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ORIGINAL ARTICLE

Suitability Analysis of Solar Tracking PV System in the Airport Based on Glare Assessment

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ABSTRACT – Due to the concerns with harmful emissions, airports have a great interest in solar photovoltaic technology. On the one hand, the vacant land areas in the airport can house solar PV arrays. On the other hand, there is an aviation safety issue due to the reflections from the solar PV arrays. This paper aims to perform a glare analysis of a conceptual solar PV array for three different solar tracking techniques. This suitability analysis is carried out for fixed-tilt, single-axis and dual-axis tracking techniques using ForgeSolar software. It is observed that a single-axis tracking solar PV system is a suitable tracking technique for the selected site. This can be attributed to zero minutes of glare duration and the highest value of energy generation. In addition to compliance with the FAA's solar glare policy, the single-axis tracking solar PV system will generate 40 % more electricity than a fixed-tilt solar PV system. Unlike previously reported studies, the results of this study strengthen the theoretical support for tracking solar PV systems in airport locations. The findings provided in this study will be beneficial to energy professionals and serve as reference material for tracking solar PV in airports.

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INTRODUCTION

Solar PV technology has become the fastest growing renewable source of electricity [1]. Solar PV systems do not pollute the environment during their operational time. The application of solar PV is visible on wastelands, rooftops, facades, car parks, over water bodies. The vast open spaces in airport premises can also be effectively utilised for solar PV applications. The electricity generated from these onsite power plants can meet the electrical energy requirement in airports. The consumption of solar PV energy in airports is advantageous over the purchase of grid electricity. It includes stabilising the airport's energy bill, mitigating greenhouse gas emissions, achieving sustainability goals, and non-aviation revenue [2]. However, the reflected sunrays from solar PV may hit the pilots and air traffic controllers, which concerns aviation safety. The technical guidance released by the FAA (Federal Aviation Administration) reports the possibility for glare and glint as a new and unforeseen issue from solar energy application in airports [3].

The energy generation from solar PV systems mainly depends on the availability of sunlight [4]. The solar intensity at a location varies with the daily and seasonal movement of the sun. This problem can be solved to some extent if the PV array tracks the sun's direction from sunrise to sunset. In the sun-tracking solar PV system, the reflective surface of the solar module rotates to follow the sun's movement (Figure 1). Solar PV array rotates in one axis of movement (usually aligned with north and south) in a single-axis tracking solar PV system. In a dual-axis tracking technique, the solar PV array follows the sun's trend in two axes (elevation and azimuth). Most solar PV installations have a fixed-tilt mechanism in which PV modules are set at a particular angle (tilt angle) with no sun tracking. The cost, reliability, and performance of tracking solar PV systems have improved significantly in recent years. In this regard, the number of solar PV systems that employ solar tracking systems has increased. In dual-axis tracked solar PV system, more solar irradiance is received on the collector area than single-axis tracked one. This can be attributed to the reduction in loss due to the cosine effect by the rotation of the axis. The tracking mechanism of solar PV can be classified as passive and active tracking. In passive tracking, the movement is caused by the thermal expansion with a low boiling point. This fully mechanical technique is not common owing to its low efficiency and high complexity. The active tracking system uses a motor, gear mechanism, sensors and controllers to cause movement of the solar PV array (electromechanical system). The microprocessors sent control signals to the motor and gear based on the position of the sun and the direction of tracking. Since the investment and maintenance cost is higher, the solar tracking system may not necessarily imply a more significant benefit than a fixed-tilt system.

Some authors compared the performance of fixed tilt and tracker solar PV (prototype with capacity in watts) and reported that tracking solar PV generated more electrical energy than the fixed-tilt solar PV [6]–[8]. Fazlizan et al. assessed the energy output for 12 kilowatts (kW) dual-axis solar tracking systems in a tropical climate. They reported that

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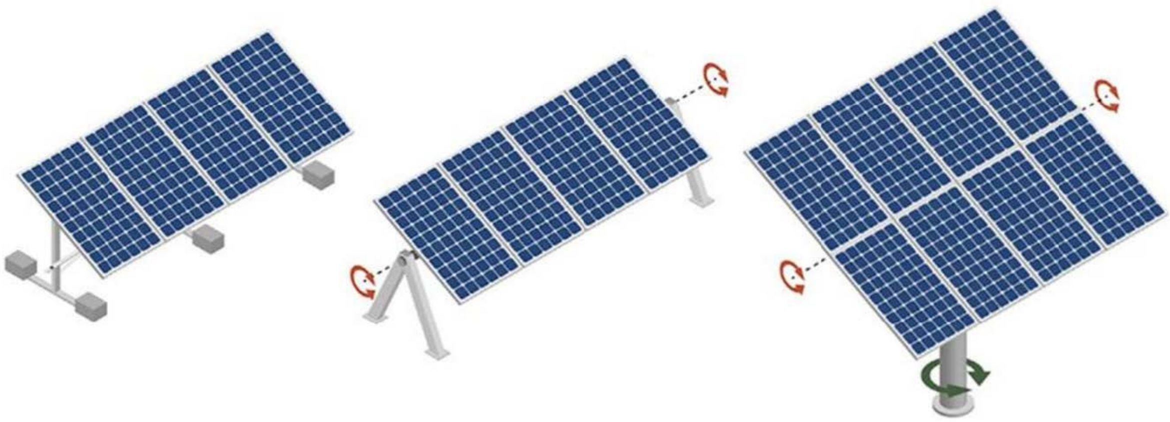
the energy generation from the tracking system is 49% more than a similar fixed-tilt PV system for a gloomy day [9]. Maatallah et al. studied different aspects of fixed tilt and tracker solar PV array and reported that single-axis tracked system could generate 5.76 % more energy annually than fixed tilted PV array in Monastir city, Tunisia [10]. Bahrami assessed the energy generation from fixed, single and dual-axis solar tracking PV for nine different sites of Nigeria and reported that annual increase in energy output from dual-axis tracking solar PV varied between 12.52% and 29.58% compared to the fixed tilted solar PV [11]. Using PVSyst software, Abdelsalam et al. predicted that azimuth tracking could improve the average energy generation by 17.28 % than fixed-tilt solar PV system in climatic conditions of UAE [12].



(a) (b) (c)

Figure 1. Different types of solar PV array based on its tracking of sun's movement, (a) fixed-tilt, (b) single axis tracker, and (c) dual axis tracker [5].

Some authors reported the energy performance of fixed-tilt solar PV systems in airport premises [13]–[15]. For example, Choudhary et al. proposed a grid-connected solar PV power plant for three Indian airports located at Udaipur (2.43 MW), Raipur (3.20 MW), and Aurangabad (2.08MW) and predicted that the annual energy generation as 4238.3 MWh, 5012 MWh, 3425.5 MWh respectively. Araki et al. assessed the annual energy generation of a 30 kWp bifacial solar PV system on the premise of Aichi airport, Japan. They reported that the solar plant generated 30,506 kWh (measured) and 30,628 kWh (calculated) based on one-year operational data [16]. Along with the techno-economic feasibility, Sher et al. presented a mathematical model to understand solar PV glare clearly. Based on this model, it was concluded that there is significantly little chance for glare effect at Doncaster Sheffield Airport, UK. Anurag et al. reported three main roadblocks to solar PV installation in airports: reflectivity and glare from PV array, interference to radar operation, and physical penetration into airspace [17]. The glare assessment for conceptual solar PV array in an airport was studied by Sreenath et al. using ForgeSolar software and reported that the glare is expected to occur for 6776 mins on Air Traffic Control (ATC) tower, which do not comply with FAA's solar glare policy [18].

Since the application of solar PV in airports is not common, only a few authors carried out research on airport-based solar PV systems [17], [19]. In addition, these studies are inclined to the techno-economic aspects. None of them studied the impact of glare and its occurrence. It is ascertained that the main roadblock in solar deployment in airports is the possibility of glare hazards. However, the glare aspects in the airport environment are not explored fully. Only a few literature reported solar the glare assessment of solar PV in airports [18], [20]. Interestingly, fixed-tilt solar PV is considered in these research works. This can be attributed to the common notion of minimal glare probability with the static nature of the solar PV array. Hence, there is a need for a research study to compare the glare occurrence between fixed-tilt and tracking solar PV. In addition, energy generation is another factor influences the suitability of solar PV system. The energy output of single and dual tracking of airport solar PV systems is not reported anywhere. To fill this research gap, a dedicated study is to find the best type of tracking based on glare occurrence and energy generation.

This paper aims to assess the glare impact from solar PV arrays located in airport premises for different tracking techniques and to find the suitable type of tracking technique for solar PV array in the selected airport site. To implement this approach, a random site in Mysore airport, India, is chosen. This is the first attempt to analyse the suitability of different solar tracking techniques based on glare assessment to the best of our knowledge. Despite the considerable increase in solar airports, several airports are still mainly concerned about glare impact from PV arrays. The presented results can be valuable study material to aviation stakeholders and energy professionals. Further, this study is expected to strengthen theoretical support for tracking solar PV systems in airport locations. In this regard, airports will increasingly consider tracking techniques for their solar projects.

METHODOLOGY

Site Selection

In the present work, Mysore airport (12.2278° N, 76.6582° E), located in the Southern part of India, is chosen as a case study. The topographical details of the selected airport are studied using Google Earth Pro software. A site within the airport perimeter is selected for the proposed solar PV system. The area of the chosen site is estimated as 19,464 m^2 using the area tool of Google Earth. As per the thumb rule, this land area is sufficient to install a 1950 kWp solar PV system (a 1 kW solar PV system approximately requires 10 m^2 of the land area) [21]. The electricity generated from the proposed solar PV system will be used to meet the energy requirement of the airport. The position of the selected site, Air Traffic Control (ATC) tower, and flight path in the airport are provided in Figure 2.

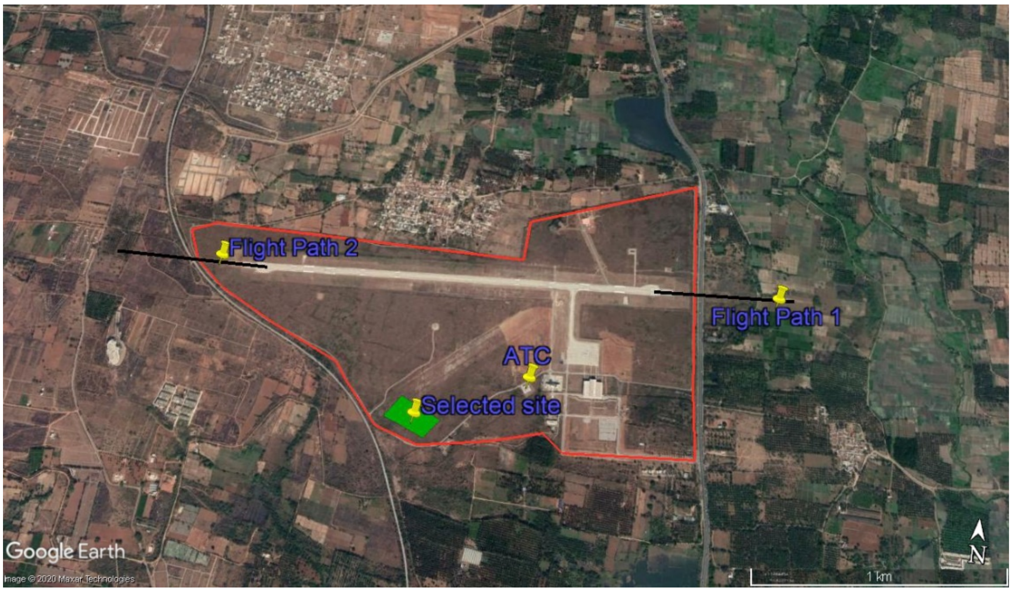


Figure 2. Location of the proposed solar PV array and sensitive observation points.

Glare Assessment Software

ForgeSolar software is a specially designed tool to assess the glare impact of the solar PV array and is widely used in glare assessments for airport areas. This tool estimates the occurrence and duration of solar glare from each PV array for the given location of the observer. The following are some features of this software. It is a web-based tool that requires little to no site visit for glare assessment. It can be used for glare analysis of sites near airports as well as other areas. It has been developed specifically to accommodate FAA's guidance on solar PV glare. The estimation and assessment of glare impact in ForgeSolar software are based on the guidance released by the Federal Aviation Administration (FAA), United States of America [3]. As of now, the technical advice by the FAA is the most detailed and specific to solar airport projects [22]. Based on the FAA's policy on solar glare in airport premises, the proposed solar PV array must not possess any kind of glare on the ATC tower and yellow glare on the flight path (as in Table 1).

Table 1. Colour codes of glare hazards and its interpretation.

Observation points	Green glare	Yellow glare	Is it acceptable as per FAA's policy?
Flight Path	Not present	Not present	✓
	Present	Not present	✓
	Present	Present	×
ATC tower	Not present	Not present	✓
	Present	Not present	×
	Present	Present	×

At first, the layout of the PV array, flight path, and observation points are entered using an interactive Google map. The flight path and the ATC tower's cabin are selected as the observer's locations. The height of the ATC tower is taken as 75 m [23]. The generalised values are considered for the observer's eye characteristic, optical properties of the PV array. Based on vector algebra and complex algorithms, this web-based tool predicts the occurrence of glare from the selected observation points. If glare is observed, then the tool estimates the impact of glare based on values of the retinal irradiance and subtended source angle. The visual effect of an impact is quantified into three categories (green, yellow, red). This categorisation helps in easy understanding of the degree of glare impact [24]. Based on previous studies, the upper and lower limits of green, yellow and red glare are determined by Ho et al. [24]. As shown in Figure 3, the glare impact is defined in terms of retinal irradiance and subtended source angle.

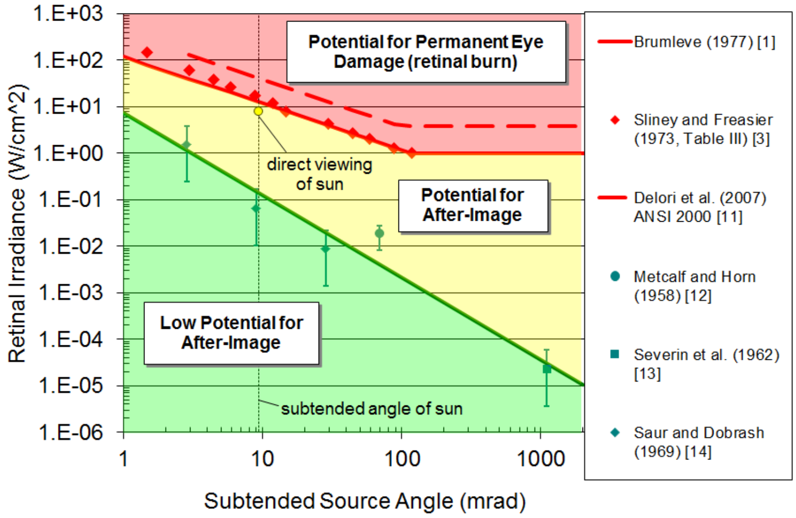


Figure 3. A sample solar glare hazard plot.

Suitability Analysis

In this study, the suitability analysis is carried out based on the type of mounting for the solar PV system (the fixed-tilt, single-axis, dual-axis tracking). The optimum tilt and orientation values to obtain maximum theoretical energy generation is considered for a fixed-tilt PV array. According to this thumb rule, the tilt angle is taken as the site's latitude, and the PV array faces south direction if it is located in the northern hemisphere. For a single-axis tracking PV system, the orientation angle is taken as a fixed value, and the tilt angle varies from a minimum value (0°) to a maximum (120°) rotation angle. For a Dual-axis tracking PV system, it is assumed that the PV array follows the sun's movement until the sun is below the horizon. So, a limit on the angle of rotation is not provided. Solar PV modules made of crystalline silicon material with a smooth glass top cover and an anti-reflective (AR) coating are considered. To compare glare occurrence from a selected site, the land area required for each tracking type of solar PV is assumed to be the the same. The specifications of the PV array for the three different scenarios are provided in Table 2. For each solar PV tracking scenario, the glare assessment is performed using Forge Solar software. The values of duration and impact of glare are recorded for studied strategies. The adherence to FAA's policy on solar PV glare is also analysed. In addition, the annual energy generation (obtained from the software) is noted down for each tracking mode.

Table 2. Tracking specification of Solar PV array considered in the study.

Type of tracking	Tilt angle (degree)	Orientation angle (degree)
Fixed tilt	12	180 (south)
Single-axis	Rotates from 0 to120	180 (south)
Dual-axis	Follows sun's movement	NA

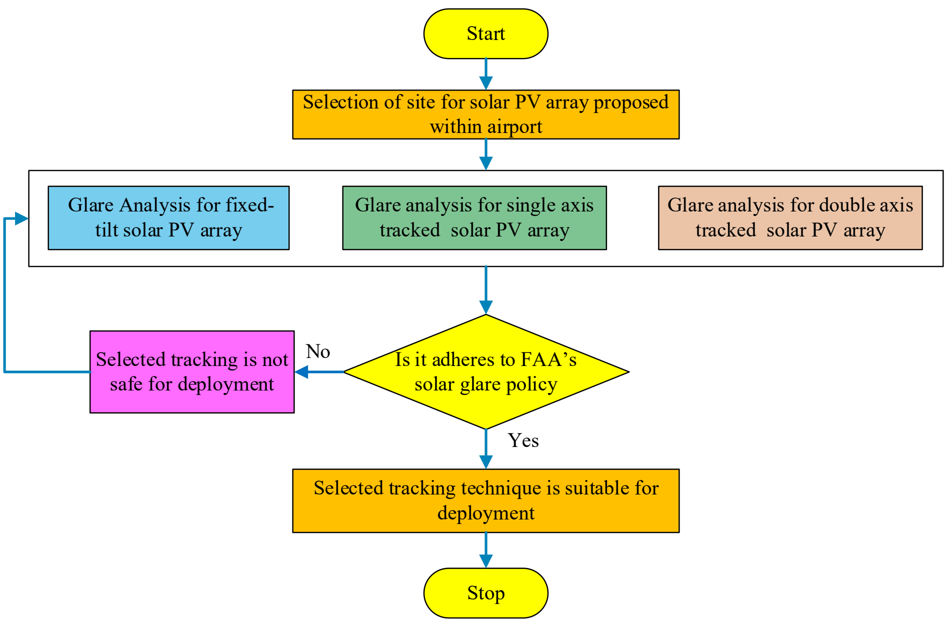


Figure 4. Methodology of suitability analysis of solar tracking based on glare.

RESULTS AND DISCUSSION

The glare assessment for three different sun tracking solar PV system types is carried out using ForgeSolar software. The energy generation from each kind of Solar PV system is also analysed. A glare assessment is carried out for a fixed-tilt (without tracking) solar PV array in the airport area. The results in Table 3 show that there would be potential for glare strikes on pilots and air traffic controllers. One thousand six hundred seventy-six minutes of annual yellow glare and 0 minutes of annual green glare could occur at the ATC tower (as in Figure 2). This occurrence of the glare is predicted to take place between 18:00 and 19:00 time (in 24hr format), from mid-October to late March. This glare will last for a maximum duration of 20 minutes. As per FAA's policy, ATC tower must be free of any potential glare from the PV array. The green glare in flight path two is expected to happen only 13 minutes in a year. Though glare may occur in the flight path, it is acceptable as per FAA solar glare policy.

Table 3. Duration of glare occurrence on observation points for fixed-tilt solar PV array.

Observation point	Annual green glare (min)	Annual yellow glare (min)	Glare hazard summary	Is it acceptable as per the FAA's policy?
Flight Path 1	0	0	No potential for after image	✓
Flight Path 2	13	0	Low potential for after image	✓
ATC tower	0	1676	Potential for after image	×

A glare assessment is carried out for single-axis tracking solar PV array in the airport area. Zero minutes of glare occurrence is predicted for observers at both flight path and ATC (as in Table 4). As per FAA's solar glare policy, it is observed that a solar PV array with single-axis tracking is acceptable for deployment in the selected site. A glare assessment is carried out for dual-axis tracking solar PV array in the airport area. The results show that glare would occur for all three observation points (as in Table 5). Since yellow glare is expected to occur for observers in the flight path and both types of glare (yellow and green) may occur for observers in ATC, the dual-axis solar PV poses a risk to aviation safety as per FAA's solar glare policy. The proposed PV array is expected to produce 1597 minutes of green glare with a low potential to cause temporary after-image and 345 minutes of yellow glare with the potential to cause temporary after-image for observers on flight path 1 (see Figure 4).

Table 4. Duration of glare occurrence on observation points for single-axis tracking solar PV array.

Observation point	Annual green glare (min)	Annual yellow glare (min)	Glare hazard summary	Is it acceptable as per the FAA's policy
Flight Path 1	0	0	No potential for after image	✓
Flight Path 2	0	0	No potential for after image	✓
ATC tower	0	0	No potential for after image	✓

Table 5. Duration of glare occurrence on observation points for dual-axis tracking solar PV array.

Observation point	Annual green glare (min)	Annual yellow glare (min)	Glare hazard summary	Is it acceptable as per the FAA's policy
Flight Path 1	1597	345	Potential for after image	×
Flight Path 2	546	109	Potential for after image	×
ATC tower	3616	743	Potential for after image	×

Similarly, the proposed PV array is expected to produce glare at observers of ATC between 6.00 to 8.00 from mid-April to late- September. The glare impact (potential for after image) is predicted to occur on pilots approaching the runway at either of the flight paths. The months of glare occurrence are similar for observers on flight path 1, flight path 2, and ATC tower. The time of glare occurrence for observers on flight path 1 and ATC is in the morning, while that for observers on flight path 2 is in the evening (as in Figure 3 and Figure 5). This can be attributed to the relative position between the observers and the solar PV array with sun movement. Since the potential for after image is expected on all three observers, the dual-axis tracking based on a solar PV array is hazardous to aviation safety in the studied site.

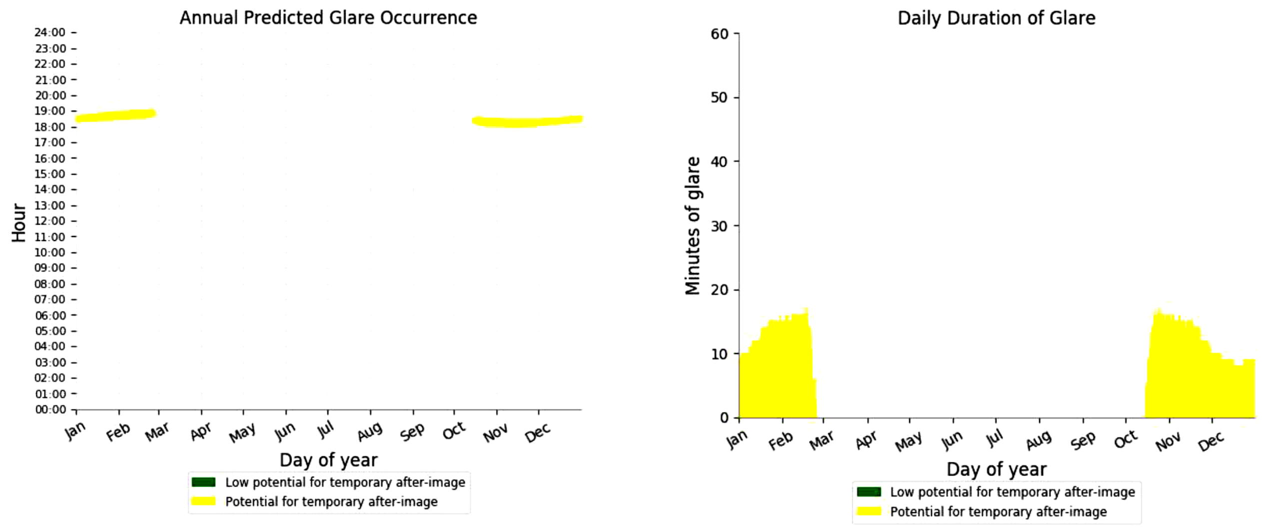
Single tracking solar PV system is expected to generate a comparatively higher amount of electricity, complying with FAA's glare policy for the selected site (Table 6). However, solar tracking systems are more complex than fixed-tilt systems in terms of site preparations, shading analysis, and cabling design. These systems also contain a more complex control mechanism and require regular maintenance due to rotating parts. So, the study on these aspects (extra cost) of the single-axis tracking should be considered before its implementation. It is expected that the reliability and accountability of tracking solar PV systems can be further improved by using artificial neural network-based tracking algorithms. At the same time, fixed-tilt solar PV systems can accommodate tougher topographical conditions and requires the least maintenance. Though energy output is comparatively low, fixed-tilt solar PV is highly suitable for cost-effective and less complex implementation of solar PV projects in the airport. The glare occurrence in fixed-tilt solar PV can be avoided by selecting an appropriate set of tilt angles and orientation angles not considered in the present study [25]. Glare duration and its visual impact from dual-axis PV array are much higher (nearly 100 %) than the values for single-axis tracker and fixed-tilt PV array for the selected site. So, the glare-free implementation of dual-axis tracking solar PV systems in the airport premises may be complicated.

Table 6. Comparison of energy generation and glare impact of 3 types of solar tracking techniques

Type of tracking	Energy generation (MWh/ year)	Percentage increase than fixed-tilt (%)	Is it adhering to Glare policy	Remarks
Fixed tilt	4724	0	×	Lowest energy generation and do not comply FAA's policy
Single-axis	6634	40	✓	High energy generation equals and comply with FAA's policy
Dual-axis	6591	39.5	×	Highest energy generation and do not comply FAA's policy

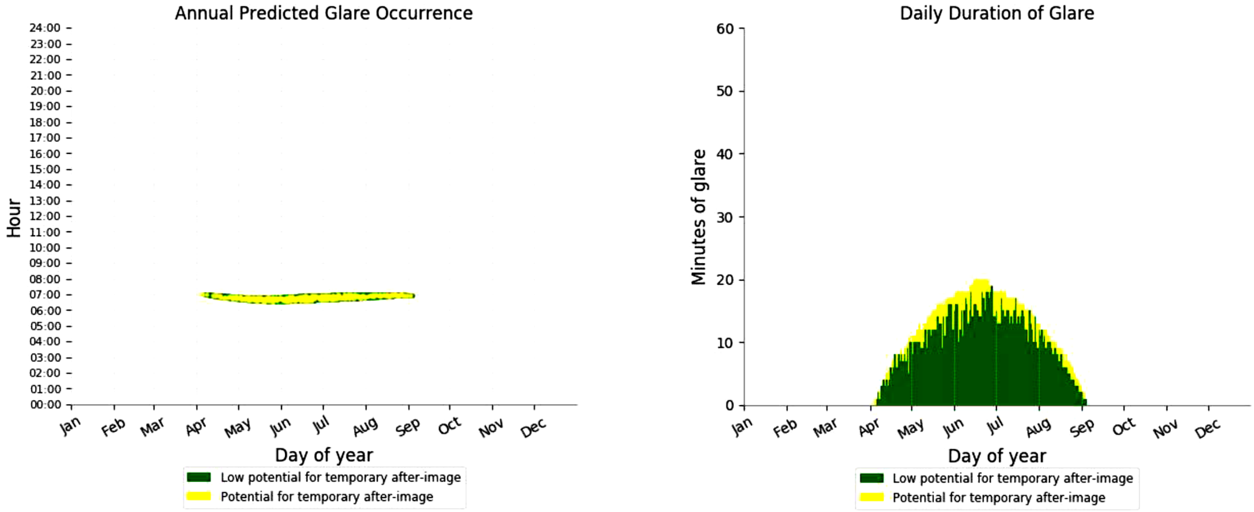
Namaste Solar reported similar results, which has conducted a solar glare analysis for the ground mount single-axis tracking solar photovoltaic system [26]. In another technical report, glare assessment is carried out for a ground-mounted solar project (The Viewbank Solar Farm), which has a proposed capacity of 75 MW with Single-axis tracking technology. From the results of ForgeSolar software, it was identified that there are no potential glare impacts throughout the year (either yellow or green glare) at any of the observation points or routes [27].

The glare from the PV array is influenced mainly by sun's movement provided in a Sun Path chart. The glare occurrence for the selected site in Mysuru airport can be elucidated by analysing its Sun path chart. Based on the software results shown in Figure 5, Figure 6, Figure 7 and Figure 8, a common fact is that glare occurrence has been predicted in the morning and evening time. In Figure 9, morning time is denoted by the letter 'a' and evening time is represented by 'b'. From the Sun Path diagram, it is understood that solar elevation is less than 25° which means the Solar PV array is facing the sun at a low angle. At lower angles of solar elevation, the angles of reflection are also low [20]. These solar reflections at lower trajectory could possibly hit objects above ground, including ATC towers and aircrafts approaching runway. Thus, it is predicted that glare is more likely to occur during this time.



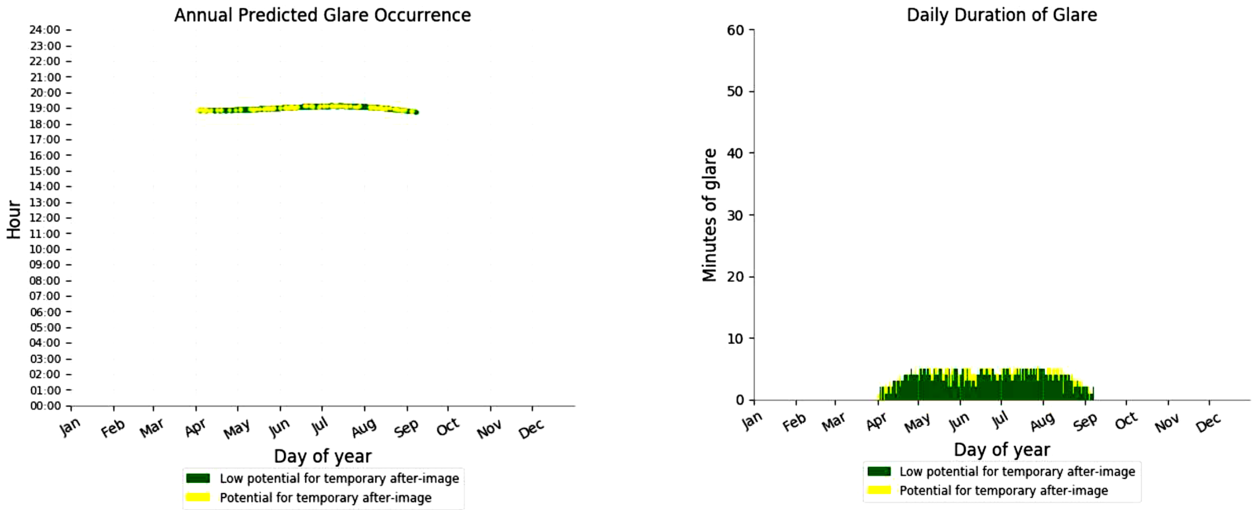
(a) (b)

Figure 5. Variation of (a) glare duration occurrence and (b) duration from fixed-tilt solar PV array for ATC.



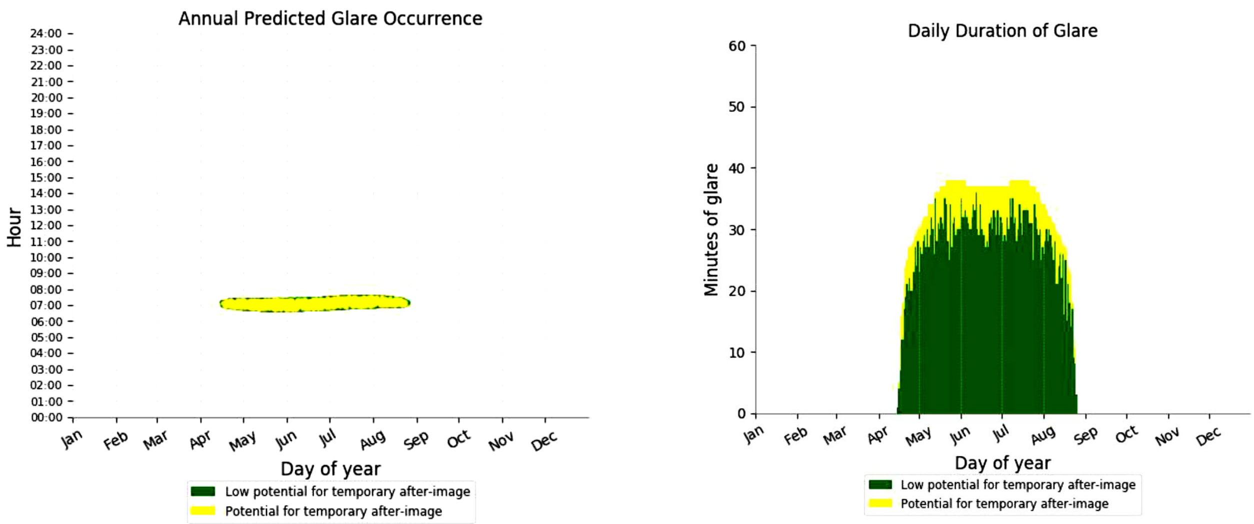
(a) (b)

Figure 6. Variation of glare (a) duration occurrence and (b) duration from dual axis solar PV array for flight path 1.



(a) (b)

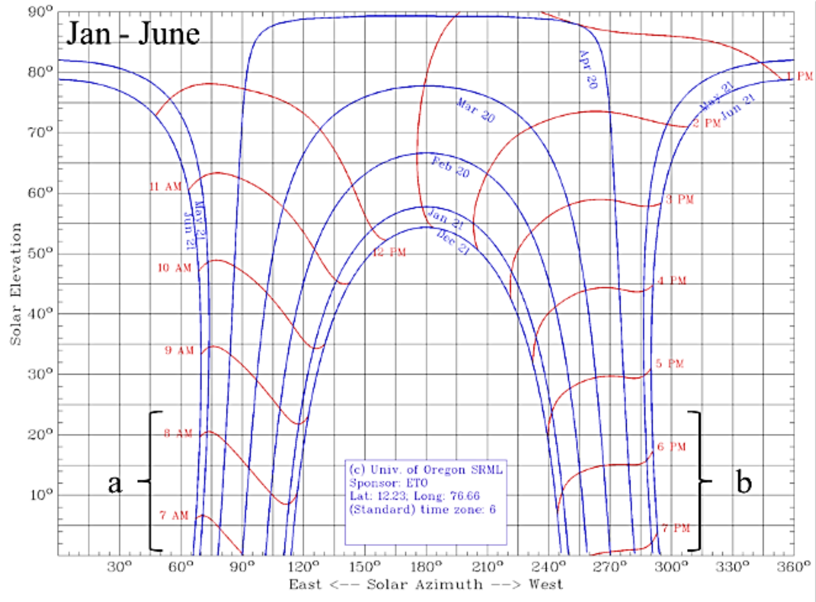
Figure 7. Variation of glare (a) duration occurrence and (b) duration from dual axis solar PV array for flight path 2.



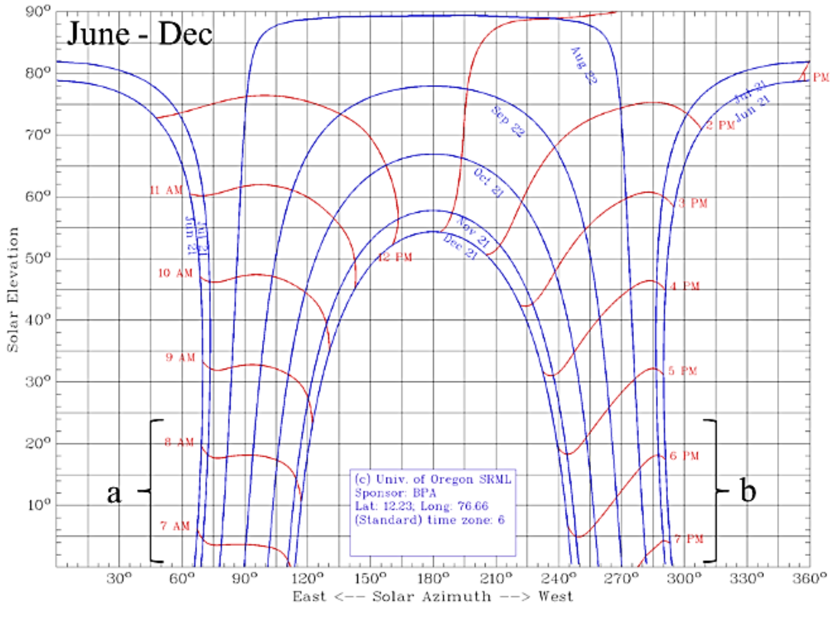
(a) (b)

Figure 8. Variation of glare (a) duration occurrence and (b) duration from dual-axis solar PV array for ATC.

The glare assessment software, ForgeSolar is unique in its way because of its capability in glare prediction and energy estimation [29]. Also, the glare results are displayed graphically in terms of colour-coded charts for easy identification. However, the glare prediction does not account for the obstructions (if any) present between the solar PV array and the observers. The software assumes unobstructed visibility of the solar PV modules from the observation point. Further, this software assumes that the days are clear sunny at all times with no atmospheric attenuation. Therefore, the results are conservative in their prediction.



(a) Jan-June



(b) June-Dec

Figure 9. Sun Path chart and glare occurrence in PV array [29].

CONCLUSION

In this paper, glare assessment is carried out for a conceptual solar PV array. Then the suitable type of solar tracking for the selected site is found out. The following conclusions are drawn.

i. The flight paths and ATC observation points will not experience glare from single-axis tracked solar PV arrays. Zero minutes of glare is predicted for this type of solar PV array in the selected site.
ii. It is concluded that the single-axis tracking solar PV system is the suitable tracking technique for the selected site in the airport premise. In addition to compliance with the FAA's solar glare policy, the single-axis tracking solar PV system will generate 40 % more electricity than a fixed-tilt solar PV system.
iii. For dual-axis tracked PV array, 5,759 minutes of green-glare and 1,197 minutes of yellow-glare are predicted (in total). These values are quite higher than single-axis tracked and fixed-tilt PV arrays.

iv. The future scope of this study includes economic aspects into the suitability analysis of solar tracking systems. Also, the feasibility of intelligent solar tracking to alleviate glare can be explored further.

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DATA AVAILABILITY

The data in this research study cannot be shared publicly due to the sensitive nature of the information.

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