

Introduction

The Incidence Angle Modifier (IAM) is a crucial parameter for PV performance modeling, and accounts for solar energy losses through the glass cover sheet of a solar module caused by angles of incidence (AOI) other than perpendicular. This is particularly impactful during the morning and evening hours as well as in winter, when the sunlight angle is steep. Significant differences have been seen between manufacturer-provided IAM curves, predicted losses based on Fresnel's law, and IAM curves measured by independent laboratories. Manufacturer IAM data are often derived from the models or set of standard assumptions, which may not fully capture the real-world losses due to reflection, anti-reflective coatings, texture, materials, etc. In contrast, the third-party laboratory data are independently tested and validated under controlled testing conditions, offering greater reliability and credibility. These differences can lead to significant variations in the predicted energy yield, potentially reducing accuracy, increasing financial risk and diminishing the bankability of PV projects. This impact is typically higher for fixed-tilt systems and lower for single-axis tracker systems. The table below shows the factors and their relative impact on the IAM loss and consequently on the energy production.

Factors	Relative Impact	Practical Interpretation
Incidence Angle	Very High	Low sun angles (morning, evening, winter) cause most IAM losses
Module Glass Type	Very High	AR-coated or textured glass significantly improves IAM
Tracking vs Fixed Tilt	Very High	Dual-axis tracking nearly eliminates beam IAM losses
Tilt angle	High	Tilt optimized to latitude minimizes IAM losses
Azimuth	High	East-west arrays suffer higher IAM losses in morning/evening
Latitude	High	Higher latitude cause higher winter IAM losses
Seasonal Sun Path	Medium	IAM losses are seasonally highest in winter
Diffuse Radiation Share	Medium	Cloudy sites still see IAM loss
Soiling & Snow	Medium	Worsens IAM at high AOI can cause severe short-term IAM losses
Cell technology	Low	Much smaller effect than glass or geometry
Longitude	Low	Affects when losses happen, not how much annually

Framework

For this analysis, five different PV module types were taken into consideration. Each module type included two PAN files, one provided by the manufacturer, and one obtained from independent third-party laboratories. For reference purpose, an IAM profile predicted by Fresnel's law was also included. Simulations were conducted at ten representative locations across the United States for each module type. To ensure consistency, the overall DC system size was maintained the same when using different module types. All batch simulations were performed using PVsyst software with identical system configuration, tracking limits, shading scene, inverters and loss parameters.

Results

There are three graphs shown for each module type. The first graph represents the input IAM profile, while the other two graphs show the output IAM loss and the comparison with respect to third-party tested PAN file.

- Graph 1** shows the IAM profiles from manufacturer-provided PAN file, third-party tested PAN file and Fresnel's law-based profile. In some module PAN file cases, deviations in IAM curve with respect to incidence angle can be observed. These deviations are more pronounced for certain PAN files when compared to others. Key points to note include whether the profile starts at one, decreases monotonically, approaching zero at high incidence angles and does not exhibit bumps or increases.
- Graph 2** shows the IAM losses derived from the three IAM profiles after simulation in the PVsyst software. Ten different locations were used to illustrate the magnitude of IAM losses and how the differences increase for higher latitude sites.
- Graph 3** shows that, in most cases, the IAM loss from the manufacturer-provided PAN file is on the aggressive side, whereas the IAM loss from the Fresnel's law-based profile is more conservative when compared to the third-party tested PAN file.

Conclusion

Manufacturer-provided PAN files with IAM profile "Uses definition of the PV module" can be used, but with caution due to the potential for aggressive IAM assumptions. While third-party tested PAN files are not always available, they significantly reduce potential for over-prediction. In cases where only manufacturer PAN files are available, using a Fresnel anti-reflective coating-based IAM profile provides results that average close to and are occasionally higher than measured IAM losses. Although this approach is sometimes conservative, it helps accommodate uncertainties and additional uncaptured losses that tend to accumulate as a project progresses, providing useful modeling margin until more accurate third-party data becomes available.

