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Impact of Solar Panel Orientation on Large Scale Rooftop Solar Photovoltaic Scenario for Mumbai

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Abstract

Application of solar photovoltaic systems at a large scale is becoming increasingly interesting for researchers, policymakers and investors. Singh and Banerjee (2015) [1] have presented a methodology for estimation of the rooftop solar photovoltaic potential of a city. The methodology has been applied and illustrated for the Indian city of Mumbai (18.98^{0}N, 72.83^{0}E). In this paper, different orientations of the solar panels to be used for the Mumbai rooftop solar photovoltaic scenario have been analyzed and compared in terms of their impact on the generation from the scenario. The three possible orientations studied and compared in this study are – fixed tilt orientation, two-point system orientation, and horizontal N-S axis E-W tracking.

The results show that for the fixed tilt orientation, the best tilt angle for year-round optimal performance is same as the latitude of the place, i.e. 19^0. However, optimization of seasonal output would warrant another tilt angle. Further, it has been found that, as compared to the fixed tilt at 19^0, the two-point system gives 2.21% higher annual plane-of-array insolation; and horizontal N-S axis E-W tracking gives 10.18% higher annual plane-of-array insolation. However, in terms of the annual generation from the large scale Mumbai rooftop scenario, the gain is only 1.97% with the two-point system, and 9.62% with the horizontal N-S axis E-W tracking, as compared to the fixed tilt (at 19^0) orientation. Incremental cost-benefit analysis for the excess capital expenditure on the tracking equipment has also been done. For this analysis, the Average Unit Cost of Power Supply for India has been taken into account, which is found to have a CAGR of 8.57% over the last decade; discount rate has been estimated as per the Renewable Energy Tariff Regulations passed by the Central Electricity Regulatory Commission (CERC), and has been found to be 10.76%. The ensuing analysis gives a discounted payback period of around 13 years for the excess capital expenditure due to the tracking equipment costs.

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Keywords: rooftop solar photovoltaic scenario; solar panel orientation; fixed tilt; two-point system; horizontal N-S axis E-W tracking.

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1. Introduction

The rooftop solar photovoltaic scenario presented for Mumbai in Singh and Banerjee (2015) [1] is the basis for this paper. In the scenario presented in Singh and Banerjee (2015) [1], standard system orientation was chosen as fixed tilt panels at 19^0 tilt angle (same as the latitude of the place). In this present paper, various possible panel orientations have been analyzed and compared. These include fixed tilt panels at angles other than the latitude angle, two-point system orientation and horizontal N-S axis E-W tracking.

Nomenclature

POA	plane-of-array
DNI	Direct Normal Irradiance
DHI	Diffuse Horizontal Irradiance
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
PTC	Power Temperature Coefficient
PVA	Photovoltaic-Available-Area
AUCPS	Average Unit Cost of Power Supply
CAGR	Compounded Annual Growth Rate
CERC	Central Electricity Regulatory Commission
ROE	Return on Equity

Kacira et al (2004) [2] have conducted a study on determining the optimum tilt angles and orientations of solar photovoltaic panels in Sanliurfa, Turkey. They have estimated the total solar radiation on the tilted PV surface using a mathematical model developed from inputs from Duffie and Beckman (1991) [3] and Lunde (1980) [4]. Using the mathematical model they have estimated the monthly and seasonal optimal tilt angles. They have estimated that by adopting monthly optimal tilt angles, there is a 1.1% increase in annual solar radiation received as compared to the seasonal optimal tilt angles; and that there is a 3.9% increase as compared to the tilt angle same as latitude angle. Lubitz (2011) [5] has studied the effect of manual adjustments to the tilt angle on fixed and tracking solar photovoltaic panels. He has used hourly irradiance data with Perez radiation model to compare the insolation received on fixed tilt, azimuth tracking and two-axis tracking panels, at diverse locations across the United States of America. He has found that the optimal tilt angle varies from the latitude angle at low-latitude, high-clearness sites, to up to 14^0 less than the latitude angle at high-latitude, low-clearness sites. He also reports that azimuth tracking increases the incident annual solar radiation by around 29%, as compared to a fixed tilt panel; and that two-axis tracking increases the incident annual solar radiation by 34% as compared to a fixed tilt panel. Kelly and Gibson (2009) [6] have analyzed and compared panel orientations for cloudy and overcast conditions. They have found that during such sky conditions, horizontal module orientation is the best, and that it increases the incident solar energy by about 50% as compared to two-axis tracking systems. Helwa et al (2000) [7] have made practical studies to evaluate and compare the performance of different types of solar trackers. They report that the gain in incident solar energy is the highest for two-axis tracking, followed by vertical-axis tracking, and lastly by tilted-axis tracking. Lave and Kleissl (2011) [8] have determined the optimal tilt angle for solar photovoltaic panels in different states of the United States of America. They have estimated that, compared to the global horizontal irradiation, these optimal tilt angles give 10% - 25% higher annual incident solar radiation; whereas, two-axis tracking panels give 25% - 45% higher annual incident solar radiation.

In this present paper, the variations in the annual average plane-of-array (POA) incident solar radiation have been studied for different tilt angles, as well as two-point system and horizontal N-S axis E-W tracking system. Further, taking into account the effective sunshine hours for the Mumbai rooftop scenario, the impact of these different orientations on the generation profile from the rooftop photovoltaic scenario has been studied.