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Software for calculating the optimum tilt angle of PV modules in different latitudes of the Southern hemisphere and solar plant sizing

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Abstract. Through the development of photovoltaic technologies, the market related to this type of renewable energy grows constantly. In Brazil, the generated power through photovoltaic (PV) power stations approximates to 2.3 GW representing 1.3% of the total Brazilian energy mix. To supply the public it is necessary to offer tools that facilitate consumer decision making or even the work of a solar farm designer. By analyzing the user's necessity, it is possible to determine that a great parcel needs a quick and simple response to help them with their questions, and programs that are already well established in the marketplace are complex for inexperienced users. For this reason, a software that calculates the best inclination for PV modules using the method proposed by Liu and Jordan in 1962 is developed. It also determines the number of modules that can be installed without any shading between arrays within a user-defined area. This calculation is possible through the standard dimensions provided by the module manufacturers and the solar height and declination study. Through a simple interface, the user quickly receives the optimum tilt angle of installation, the number of PV modules and the maximum generated power.

Key words. Renewable energy, PV modules, software, optimum tilt angle, shading.

1. Introduction

The reduction of fossil fuel reserves and increasing pro-environment concern creates a demand for alternative sources of energy, which grows exponentially each year.
According to the International Energy Agency (IEA) solar PV power generation is estimated to have increased by more than 30% in 2018, to over 570 TWh, and by year 2030 it estimates that this number reaches almost 3300 TWh [1].
The SolarPower Europe states that the preference for solar over other technologies is due to the steep cost reduction curve. Solar power generation costs are significantly lower than for new nuclear and coal plants, and usually below gas and wind depending on the region. However, this technology is still expensive for developing countries [2].
In Brazil, although most of the energy mix is constituted of renewable energy [3] - predominantly hydropower - the demand for PV systems has shown exponential leaps due to the reduction of material prices, high-energy potential and good financial return. The installation shows an increase in energy efficiency and a reduction in electricity consumption from the energy utilities, behavior similarly reported by [4].
This ongoing situation represents an increase of consumers in this sector and, consequently, a diversification of the public. Thus, is created a new market: PV system software. In the complete ones, it is possible to calculate a preview of the generation with high precision, including losses, tariffs and weather conditions. However, to access all the functions that the software contain it is necessary to purchase a license.
The software developed in this paper offers the user simpler answers when compared to paid software. However, it meets the needs of the targeted audience: users that wants simple responses about the implementation of a solar farm.
The software, for each latitude, optimally dimensions the PV system. Therefore, it uses a method of predicting the solar irradiance incident on a flat terrestrial surface for calculating the optimal tilt angle. The study about this prediction is divided in methods that considers the solar irradiation scattered as uniform in all directions (isotropic) or variable to each direction (anisotropic).
Liu and Jordan [5] used the isotropic method for predicting the radiation upon solar-energy collectors through data about the daily radiation and developed a method for predicting its long-term performance. Latter, Klutcher [6], Temps and Coulson [7], and Perez, et al. [8] used the anisotropic method to further improve the prediction. Yadav and Chandel [9] then reviewed the majority of methods for predicting the radiation incident on a terrestrial flat surface.
The software uses the method described by Liu and Jordan [5]. It considers that the total irradiation on a terrestrial surface is the sum of the following irradiations:

- Direct irradiation: solar irradiation that directly reaches the module;
- Diffuse irradiation: solar irradiation that indirectly reaches the module. The solar radiation is scattered by the mean it is passing through (e.g. clouds, fog and suspended dust particles);