Glare prediction of solar PV system in airport environment: A scenario analysis of material, tilt and orientation

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Abstract The application of solar PV is suitable in airport areas for energy generation due to the availability of vast open spaces. At the same time, there is possibility of glare from solar PV array which may affect the visibility of pilots and air traffic controllers. This paper attempts to perform glare assessment for conceptual solar PV system located in an airport of India using ForgeSolar software under four different scenarios. These four scenarios are solar PV modules with smooth glass, smooth glass with anti-reflective coating (ARC), light textured glass with ARC and different tilt & orientation angles respectively. The location of the proposed site, details of solar PV array and characteristics of observers are provided. The occurrence and duration of glare for each scenario is obtained from the software. The impact of glare is assessed based on solar glare standard set by Federal Aviation Administration (FAA). Among the studied scenarios, safe value of glare is obtained in Scenario 4 only at specific values of tilt and orientation angle. A tilt angle of 15 degrees and orientation angle of 135 degrees is the suitable value with 99.1% of theoretical energy output. It is observed that the yellow glare impact on ATC reduced in the descending order of Scenario 1 (2122 min), Scenario 2 (296 min) and Scenario 3 (0 min). It is concluded that proper selection of tilt and orientation angle of solar PV array aids in achieving zero minutes of glare for airport conditions.

Keywords: Airport, Aviation, Glare, Photovoltaic, Solar PV

1 Introduction

Solar PV technology is now well-known renewable energy source that is versatile, sustainable and environment friendly. The electricity consumption in airports usually comes from nearby grid which is owned by electric utility [1]. This electricity can be substituted with electricity generated from solar PV system. The vacant land areas in airport is suitable for solar PV installations. Airport based solar PV system helps to stabilise energy cost, mitigate carbon emissions, meet sustainability targets, create robust & reliable electricity [2].

However, the implementation of solar PV may affect the safe operation of airports. Anurag et al. (2017) reported three main roadblocks to solar PV installation in airports namely reflectivity & glare
from PV array, interference to operation of radar and physical penetration into airspace [3]. In the technical guidance released by FAA, it is reported the possible glare & glint is a new and unforeseen issue from solar energy application in airports [4]. The reflections from solar PV surface may cause either glint or glare to pilots or airport staff which affects their visibility leading to incorrect decisions which is a concern to safe airport operations. Solar PV modules are integral part of any solar PV system. The top layer of PV module is made of glass material. A part of solar rays falling on PV surface reflects in different directions. These reflected rays may reach the cockpit of aircraft (landing & take-off) or window of ATC tower [5]. This may affect the visibility of pilots and air traffic controllers which is a serious aviation issue. In 2012, a portion of the solar PV arrays in Manchester-Boston airport was covered with wrap temporarily to prevent glare strike on staff of ATC tower. Later, the PV array was rotated 90 degrees to the east from the current position to mitigate glare problems [6]. Prior glare prediction helps in mitigating such problems, reduce unnecessary cost on reconstructions and avoiding delays in permissions and approvals. In this regard, a glare assessment tool called Solar Glare Hazard Assessment tool (SGHAT) was developed by FAA and Sandia National Laboratories. In the interim policy statement, FAA sets forth the standards for glare assessment and required prediction tool [7]. Now, this tool can be accessed by internal Sandia users only. However, ForgeSolar software, which is a licensed version of SGHAT tool, is available for public use with subscription fee. Sreenath et al. (2020) assessed annual glare from conceptual solar PV array in an airport in Malaysia and concluded that the selected area is not suitable for solar PV installations as per FAA’s solar glare policy.

Some authors reported the energy performance of airport based solar PV systems [9]–[11]. However, the glare aspects of solar PV in airports are not mentioned in those literatures. In few literatures, the glare assessment is carried out for solar PV in airports using predication tool. None of them studies the effect of anti-reflective coating (ARC), glass texturing on glare occurrence and its duration. A comparative study of ARC, texturing and PV array orientations on glare reduction is not reported yet. This study is classified into four scenarios namely PV module with smooth glass & without ARC, PV module with smooth glass & with ARC, PV module with light texturing & with ARC, PV module in different tilt and orientation angles. This research work can be a reference material to staff considering solar projects in their airport. It is expected that this work will influence decision making and policies related to solar PV glare that are in revision or development phase. The objective of this paper is to assess the glare occurrence from solar PV array in airport under four scenarios and to compare the glare impact in these scenarios.
2. Methodology

2.1 Site selection

In this study, an international airport located in Kerala state, India is chosen. Using google earth pro tool, the location and details of airport are studied. A site lying close to terminal building is chosen for the proposed solar PV array. The selected site spans over an area of 9,129 m². One kW solar PV system approximately requires 110 m². So, 80 kWp solar PV system can be installed in the selected site. The ATC lies to the west of selected site and runway lies to the north of selected site. It is assumed that the energy generated from the proposed solar PV system is used to partially meet the energy demand of airport’s terminal building. The location of site, position of ATC and pilot’s approach path is shown in Figure 1. The movement of sun for the selected airport location is seen in Figure 2.

![Bird eye’s view of Kannur airport, India and details of observer positions](source: Google)

![Sun's movement in the selected location of airport](source: Google)
2.2 Framing of scenarios for glare analysis

The site is chosen in such a way to study the effect of ARC, texturing and tilt & orientation of PV array. This study is classified into four scenarios namely PV module with smooth glass & without ARC, PV module with smooth glass & with ARC, PV module with light texturing & with ARC, PV module in different tilt and orientation angles. For each scenario, the duration and severity of glare is assessed using ForgeSolar software. The impact of glare on aviation safety is assessed based on solar glare policy of Federal Aviation Administration (FAA). The characteristics of four scenarios is shown in Table 1.

| Name          | Is ARC present | Is PV module textured | Tilt angle (degree) | Orientation angle (degree) |
|---------------|----------------|-----------------------|--------------------|-----------------------------|
| Scenario 1    | x              | x                     | 10                 | 180                         |
| Scenario 2    | ✓              | x                     | 10                 | 180                         |
| Scenario 3    | ✓              | ✓                     | 10                 | 180                         |
| Scenario 4    | ✓              | x                     | 15 to 60           | 120 to 240                  |

2.3 Glare analysis software: ForgeSolar

ForgeSolar is a glare prediction software that assess glare potential of solar PV array exclusively in airport areas. This software is a licensed version of SGHAT tool and it contains two assessment tools. The GlareGauge and GlareReduce tool of ForgeSolar software is used to predict the occurrence of glare and to optimize the PV design for glare mitigation. The glare assessment methodology and glare impact analysis follow the standards set by FAA (78 FR 63276). Initially, the user draws selected site using the interactive map feature provided by the software. The details of Solar PV array such as tilt angle, orientation angle, PV top layer covering are given in a separate tab. Then the location of observers who visual performance is to be assessed are provided in the map. The observer's considered in the present study are staff in ATC tower and pilots in approach path (flight path). The default values are considered for parameters such as height of ATC tower, viewing angle. Based on these input values, the Glaregauge tool provides the occurrence and duration of glare (monthly variation). As per FAA's solar glare policy, a proposed solar PV array must not possess potential for after-image on ATC tower (green or yellow glare) and low potential for after-image on final approach path of flight (yellow glare). This software allows to choose PV module with different top layer covering whose effects on the occurrence and duration of glare is studied. Using GlareReduce tool, the glare occurrence for different tilt and orientation of solar PV array is estimated. The inputs needed for the software such as flight path, Air Traffic Control (ATC) tower are accessed through publicly available sources.

3. Results and Discussions

3.1 Glare assessment for Scenario 1 (Smooth glass without ARC)

Glare assessment is carried out for solar PV array with smooth glass and without ARC. In this scenario, considerable duration of glare is predicted from the proposed solar PV array (Table 2). Hence, the visibility of pilots in Flight path and airport staff in ATC are affected by the glare. As per FAA guidelines, the glare from solar PV array is not safe for aviation (Figure 3). The annual duration of glare
for Flight Path 2 is zero mins which can be attributed to its relative position from solar PV array. The predicted glare on flight path occurs at around 7 am and it last for less than 10 minutes only during five months (March, April, May, August, September). The glare impact on ATC tower is mainly yellow glare (more intense) which occurs in April, May, August, September (Figure 4).

Table 2. Duration of green and yellow glare at receptors for scenario 1

| Receptor      | Annual Green Glare (min) | Annual Yellow Glare (min) | Is it acceptable as per FAA’s policy |
|---------------|---------------------------|---------------------------|-------------------------------------|
| Flight Path 1 | 437                       | 0                         | ✓                                   |
| Flight Path 2 | 0                         | 0                         | ✓                                   |
| ATC tower     | 43                        | 2122                      | ×                                   |

Figure 4. Variation of glare occurrence and duration at ATC for Scenario 1

Figure 3. Variation of glare occurrence and duration at ATC for Scenario 1
3.2 Glare assessment for Scenario 2 (Smooth glass with ARC)

Glare assessment is carried out for solar PV array with smooth glass and with ARC. Since glare is predicted at ATC tower from the proposed solar PV array, the visibility of airport staff in ATC can be affected by the glare. The glare impact and duration does not adhere to FAA’s policy (Table 3). The annual duration of glare for Flight Path 2 is zero mins as seen in Scenario 1. It is observed that the duration of yellow glare reduced by 86 % when smooth glass with AR coated PV module is considered (Figure 5). It means that the intensity of reflections reduced which caused the increase in the duration of green glare (less intense). The glare occurrence and duration for flight paths did not vary much from Scenario 1 (Figure 5). The glare impact on ATC tower changed from yellow glare in Scenario 1 to green glare in Scenario 2.

Table 3. Duration of yellow and green glare at receptors for Scenario 2

| Receptor       | Annual Green Glare (min) | Annual Yellow Glare (min) | Is it acceptable as per FAA’s policy |
|----------------|--------------------------|---------------------------|--------------------------------------|
| Flight Path 1  | 529                      | 0                         | ×                                    |
| Flight Path 2  | 0                        | 0                         | ✓                                    |
| ATC tower      | 2493                     | 296                       | ×                                    |

Figure 5. Variation of glare occurrence and duration at ATC for Scenario 2
3.3 Glare assessment for Scenario 3 (Light textured glass with ARC)

Glare assessment is carried out for solar PV array with textured surface and ARC (less reflective). A considerable duration of glare is predicted from the proposed solar PV array in this scenario also (Table 4). The visibility of pilots in Flight path 1 and airport staff in ATC will be affected by the glare. The annual duration of glare for Flight Path 2 remains as zero mins (similar to Scenario 1 and Scenario 2). The duration of yellow glare on ATC tower is predicted as zero mins in this scenario. It can be attributed to reduced reflections from the chosen less reflective solar PV module. At the same time, the duration of green glare (ATC) increased from 2493 mins to 3038 mins which account to presence of low intense reflections (Figure 6). The predicted glare occurrence and duration for flight path is almost same as those observed for Scenario 1 and Scenario 2 (Figure 7).

| Receptor         | Annual Green Glare (min) | Annual Yellow Glare (min) | Is it acceptable as per FAA’s policy |
|------------------|--------------------------|---------------------------|-------------------------------------|
| Flight Path 1    | 565                      | 0                         | ✗                                   |
| Flight Path 2    | 0                        | 0                         | ✓                                   |
| ATC tower        | 3038                     | 0                         | ✗                                   |

Figure 6. Variation of glare occurrence and duration at flight path 1 for Scenario 2
3.4 Glare assessment for Scenario 4 (Variation of tilt and orientation)

In this scenario, the glare prediction for varying tilt and orientation of PV array is carried out keeping PV top layer covering as constant (smooth glass with ARC). The configurations with adherence to FAA’s policy are (15°, 120°), (15°, 135°), (30°, 120°), (30°, 135°), (30°, 150°), (45°, 120°), (45°, 135°), (45°, 150°), (60°, 120°), (60°, 135°), (60°, 150°), (60°, 195°), (60°, 210°), (60°, 225°). Among these configurations, PV array tilted at 15 degrees and oriented at 135 degrees have highest percentage of theoretical maximum energy output (99.1 %). The duration of annual green and yellow glare for considered set of tilt and orientation angle is given in Table 5.
Table 5. Variation of glare occurrence and energy output for different PV orientations

| Tilt angle | Orientation angle | Annual Green Glare (min) | Annual Yellow Glare (min) | Expected energy generation (% max) | Is it acceptable as per FAA’s policy |
|------------|-------------------|--------------------------|---------------------------|-----------------------------------|-------------------------------------|
| 15         | 180               | 3,117                    | 15                        | 100                               | ✗                                   |
| 15         | 165               | 2,341                    | 475                       | 99.9                              | ✗                                   |
| 15         | 195               | 3,118                    | 0                         | 99.9                              | ✗                                   |
| 15         | 150               | 1,143                    | 180                       | 99.6                              | ✗                                   |
| 15         | 210               | 3,151                    | 426                       | 99.6                              | ✗                                   |
| 15         | 135               | 0                        | 0                         | 99.1                              | ✓                                   |
| 15         | 225               | 3,340                    | 0                         | 99.1                              | ✓                                   |
| 15         | 120               | 0                        | 0                         | 98.3                              | ✓                                   |
| 15         | 240               | 3,707                    | 0                         | 98.3                              | ✓                                   |
| 30         | 180               | 2,830                    | 126                       | 95.1                              | ✗                                   |
| 30         | 165               | 1,678                    | 0                         | 95.1                              | ✗                                   |
| 30         | 195               | 2,871                    | 0                         | 94.8                              | ✓                                   |
| 30         | 150               | 0                        | 0                         | 94.8                              | ✓                                   |
| 30         | 210               | 0                        | 0                         | 94.4                              | ✓                                   |
| 30         | 135               | 0                        | 0                         | 94.4                              | ✓                                   |
| 30         | 225               | 2,859                    | 0                         | 94.3                              | ✓                                   |
| 30         | 120               | 0                        | 0                         | 93.5                              | ✓                                   |
| 30         | 240               | 2,941                    | 0                         | 93.4                              | ✓                                   |
| 45         | 120               | 0                        | 0                         | 84.4                              | ✓                                   |
| 45         | 135               | 0                        | 0                         | 84.7                              | ✓                                   |
| 45         | 225               | 5326                     | 0                         | 84.7                              | ✓                                   |
| 45         | 150               | 0                        | 0                         | 84.5                              | ✓                                   |
| 45         | 210               | 5,555                    | 0                         | 84.5                              | ✓                                   |
| 45         | 240               | 3,114                    | 0                         | 84.3                              | ✓                                   |
| 45         | 165               | 785                      | 21                        | 84.2                              | ✓                                   |
| 45         | 195               | 4,329                    | 0                         | 84.1                              | ✓                                   |
| 45         | 180               | 2,915                    | 0                         | 84.0                              | ✓                                   |
| 60         | 120               | 0                        | 0                         | 72.1                              | ✓                                   |
| 60         | 240               | 4,098                    | 0                         | 72.0                              | ✓                                   |
| 60         | 135               | 0                        | 0                         | 71.3                              | ✓                                   |
| 60         | 225               | 0                        | 0                         | 71.2                              | ✓                                   |
| 60         | 150               | 0                        | 0                         | 69.7                              | ✓                                   |
| 60         | 210               | 0                        | 0                         | 69.7                              | ✓                                   |
| 60         | 165               | 74                       | 0                         | 68.2                              | ✓                                   |
| 60         | 195               | 1,709                    | 0                         | 68.2                              | ✓                                   |
| 60         | 180               | 3,063                    | 0                         | 67.5                              | ✓                                   |

3.5 Discussions

In the first three scenarios, the tilt and orientation angle are constant but top layer material of PV module surface is different. In Scenario 4, the top layer of PV module is made of smooth glass with ARC. The ARC helps in reduction of reflectivity of solar PV surface which in turn leads to better absorption of sunlight. A reduction in glare duration and its intensity is observed from Scenario 1 to Scenario 3. The duration of yellow glare is longer for smooth glass without ARC (Scenario 1) than light textured PV module. In general, the PV modules that are available in solar market are coated with anti-reflective material. Light textured solar PV modules are not commonly manufactured for commercial applications. Nowadays, antiglare PV modules are specially manufactured for solar applications in
airports. The acceptable value of safe glare obtained by variation of tilt and orientation angle is the cheapest method at first sight. The variation of tilt or orientation angle (Scenario 4) provide wide possibilities of glare mitigation as compared to glass texturing and AR coating in PV modules (Scenarios 1, 2, 3). However, the energy generation varies with the change in angles. Using glare prediction software, a trade-off between safe-glare and energy output can be estimated.

4 CONCLUSIONS

In this study, the glare assessment for different scenarios of PV array is carried out using glare prediction software. Among the studied scenarios, safe value of glare is obtained in Scenario 4 only for specific values of tilt and orientation angle. A tilt angle of 15 degrees and orientation angle of 135 degrees is the most suitable set with 99.1 % of theoretical energy output and 0 mins of yellow and green glare. The yellow glare duration on ATC reduced in the descending order of Scenario 1 (2122 min), Scenario 2 (296 min) and Scenario 3 (0 min). It can be attributed to the reduction in reflectivity from PV module surface. Zero minutes of glare is predicted for 14 sets of tilt and orientation angles with energy generation variation from 99.1 % to 68.2 %. It is concluded that the best way to mitigate glare is by varying the orientation and tilt angles. The best-case scenario is observed for solar PV array fixed at 15 degrees and oriented at 135 degrees (Scenario 4). The worst case of glare impact is obtained for solar PV array with smooth glass & without ARC (Scenario 1). The software used in this study is validated with real life situations. However, the developers report that the glare assessment methodology involves several assumptions and approximations. So, the actual results may differ from the predicted glare occurrence. Though glare impact standard set by FAA is considered in this study, the safe limit of glare may vary with different judications. The future work includes selection of different sites within airport, analysis of financial implication of each scenario, using different glare prediction software.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in the submitted manuscript. The findings, opinion, insights and discussions in this manuscript are solely of the authors and do not necessarily reflect the opinion of the any organization involved directly or indirectly. The assumptions and case studies reported within this article are only examples and are based on limited open-source information. The authors are not responsible for any consequences thereof with the use of information presented in the work.

REFERENCES

[1] S. O. Alba and M. Manana, “Energy research in airports: A review,” Energies, vol. 9, no. 5, pp. 1–19, 2016, doi: 10.3390/en9050349.
[2] S. Sreenath, K. Sudhakar, and Y. Ahmad Fitri, “Airport-based photovoltaic applications,” Prog. Photovoltaics Res. Appl., 2020, [Online]. Available: https://doi.org/10.1002/pip.3265.
[3] A. Anurag, J. Zhang, and J. Gwamuri, “General Design Procedures for Airport-Based Solar Photovoltaic Systems,” pp. 1–19, 2017, doi: 10.3390/en10081194.
[4] J. Plante, F. A. A. Airport, and E. Division, “Technical Guidance for Evaluating Selected Solar Technologies on Airports,” 2013.
[5] P. Devita and S. Barrett, “Energy technologies ’ compatibility with airports and airspace : Guidance for aviation,” vol. 8, no. 4, pp. 318–326, 2014.

[6] A. Kandt and R. Romero, “Siting Solar Photovoltaics at Airports Preprint,” no. June, 2014.

[7] F. Register, “Interim Policy, FAA Review of Solar Energy System Projects on Federally Obligated Airports,” 2013. [Online]. Available: www.federalregister.gov/articles/2013/10/23/2013-

[8] S. Sreenath, K. Sudhakar, A. F. Yusop, E. Cuce, and E. Solomin, “Analysis of solar PV glare in airport environment: Potential solutions,” Results Eng., vol. 5, no. November 2019, p. 100079, 2020, doi: 10.1016/j.rineng.2019.100079.

[9] S. Sukumaran and K. Sudhakar, “Fully solar powered airport: A case study of Cochin International airport,” J. Air Transp. Manag., vol. 62, pp. 176–188, 2017, doi: 10.1016/j.jairtraman.2017.04.004.

[10] M. Mpholo, T. Nchaba, and M. Monese, “Yield and performance analysis of the fi rst grid-connected solar farm at Moshoeshoe I International Airport , Lesotho,” Renew. Energy, vol. 81, no. 2015, pp. 845–852, 2020, doi: 10.1016/j.renene.2015.04.001.

[11] M. H. Banda, K. Nyeinga, and D. Okello, “Performance evaluation of 830 kWp grid-connected photovoltaic power plant at Kamuzu International Airport-Malawi,” Energy Sustain. Dev., vol. 51, pp. 50–55, 2019, doi: 10.1016/j.esd.2019.05.005.