PROPOSING OPTIMAL ORIENTATION AND TILT ANGLE FOR A PHOTOVOLTAIC-THERMAL PANEL IN ADANA, TURKEY

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Abstract

This paper determines the optimum orientation and the tilt angle for a 1.59 m^2 photovoltaic-thermal (PVT) panel with 60 mc-Si cells using the typical meteorological year data of Adana, Turkey. The technical specifications of the PVT were taken from the manufacturer. The typical meteorological year data for the location was taken from Meteonorm software and transient modeling was carried out for the prediction of a full year system performance by System Advisor Model. The optimum voltage-current points for varying irradiance were obtained as a result of the simulation and the optimum orientation and the tilt angle for the specified PVT were respectively found to be 180° azimuth (due south) and 30−32° for maximizing the annual electricity production. The results presented here will provide PVT manufacturers or installers to specify the optimum orientation and tilt angle of PVT for domestic or industrial installations.

Keywords: photovoltaic-thermal, optimum orientation, optimum tilt, typical meteorological year, transient simulation, System Advisor Model.

INTRODUCTION

The electrical efficiency of photovoltaic (PV) cells typically ranges from 15% to 20% while 65−70% of the solar spectrum is converted into heat which increases the temperature of PV modules, in turn, lowers the electrical efficiency. However, PV-thermal (PVT) hybrid collectors combine the production of solar electricity and heat in a single device and thus achieve higher overall efficiency and better harvesting of solar energy than conventional PV modules (Furbo et al., 2021). These collectors are generally installed stationary and their overall efficiency depends on various factors such as the cell technology, orientation of the PV/T, weather characteristics, working fluid thermophysical and flow properties, electric load management (Yılmaz and Yıldızhan, 2021).

The main goal of the PVT is electric production which is more qualified than thermal energy. While a standard PV panel is cooled to prevent degradation in conversion efficiency, a PVT panel aims to use waste heat smartly in a heating or cooling application. This idea increases the energy efficiency of the panel and lowers the negative environmental impact (Yılmaz, 2018a).

This paper proposes an optimal orientation for a PV or PVT panel installation and a case study has been made for the panels to be installed in Adana, Turkey. For this reason, transient long-term modeling was performed using System Advisor Model (SAM) and the orientation parameters were parametrically simulated and the results were discussed.

MATERIALS AND METHODS

PVT Specifications

The PVT collector shown in Fig. 1 was taken into account in the study. Each module has dimensions of 1.67×0.95×0.06 m and a 1.59 m^2 gross collecting area with 60 mc-Si cells (Solimpeks, 2021). 7 riser tubes with 1.445 m in length and 0.0071 m in inner diameter are attached to the backside of the PV and insulated with 0.05 m glass wool.

Fig. 1. PVT under consideration

Table 1 shows the electrical specifications of the PVT. The working fluid passing through the riser tubes was selected as water since the long-term measurements reveal that the lowest ambient temperature in Adana is over the freezing temperature of water.

Table 1. Technical specifications of Excell PV-T 300W

Property	Value
Maximum power point voltage (Vmp)	34.30 V
Maximum power point current (Imp)	9.62 A
Maximum power (Pmp)	330 W
Open circuit voltage (Voc)	41.67 V
Short circuit current (Isc)	10.17 A
Nominal operating cell temperature, NOCT	36.9 °C
Temperature dependence of Voc	−0.104 V/°C
Temperature dependence of Isc	0.005 A/°C
Temperature dependence of Pmp	−0.314 %/°C

Typical Meteorological Year Data

For the long-term transient simulations, the typical meteorological year (TMY) data of the location is usually used to normalize the obtained outputs. Fig. 2 represents the TMY data of Adana city (37.0° N latitude 35.3° E longitude, 20 m from sea level) which was delivered from Meteonorm to add it to the solar resource library of SAM in the TMY2 weather file format (Yılmaz, 2018b).

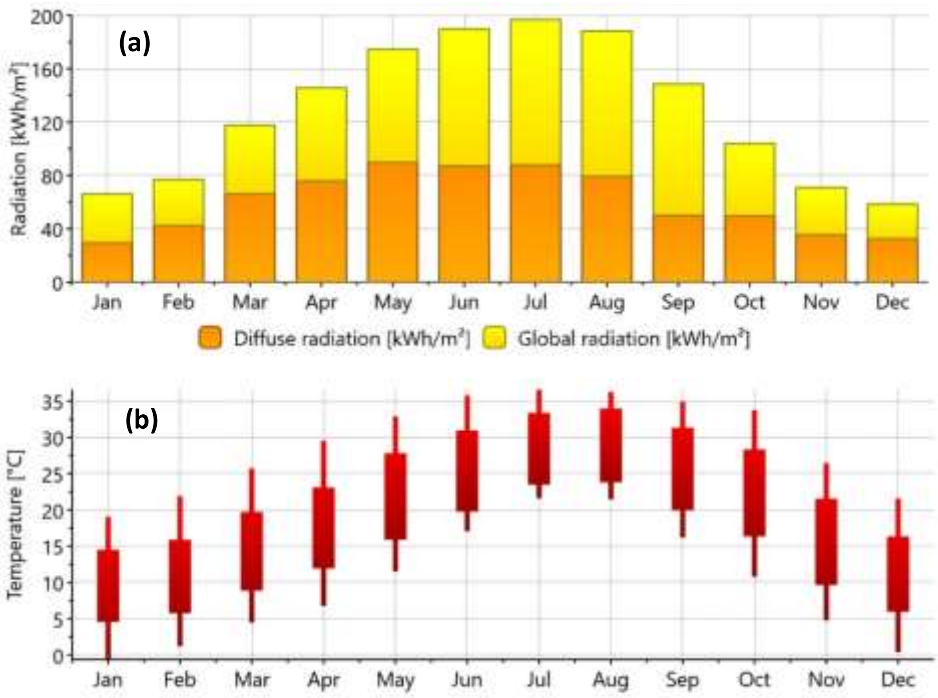

Fig. 2. (a) Monthly average global radiation over the period of 1991−2010; (b) Monthly average ambient temperature over the period of 2000−2009

System Advisor Model

A new open-source software program developed by the NREL, named SAM was used for simulation due to very fast runtimes and good agreement for a time-based analysis (SAM, 2021). Various renewable energy systems including PV can be modeled and simulated parametrically using this software. It is possible to either provide your own module and inverter specifications from a manufacturer's datasheet or choose a module and inverter from libraries.

RESULTS AND DISCUSSION

PV inverters are implemented with maximum power point tracking (MPPT) algorithm to continuously adjust the PV system operating at, or close to, the peak power point of the PV panel under varying conditions of solar irradiance, ambient temperature, and electric load. Fig. 3 shows the voltage-current curves versus solar irradiance at standard test conditions for the PVT properties in Table 1.

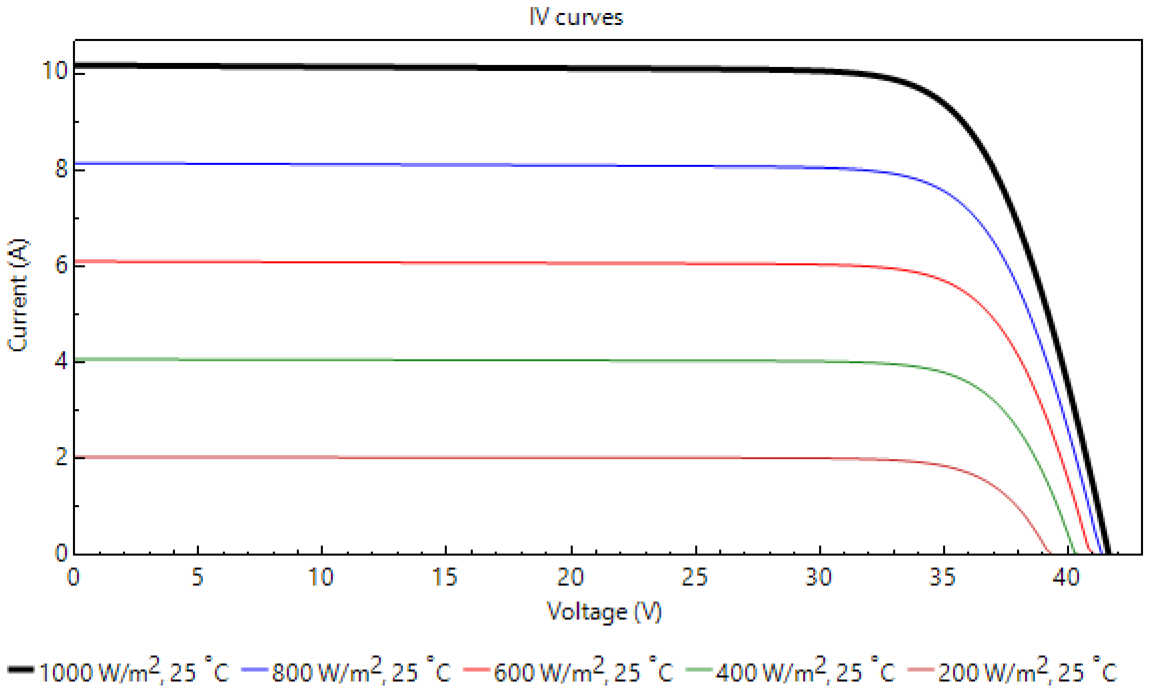

Fig. 3. Current-voltage curves at standard test condition

Fronius inverters are widely used in the Turkish PV market ranging from 1.5 to 100 kW (Fronius, 2021). Fronius USA: Galvo 1.5-1 208-240 [240V] model was chosen from the library of SAM. The inverter's nominal rated DC-to-AC conversion efficiency curves are illustrated in Fig. 4.

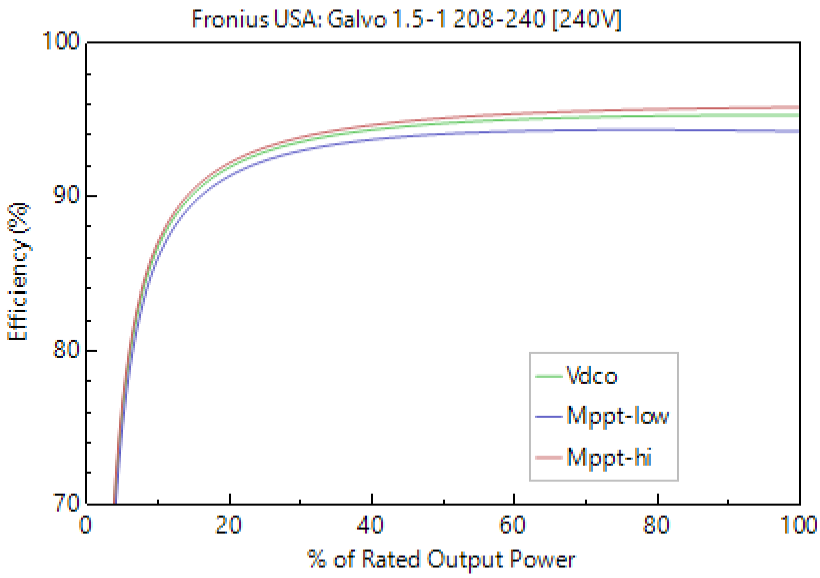

Fig. 4. Efficiency curves of the inverter

SAM has the ability to size and configure the PV subarrays as schematically shown in Fig. 5. It also provides a parametric design which provides assigning more than one value to one or more input variables to explore the dependence of a result on the inputs.

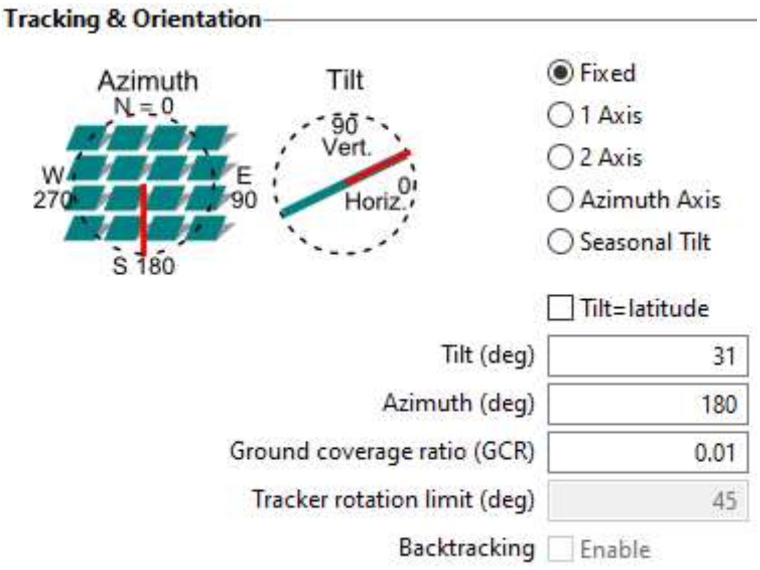

Fig. 5. System design mode of SAM

For a fixed PVT, its orientation i.e., the tilt angle and surface azimuth are significant for maximizing the annual electricity production (Yılmaz, 2018a). A typical azimuth value would be 180° for systems north of the equator and 0° for the ones south of the equator. The performance ratio is a measure of a photovoltaic system's annual electric generation output in AC kWh compared to its nameplate rated capacity in DC kW, taking into account the solar resource at the system's location, and shading and soiling of the array. Fig. 6 demonstrates the variation of the performance ratio of the PVT with azimuth angle where Run number 1 corresponds to 10° angle and increases in 10° increments i.e., Run number 18 corresponds to 180°. As seen, the performance decreases with increasing azimuth thus 180° azimuth will be the most suitable orientation for better electricity production in Adana where locates in the north of the equator.

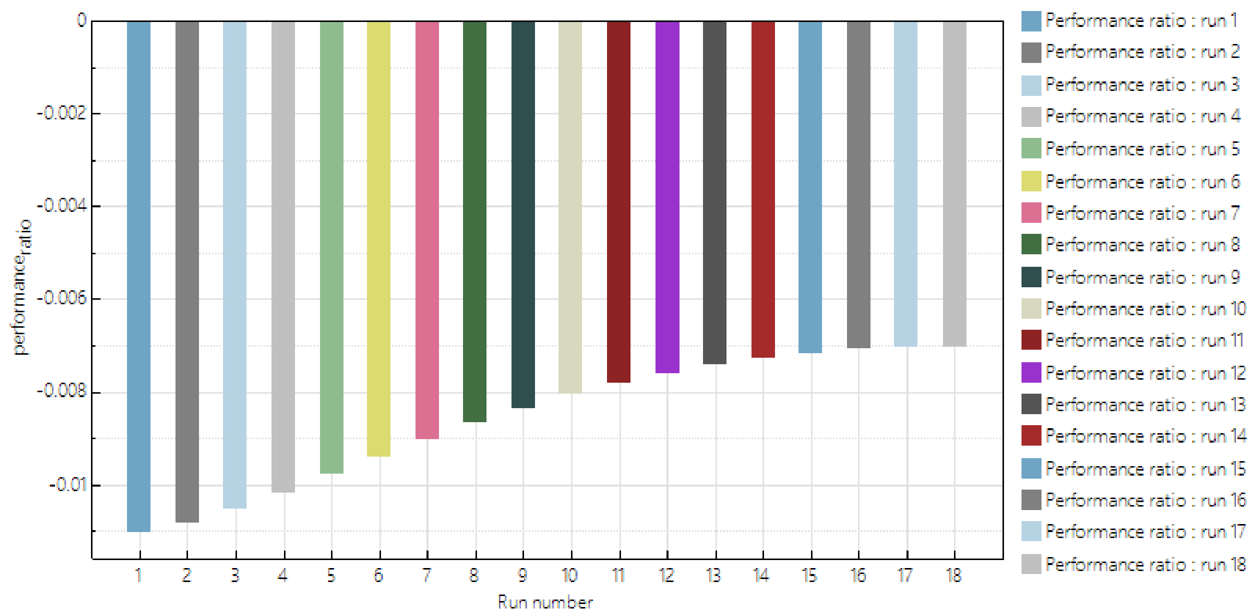

Fig. 6. Variation of the performance ratio with azimuth angle

Fig. 6 demonstrates the variation of the performance ratio of the PVT with tilt angle where Run number 1 corresponds to 10° angle and increases in 2° increments i.e., Run number 18 corresponds to 44°. As a rule of thumb, system designers sometimes use the location's latitude as the optimal array tilt angle. The analysis indicates that for a PVT installation in Adana, decision-makers should select the tilt angle between 30−32° where the performance ratio is the minimum as seen from Fig. 7.

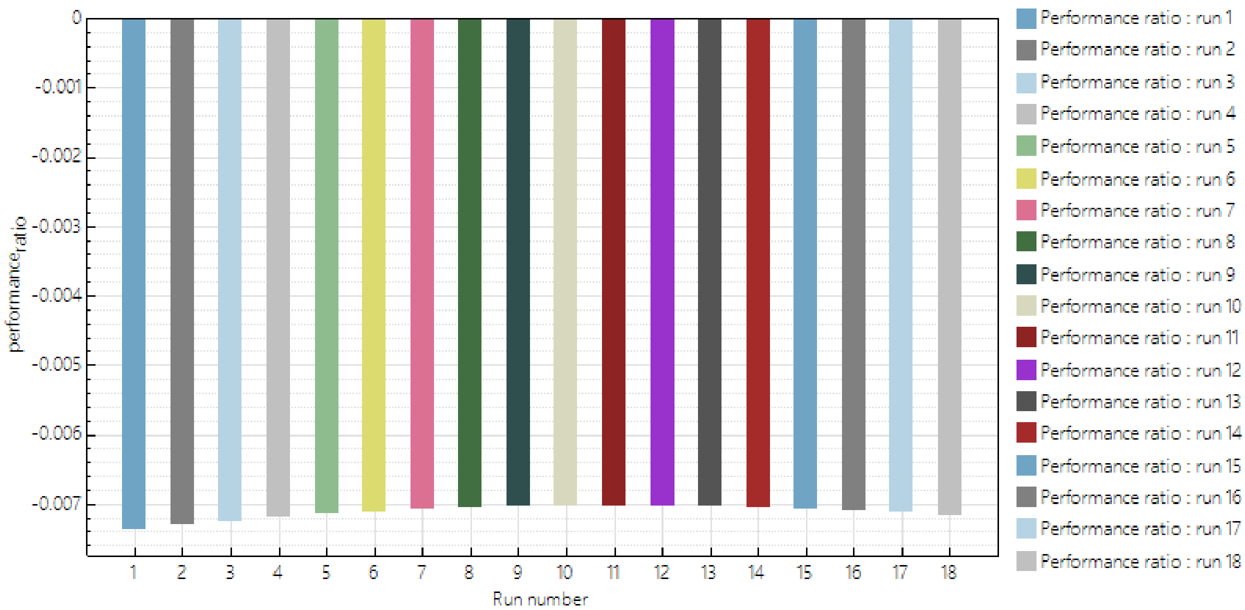

Fig. 7. Variation of the performance ratio with tilt angle

CONCLUSION

The PVT hybrid collector is a promising technology particularly for domestic and industrial applications. Various studies were performed in the literature to show the methods of having better system performance. The proper installation will provide benefits for the long-term performance and electricity generation. This paper proposes an optimal orientation for the specified PV or PVT panel installation in Adana, Turkey. Various free software packages are available in the literature but transient simulation is not performed by all of them. A more detailed design/model would always give more reasonable system outputs. Even though free software provides benefits in the preliminary design stage, commercially licensed software or user modeling for better analysis of these systems.

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