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# Analysis of solar PV glare in airport environment: Potential solutions

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ABSTRACT

Solar PV plants are being installed in many airports around the globe. Reflection from the solar PV arrays is a big concern for airport stakeholders. This paper aims to assess the glare occurrence and its impact from the proposed solar PV plant installed in an airport. The prediction of glare is carried out with the help of computational software for a randomly selected area within the boundary of Kuantan airport, Malaysia. The selected zone is not suitable for solar installations as per FAA's glare policy. In the selected area (Apv), the duration of glare on ATCT from solar modules installed is 6778 min (green and yellow glare). Also, the flight path is free from any kind of glare occurrence. Glare occurs between March to mid-October, mostly from 7.00 a.m. to 8.00 a.m. Green and Yellow glare last up to 10 min and 30 min respectively in a year. In this regard, remedial steps for mitigating possible glare are discussed. Glare prediction helps in the early adoption of suitable remedial measures against glare hazard.

## 1. Introduction

Climate change and Greenhouse gas emissions are the biggest threats faced by the world population [1]. As of 2019, the majority of electrical energy is generated from polluting energy sources[2]. In this regard, solar PV systems which are the greenest source of energy have immense relevance. Photovoltaic panels can be used to provide power for various remote and large-scale applications. It can be observed that solar PV technology became mature technology over the years. Nowadays, solar PV installations are increasingly visible in human movement regions such as homes, offices, airports, railway stations, highways, etc [3]. Furthermore, PV modules can be floated on waterbodies with the help of special mounting structures [4,5]. Clot et al. studied the possibility to combine solar PV plants with wastewater basins based on test cases in South Australia [6]. The reflectivity from water bodies can be reduced by PV modules due to its low refractive index [7]. As the installation of PV systems became popular, jurisdictional authorities and other stakeholder groups are increasingly scrutinizing the potential impacts of PV arrays [8]. In the legislation of country such as Canada, Australia, glare from surrounding surfaces is mentioned as a nuisance like noise.

For rooftop solar PV systems in residential areas, there is a greater chance for solar reflections to travel towards the sky [9]. Also even if a PV array causes glare, the nearby persons are unlikely to observe it due to the building's height. But the scenario in an airport is different due to the presence of control towers, runways, taxiways and flight paths [10]. Due to this, the installation of solar PV modules in certain areas such as airport premises have raised eye brows.

There are a few instances of reflectivity issues reported by airport and transport departments. In 2012, the Manchester Boston Airport had to cover temporarily and then redesign its 530 kWp PV array to avoid hours of blinding glare every morning at the control tower. These changes affected the project performance and reportedly to cost millions of dollars. To avoid such situations, the Federal Aviation Administration (FAA) has framed certain conditions on ocular impact [11]. According to these guidelines, the project developer is required to demonstrate that the system meets the following standards: No potential for glint/glare in the existing or planned Airport Traffic Control Tower (ATCT) cab and No potential for glare or Low potential for after image along the flight path. In this regard, the solar panels in Athen's International airport are chosen such that it has a very low reflectivity factor (much lower than most objects found at airports such as parked cars). Mostafa et al. described about the possible remedial measures from glare related risk from solar installations in the airport [12].

Airports are situated on flat terrain and thus compass a large area of

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unused terrain between runways, taxiways and the airport buildings. The land close to and at the airport often not suitable for other commercial facilities due to low flying aircraft noise, limitation from airspace rules and bird hazards [13]. The airport itself is an intensive consumer of energy. Also, the electricity rate and surcharges are high which in turn makes solar electricity attractive in the airport environment. Hence airport areas have received the attention of solar developers. In the present study, an online-based search for academic journals published in the area of solar PV installations in the airport environment is carried out using different search engines such as Google, ScienceDirect etc. The performance of a solar PV plant installed in a few airports was reported [14–16]. Araki et al. analysed the annual energy production potential of the ground-based bifacial PV system at a site near to Aichi airport, Japan [17]. Sukumaran and Sudhakar suggested that a computer-based analysis of possible glare is needed before the installation of solar PV modules in airport premises [10]. Anurag and Anurag described that glare is one of the main roadblocks in the implementation of a solar PV system in the airport. The opportunities and challenges of the solar PV system in the airport area are discussed by a few authors [13,18]. Mostafa et al. reported that the severity and probability of glare from airport-based solar installations are hazardous as well as likely to occur [12]. Thus, it was concluded that a study on the assessment of glare from the proposed solar PV system in an airport using computational prediction software has not reported yet. The objective of the work is.

- To analyze the glare occurrence from solar PV in the airport premise using glare prediction software.
- To study the glare effects and their impact on the surrounding airport environment.
- To suggest suitable remedial measures for glare reduction from the solar installation.

## 2. Methodology of glare assessment

This section provides a detailed description of the airport site, glare analysis software used for a glare impact study.

### 2.1. Site selection

Sultan Ahmad Shah International Airport or Kuantan airport is in the state of Pahang, Malaysia and it spreads over 37,65,428.830 $m^2$ or 930.458 acres. An area within the Kuantan airport premises named as Solar PV Area, Apv is chosen. The Air Traffic Control Tower (ATCT) and the runway is shown in Fig. 1. The airport location is situated at 03°46 N latitude, 103°12 E longitude, and 18 m elevation. It is assumed that the site for PV power plant has favorable local climate, good solar resource (irradiation), easy land availability (purchasing or long-term leasing) and an accessible grid connection.

### 2.2. Forge Solar software: ocular impact analysis

The geometric approach of glare prediction is important in the safe deployment of solar PV systems in airport areas. Analysis of glare potential round the year is complex and involves complicated algorithms. Forge Solar is an online tool that encompasses geometric analysis of PV module reflectivity. It is regarded as a commercial form of Solar Glare Hazard Analysis Tool (SGHAT), a web-based software developed by Sandia Laboratories. This software is modeled in such a way that it follows the glare analysis requirements of FAA (as per document 78 FR 63,276) [19]. This tool can assess the intensity and potential of solar reflection on selected sensitive receptors around the project area with respect to the given inputs. This software package includes two tools namely GlareGauge and GlareReduce. GlareGauge performs the annual glare hazard analysis of PV arrays on sensitive receptors while GlareReduce carries out optimization analysis of a single PV array over a range of module configurations (by varying tilt and orientation angle).

Here, a computational software called Forge Solar is used to determine the occurrence of glare from PV array. The values of direct normal irradiance, PV panel reflectivity, its optical properties, ocular parameters, and orientation is used for glare prediction. The user can locate the site using an interactive Google map provided by the software. Latitude, longitude, and elevation are automatically retrieved and are used for calculating the sun's position and vector calculation. The user must draw an outline of the proposed solar energy system, specify observer locations (ATC tower cab) and the final approach path. The final approach path is defined as two miles from 50 feet above the land threshold using a standard three-degree glide path. Along with these data, orientation and tilt of solar PV panels, its reflectance, and ocular factors are either entered or default values are considered. For this analysis, a fixed-tilt solar plant consisting of PV panels with Anti Reflective Coating (ARC) inclined at 4° and oriented at 180° from the north is considered. If glare is found, the tool estimates the position and duration of solar glare round the year from a user-specified observation point, and an ocular impact plot is obtained. The plot is shown in terms of green and yellow color. Yellow-

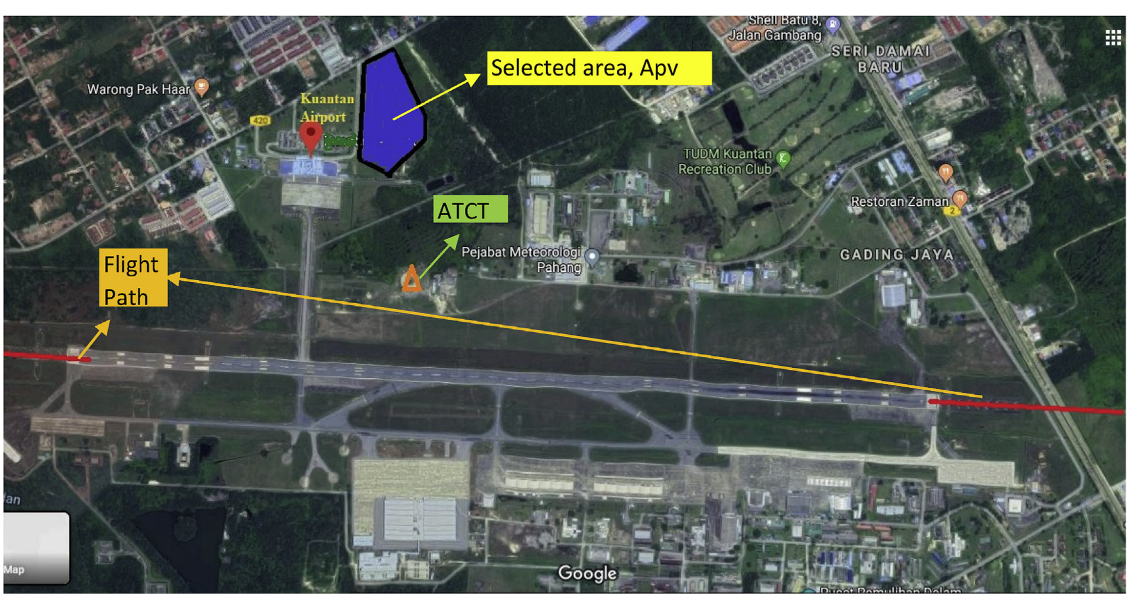


**Fig. 1.** Selected zone for glare impact study and the airport boundary.

colored line emphasizes the potential to cause after image. The tool also can predict corresponding solar energy yield and allows modification of solar plant configurations such as tilt, orientation, shape, etc so to mitigate glare and maximizing energy production at the same time.

## 3. Results and discussion

Glare impact analysis is carried out in the selected areas using Forge Solar software. The compatibility of solar PV installation in the airport environment is checked as per the glare policy framed by Federal Aviation Administration (FAA). The important results of glare analysis are summarised in Table 1. It can be observed that solar panels installed in the area, $A_{PV}$ cause glare and hence this location is not suitable for solar projects in the given system design. The duration of glare on ATCT from solar modules installed in $A_{PV}$ is 6778 min (green and yellow glare). But for this location, the flight Path receptor is safe from any kind of glare impact that can be attributed to the selected location and panel orientation.

The interpretation of results is based on time duration and colour code. Each point in the figure indicates a time gap of 1min across one year with the hours on the y-axis and months on the x-axis. Colour code indicates the intensity of glare as seen from the observer point. The low potential for low glare intensity corresponds to green color. Yellow color indicates the potential for the low intensity of glare and red color corresponds to high-intensity glare. Here the duration of glare (minutes) throughout the year is plotted as Figure. Both yellow and green glare is predicted from the PV modules. The yellow glare lasts for the maximum duration of about 40 min and occurs from March till mid-October. Green glare is present only up to 10 min during March, April, May, August, September, and October. The duration of yellow glare has two peaks; one in the month of April and others in the month of August. The predicted glare happens mostly from 6.30 a.m. to 8.30 a.m. a time of the day. In this time period, air traffic controllers and pilots must be extra cautious in case solar installations are present. Thus, the distribution of glare throughout the year can be found using Figs. 2 and 3.

The ocular impact is plotted as a function of the subtended source angle and retinal irradiance. The retinal irradiance due to the proposed PV modules lies in two regions i.e yellow and green which in turn can be correlated to Figs. 3–5. The continuous orange-colored dots correspond to retinal irradiance from proposed PV modules. In this case, the source angle varies between 10 mrad and 100 mrad and retinal irradiance is around 0.01 W/cm$^2$. Hazard for permanent eye damage did not occur as the reflections in the solar PV plant is not fully specular. The yellow circle indicates the hazard from viewing the bare sun and it lies close to the boundary of the retinal damage zone. The glare hazard plot helps to visualize the impact of glare and identify its type [20].

The distribution of solar reflections contributing to glare on the selected PV footprint is given in Fig. 5. The reflections that cause yellow glare is more pronounced than green. The northwest corner of the selected land area has more influence in the glare occurrence. The green lines are thin which indicates that its share in solar reflections is small.

### 3.1. Effects of glare

Sunlight falls on solar photovoltaic panels which in turn lead to the production of electricity through the photoelectric effect. Since PV panels have a front surface made from glass material, the reflected sunlight has the potential to cause glare impact on nearby systems [21]. Solar reflection may cause glint (a quick reflection) or glare (a longer reflection) to those observers that are on the viewing angle. Glare/glint may impair the visibility of observers and cause annoyance, discomfort, or loss in visual performance. If solar insolation around 7 W/m$^2$ enters the eye of the observer, it can cause after image that lasts from 4 to 12 s. This represents 1–2% of typical solar irradiance (800–1000 W/m$^2$).

**Table 1**
Results of glare assessment impact on the chosen areas.

| Analysed Area | Receptor | Green Glare (min) | Yellow Glare (min) |
|---|---|---|---|
| Solar PV Area, Apv | Flight Path (FP) | 0 | 0 |
| | ATCT | 833 | 5945 |

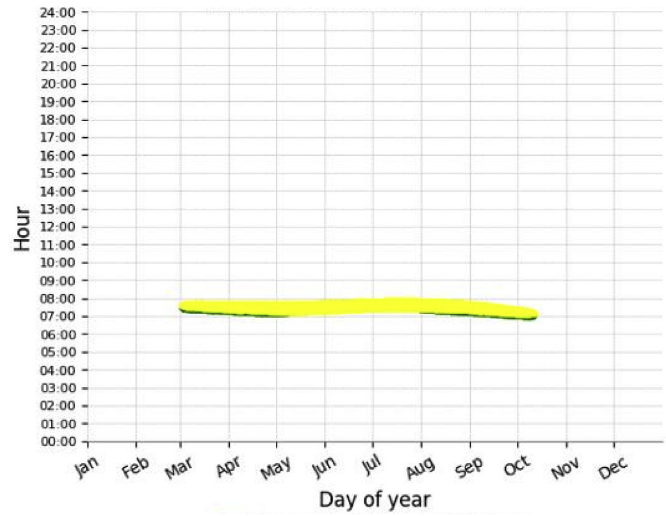


**Fig. 2.** Variation of predicted glare in a year.

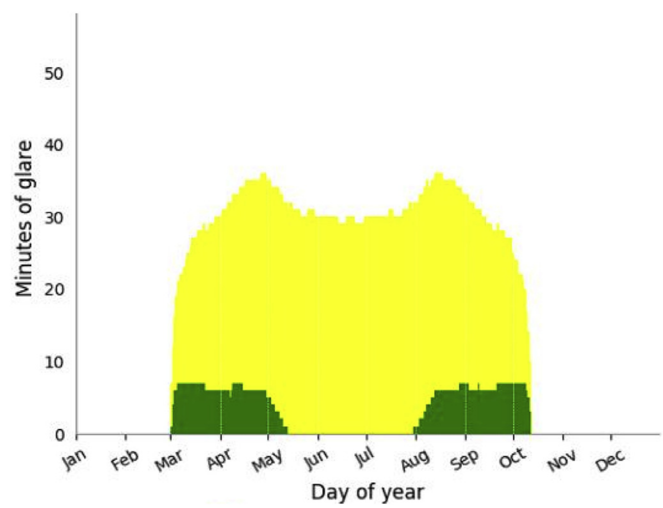


**Fig. 3.** Duration of Glare in a year.

The impact of glare can be broadly classified as permanent eye damage, the potential for after-image, low potential for after image. Since comfort is a matter of human feeling, visual performance cannot be estimated easily and requires the use of complex prediction algorithms. Typical blink response time for the observer is assumed. For scenarios where the glint or glare causes sufficiently high irradiances, permanent eye damage (retinal burn) can occur. It must be noted that retinal burn does not happen from PV glare as the reflected light is not focused. The yellow area in the glare hazard plot denotes sufficiently high retinal irradiance and can cause temporary flash blindness [22]. Temporary flash blindness is developed as a result of bleaching of visual pigments in the retina. The degree of glare impact from the proposed solar plant is given in Table 2.

### 3.2. Remedial measures

Solar PV systems can safely coexist in airport premises provided that remedial/preventive measures are undertaken if needed. The area, $A_{PV}$

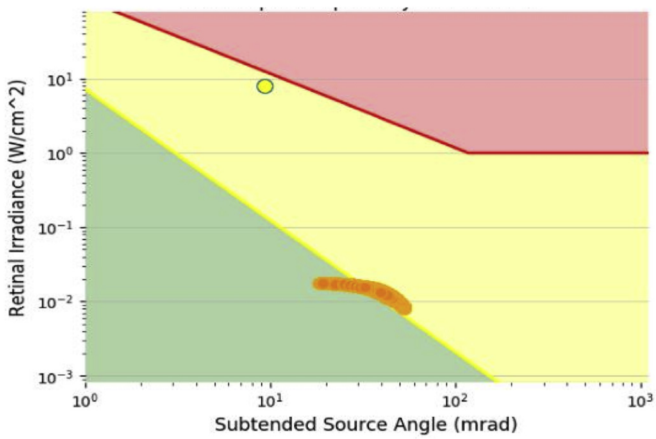


**Fig. 4.** Glare hazard plot for the selected area.

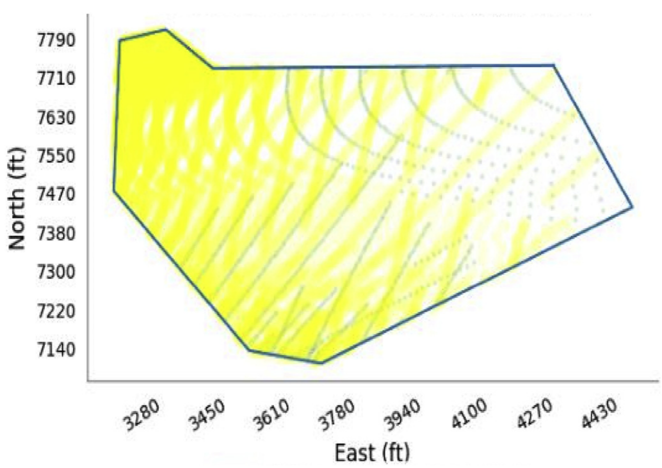


**Fig. 5.** Glare reflections from the selected area.

can be made suitable for solar PV installations by adopting PV modules with special anti-reflection coating, texturing of the PV module surface and varying the alignment of the PV array.

**Selection of PV modules with special Anti-Reflective (AR) coating:** Manufacturers typically reduce reflectance by using low iron in high transmission glass followed by treatment with an anti-reflective coating. In recent generations of panels, an extra layer of anti-reflective material on the outer surface of the glass is employed to further limit sunlight reflection [18]. Reflectivity can be brought down to less than 10% with AR coating. This helps to increase the absorption of sunlight also. The solar panels in Athen's International airport are chosen such that it has a very low reflectivity factor (much lower than most objects found at airports such as parked cars). For example, Certain PV manufacturers market antiglare modules especially for solar applications in roadways, airports, and railways where glare impact is a matter of concern [23].

**PV glass surface texturing**: Another recent design feature to limit reflection is to roughen the protective glass surface [24]. A roughened surface reduces specular reflection, which has the potential to produce a sharper and more concentrated ray of light. A textured glass layer can reduce reflectivity as it produces a diffuse reflection.

**Variation in PV module orientation:** Another mitigation technique that can be employed is possible adjustment in the tilt and orientation angle of PV modules. These changes can alter the direction of solar reflection and hence the degree of glare impact. SGHAT/Forge solar can be used to check the glare potential for the new PV system design values. Since these changes can affect PV electricity generation, a relative decrease in power output is a concern and could be problematic [25]. SGHAT has the capability to identify PV configurations that produce no glare and the design with maximum energy production can be selected. Table 3 represents that the tilt and orientation angle of the solar PV system is suitable parameters for the mitigation of glare.

**Develop an Emergency Glint Response Plan:** An emergency response plan that includes procedures to quickly reduce potential glint impacts on pilots and air traffic officials can be framed for improved safety [26]. In addition, mitigation measures such as barriers and screens, notification to pilot and stow procedures can be employed if glare hazards still exist.

**Table 3**
Parameters for mitigation of glare.

| Inputs | Definitions | Default | Variation to reduce glare |
|---|---|---|---|
| Orientation angle (deg) | Indicates angle of solar panel faces from south | 180° from south | Yes, can be varied from 0° to 360° |
| Tilt angle (deg) | Angle made by PV module from ground level | Depends on latitude of site | Yes, can be changed from 0 to 90° |
| Rated power | Installed capacity in the selected area | Unit used is kW | Fixed based on the selected area |
| Time interval (min) | Minimum resolution needed for the duration of glare analysis | One minute is chosen | Fixed as per FAA policy |
| Observation points | The points for which the impact of glare must analysed | ATC tower and flight path | Fixed as per FAA policy |
| Ocular transmission coefficient | Accounts for amount of radiation passing through the eye before reaching retina. | Taken as 0.5 | Fixed as per simulation software |

**Table 2**
Degree of glare impact on each selected area.

| Degree ofGlare Impact | Definition | Colour code for glare impact (as per FAA) | Mitigation Status | Remarks |
|---|---|---|---|---|
| No impact | Reflection from solar PV module does not occur at any instant of time | Not Applicable | No mitigation required | Nil |
| Low | Solar reflection occurs at some point of time with lesser strength | Green Glare | No mitigation required | Nil |
| Moderate | PV module reflection happen at an instant with a slight disturbance to vision | Green Glare | Mitigation needed in case of some receptors such as ATC towers | Present in selected areas |
| High | A significant level of solar reflection happens and affect visibility from sensitive receptors | Yellow glare | Mitigation is mandatory for solar project approval | Seen in the selected area |

## 4. Conclusions

Airport based solar PV systems are popularising across the world. The major roadblock in the execution of such projects is the possible glare impact from the PV array which may affect the visibility of pilots or airport staff or both. Glare occurrence is predicted using Forge Solar software for a random location in the airport. The suitability of the location for the installation of a solar PV plant on the basis of FAA guidance is analysed.

- In the selected area ($A_{PV}$), the duration of glare on ATCT from solar modules installed is 6778 min (green and yellow glare). Also, the flight path is free from any kind of glare occurrence. Green glare corresponds to low potential for after-image and Yellow glare indicates a potential for after-image.
- Glare occurs between March to mid-October, mostly from 7.00 a.m. to 8.00 a.m. Green and Yellow glare exist up to 10 min and 30 min respectively annually.
- Remedial measures such as the selection of PV modules with a high absorption factor, appropriate sitting and orientation of the PV array can avoid glare hazard potential from reaching sensitive receptors. Since the design and sitting of solar arrays in the airport are not free from challenges, a detailed glare impact study is suggested for solar PV installation within 30 km of the airport.
- Though the FAA's guidance on glare is the basis for assessment, a pragmatic approach is followed to conclude whether a predicted solar reflection cause hazard to aviation safety. Solar PV systems can safely coexist in airport premises through a combined effort of design engineers and air traffic management, airlines and stakeholders.

## Authors contribution statement

KS and AF gave guidance to SS who carried out the research work on Glare study and drafted the manuscript. EC compiled them into a journal format. ES went through the text of the paper and critically checked the correlation for correctness. All authors read and approved the final manuscript.


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