system having a fixed structure [3-8].

II. METHODOLOGY:

2.1 Sun positioning Mechanism

The amount of solar radiation incident on a tilted PV module surface is component of the incident solar radiation which is perpendicular to the module surface. The figure 1 depicts calculation of the radiation incident on a tilted surface (S_{module}) with given either the solar radiation measured on horizontal surface (S_{horiz}) or the solar radiation measured perpendicular to the sun ($S_{incident}$) [10].

The equations relating S_{module}, S_{horiz} and $S_{incident}$ are:

$$S_{horizontal} = S_{incident} \sin\alpha \quad (1)$$

$$S_{module} = S_{incident} \sin(\alpha+\beta) \quad (2)$$

Where, α is the elevation angle; and β is the tilt angle of the module measured from the horizontal.

The elevation angle is given as:

$$\alpha = 90 - \phi + \delta \quad (3)$$

Where, ϕ is the latitude; and δ is the declination angle given as:

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+d)\right] \quad (4)$$

Where, d is the day of the year.

From these equations a relationship between S_{module} and S_{horiz} can be determined as:

$$S_{module} = \frac{S_{horizontal}\sin(\alpha+\beta)}{\sin\alpha} \quad (5)$$

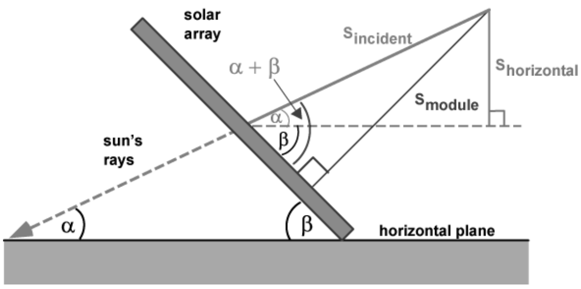

Figure 1: Solar radiation – Solar array tilt geometry. αis elevation angle, β is tilt angle of the module measured from the horizontal, S_{module}, S_{horiz} and $S_{incident}$ are mentioned in the text. [10]

The equations relating S_{module}, S_{horiz} and $S_{incident}$ are:

$$S_{horizontal} = S_{incident} \sin\alpha \quad (6)$$

$$S_{module} = S_{incident} \sin(\alpha+\beta) \quad (7)$$

Where, α is the elevation angle; and β is the tilt angle of the module measured from the horizontal.

The elevation angle is given as:

$$\alpha = 90 - \phi + \delta \quad (8)$$

Where, ϕ is the latitude; and δ is the declination angle given as:

$$\delta = 23.45 \sin\left[\frac{360}{365}(284+d)\right] \quad (9)$$

Where, d is the day of the year.

From these equations a relationship between S_{module} and S_{horiz} can be determined as:

$$S_{module} = \frac{S_{horizontal}\sin(\alpha+\beta)}{\sin\alpha} \quad (10)$$

2.2 Levelized cost of energy (LCoE)

LCOE (levelized cost of energy) is the utility industry's primary metric for the cost of electricity produced by a generator. It is calculated by accounting for all of a system's expected lifetime costs (including construction, financing, fuel, maintenance, taxes, insurance and incentives), which are then divided by the system's lifetime expected power output (kWh). All the cost and benefit estimates are adjusted for inflation and discounted to account for time-value of money. As an important financial tool, LCoE is very valuable for the comparison of various generation options. A relatively low LCoE means that electricity is being produced at a low cost, with higher likely returns for the investor [11]. LCoE is defined as equation (11):

$$LEC = \frac{\sum_{t=1}^{n}\frac{I_t+M_t+F_t}{(1+r)^t}}{\sum_{t=1}^{n}\frac{E_t}{(1+r)^t}} \quad (11)$$

Where,

LEC = Average lifetime levelized electricity generation cost

I_t = Investment expenditures in the year t

M_t = Operations and maintenance expenditures in the year t

F_t = Fuel expenditures in the year t

E_t = Electricity generation in the year t

r= Discount rate

n = Life of the system, years

2.3 Return on Investment (ROI)

A performance measure used to evaluate the efficiency of an investment or to compare efficiency of a number of different investments. ROI deals with the money one invests in the company and the return that is realized on that money based on the net profit of the business. ROI has become popular in the last few decades as a general purpose indicator for evaluating capital acquisitions, projects, programs, initiatives, as well as traditional financial investments in stock shares or the use of venture capital. It is defined as equation (12) below.

$$ROI = \frac{Earning - Initial\ Investment}{Initial\ Investment} \quad (12)$$

III. RESULTS AND DISCUSSION

In this case study, we have considered a typical location in India. The currency used is Indian Rupee. The unit 1 Lac is equal to 100000. The plant capital cost is the typical cost which is reported in present scenario of Indian market [12]. In the Table 1 and Table 2, the financial analysis of fixed tilt and single axis tracker based solar PV system is presented.

The figure 2 clearly indicates that the projected annual generation in the case of single-axis tracker system is higher by ~25% in comparison with the fixed tilt system. As estimated from figure 3, the reduction of the levalized cost of energy is ~11%.

Table 1: Financial analysis for a FIX-TILT solar PV plant of 1MW size.

Plant: Fix tilt (Non-tracked) PV Plant: Details			
Item No.	**Item details**	**Value**	**Units**
A	Solar PV system Size	1000	kW
B	Term Loan	5	years
C	Rate of Interest (Flat Rate)	12.0	%
D	Total Plant Cost	72000000	INR
Annual Generation			
E	Annual Generation, NON Tracked	1518000	kWh
F	Reduction in generation - First year	0.30	%
	Reduction in generation per year (second year onward)	0.50	%
Operating Cost			
G	Annual maintenance cost (AMC)	500000	INR
H	Inverter replacement and spares in year 12	8000000	INR
Cost Computation			
I	Plant capital cost	72000000	INR
J	Total interest of five year term loan	43200000	INR
K	Total cost of I+J	115300000	INR
L	Inverter replacement cost – H	8000000	INR
M	AMC cost (24 years) – G x 24	12000000	INR
N	Total cost K+L+M	135300000	INR
O	Total Generation in 25 years	35700000	kWh
Levelized cost of Energy (LCoE) for a NON-TRACKED PV plant 3.80 INR/kWh			

Table 2: Financial analysis for a single-axis tracker solar PV plant of 1MW size.

Plant: Single-axis Tracker PV Plant: Details			
Item No.	**Item details**	**Value**	**Units**
A	Solar PV system Size	1000	kW
B	Term Loan	5	years
C	Rate of Interest (Flat Rate)	12.0	%
D	Total Plant Cost	80000000	INR
Annual Generation			
E	Annual Generation, NON Tracked	1518000	kWh
	Additional generation expected from tracking	25	%
	Annual Generation with Tracking	1900000	kWh
F	Reduction in generation - First year	0.30	%
	Reduction in generation per year (2^{nd}yr onward)	0.50	%
Operating Cost			
G	Annual maintenance cost (AMC)	600000	INR
H	Inverter replacement and spares in year 12	8000000	INR
Cost Computation			
I	Plant capital cost	80000000	INR
J	Total interest of five year term loan	48000000	INR
K	Total cost of I+J	128100000	INR
L	Inverter replacement cost – H	8000000	INR
M	AMC cost (24 years) – G x 24	14400000	INR
N	Total cost K+L+M	150500000	INR
O	Total Generation in 25 years	44600000	kWh
Levelized cost of Energy (LCoE) for a TRACKED PV plant = 3.38 INR/kWh			

Table 3: Comparison of Fix tilt and single axis tracker system of 1 MW size with respect to system life and annual generation.

System Life		
Item	**Value**	**Unit**
Total additional units generated over 25 years of plat life	8900000	kWh
Average per unit cost of energy expected	6.49	INR
Total additional income over 25 years, ONLY due to use of TRACKING	57800000	INR
Per Annum		
Total additional units generated per annum due to use of Tracking (Averaged over first 5 years)	375000	kWh
Average per unit cost of energy expected	6.49	INR
Total additional income per annum, ONLY due to use of TRACKING (X)	2400000	INR
Additional Investment of Tracking (Y)	8000000	INR
Tracker Payback (Y/X)	3.29	years
Additional power, at no extra cost	21.71	years
Return on Investment (ROI)	**30**	**%**

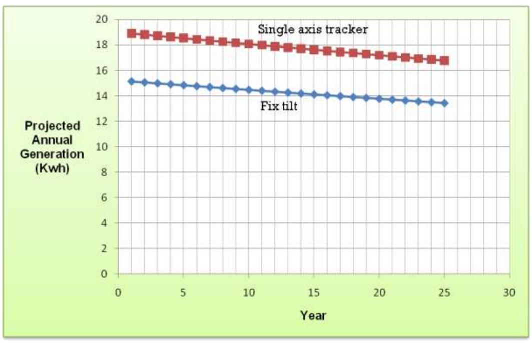

Figure 2: Projected annual generation in kWh for a typical solar PV power plant with single-axis tracker (brown) and fix tilt (blue).

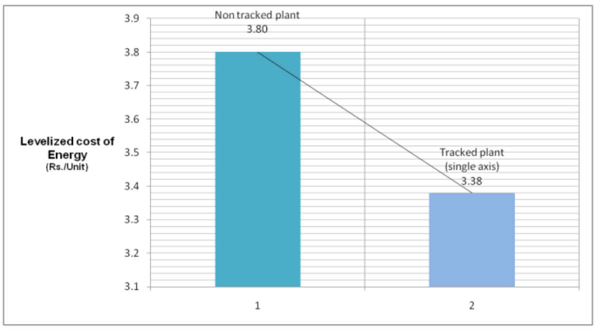

Figure 3: Levalized cost of energy for single axis tracker and fix tilt solar PV plant.

IV. CONCLUSIONS

The main conclusion of this work is that treating sun tracking photovoltaic power plants as smart systems is both possible and beneficial, from the point of view of installation costs and production; consequently, it leads to cheaper electricity price per unit. The results obtained allows for establishing the following conclusions: a) The employment of sun tracker mechanisms contributes considerably to increasing the photovoltaic systems performance. b) During clear sky days, the more amount of additional electrical energy is produced by the tracked panels than fixed tilt PV panels, this takes an advantage of the morning and evening hours and c) The additional amount of electrical energy produced by a tracked PV panel compared with the fixed panels depend mainly on the employed sun tracker system, the sky clarity level of the considered day and on the seasonal evolution of the day length.

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