



Dust effect on optimal photovoltaic modules installation

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ABSTRACT

The Algerian government plans to launch several large-scale photovoltaic solar projects, targeting a total capacity of 15 GWc by 2035 and aiming to generate 27% of its energy from renewable sources. For this reason, the optimal tilt angle of photovoltaic arrays is among the most important factors for energy production maximization. However, the dust accumulation on solar collector can significantly affect their performance and productivity. Therefore, it is indispensable to consider the dust deposition effect on the optimal tilt angle of solar modules. The annual optimum tilt angle is often set around the location latitude, based on results obtained using clear-sky solar irradiance models. Numerous studies have investigated the impact of tilt angle on dust accumulation, consequently on the performance and productivity of photovoltaic modules for different regions and seasons. This study aims to analyze the optimal tilt angle of PV modules for maximum energy production, considering undesired effects such as dust, dirt and astronomic factors. The objective is to study the effects of the dust on the tilt angle of PV arrays in desert region of Algeria, according to the two aspects concerning the effect of the inclination on the dust accumulation and the optimal incidence of solar illumination. The experiments have been conducted on the dust particle accumulation on the PV modules. It was found in this study, that the dust accumulation on the PV array surface for a period of several months could significantly reduce the PV array productivity with an average power loss of about 4.38%. Therefore, the study on an optimal tilt of the PV field under the effect of dust is irresponsible to reduce the losses.

1. INTRODUCTION

Algeria's energy policy emphasizes promoting renewable energy sources to address high energy demand and gradual declining conventional resources (BP Statistical, 2013), aiming to reduce greenhouse gas

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emissions (GHG) and transition towards a low-carbon economy through sustainable energy development and diversification of energy sources. On the other hand, the GHG emissions according to accelerated energy transition (TRANSAC) scenario 2019-2050 in Algeria, as shown in Table 1 (MEER, 2023), particularly carbon dioxide (CO₂) from the consumption of traditional fuels, achieving an attenuation of 40% in 2050, i.e. from 670 Mt CO₂eq like reference to 402 Mt CO₂eq with TRANSAC scenario. This situation underscores the urgent need to transition swiftly and effectively to alternative energy sources and to explore all avenues for rationalizing consumption and conserving fossil resources.

Table 1. GHG emissions according to TRANSAC scenario by 2050

Year	2019	2025	2030	2035	2040	2045	2050
Mt CO ₂ eq	163	214	248	288	318	355	402

Algeria's energy policy advocates for a significant integration of renewable energies into the national energy mix. The goal for Algeria by 2030 is to achieve a renewable energy contribution of 27%, including solar energy. In this regard, the integration of PV systems it planned to reach a capacity of 15 GWp by 2035 (Fig. (1)) (MEER, 2023). Nevertheless, the PV solution presents the issue of temperature and dust effects on energy production, particularly in hot desert regions. Dust reduces the absorption of incident energy, and increases the temperature of the module that affects the cell's efficiency (Almukhtar et al., 2023).

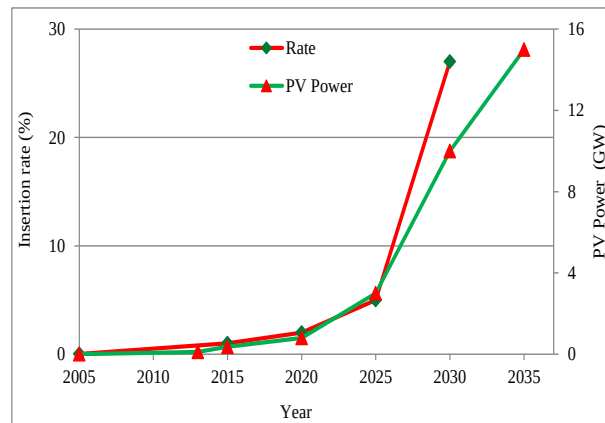


Fig 1. PV insertion into the national grid

Electricity is a form of energy that is currently an essential element in the societies live. Over the last decade, electricity in Algeria has experienced an average growth rate of 6% per year (ME, 2014). Which, 62% of electrical energy it consumed by the residential sector (ME, 2014). Global statistics estimate that nearly a quarter of the world's population lacks access to electrical grids (Ruijven et al., 2012), (Doll and Pachauri, 2010). Most of these populations live in rural areas and in developing countries, primarily in Africa and Southeast Asia (Giannini et al., 2011). The dispersion and low density of populations hinder the expansion of the national electrical grid in rural areas. The only way to provide energy to these areas is through the establishment of autonomous local micro-power plants. The typical solution of employing a diesel generator does not guarantee true autonomy of the installation under generally extreme conditions (temperature, wind, etc.) due to issues with fuel supply (isolation) and equipment maintenance (occasional sandstorms). Given the high cost associated with establishing a conventional power plant, including the transmission network, PV energy can help address this issue by offering a means to produce clean, more accessible electricity that is well suited for decentralized production in

isolated regions with strong solar energy potential. Algeria has a solar energy potential exceeding 5 billion GWh/year (ME, 2015). This potential varies by region between 2.4 and 5.2 kWh/m²/day in winter and from 4.8 to 9 kWh/m²/day in summer (CDER, 2019). These values fluctuate throughout the course of the year depending on the seasons, reaching a notable peak in the summer. Algeria also has vast expanses of territory, nearly 2 million km², which a significant portion is desert and could be utilized for harnessing solar potential. But among the natural constraints that pose a problem to PV installations in arid and semi-arid regions like the majority of the territory in Algeria is that of dust. In the literature, several works have addressed this subject. For example, the optimal installation angle for photovoltaic modules to maximize energy output is identified in the case study of Song Hu & all. The paper does not specify orientations, focusing instead on installation height and angle for effective dust deposition management (Shan et al., 2023). Another study of Juan Wang & all indicates that increasing the tilt angle, mounting height, and optimizing incoming flow direction can enhance dust accumulation on photovoltaic panels. However, specific optimal configurations vary, necessitating further investigation to determine precise angles for minimizing dust and maximizing energy output (Juan et al., 2025). In Al Seeb, Oman, a study is being conducted by Girma et al. (2025), where found that a tilt angle of 25° yielded the highest output power of 79.75 W and an efficiency of 20.5%, suggesting this angle may minimize dust accumulation and maximize energy output (Girma et al., 2025). In this work, we present the simulation results of the effect of dust on the optimal PV generator installation.

2. MATERIEL AND METHODOLOGY

The objective is to assess the performance of PV system in a desert environment under actual conditions. PV module is current generator that primarily depends on the intensity of the incident illumination on the module's plane and the voltage applied across the module's terminals. Consequently, the performance of PV generator is represented by its characteristics for a given illumination and temperature. Figure (2) shows an example of the annual irradiation distribution measured on optimal inclination of PV generator cleaned plane, with 2364 kWh/m²/year of cumulative value. The summer irradiation average is 7.412 kWh/m²/day, and an average of 4.956 kWh/m²/day it measured during the unfavorable month of winter. Figure (3) shows an example of the ambient temperature annual profile measured at the installation site, with a significant disparity between two major seasons, winter and summer. The maximum temperature exceeds 45°C in the shade, while the minimum can drop below 3°C. This phenomenon affects the PV generator proper functioning (efficiency reduction) (Madjoudj et al., 2024).

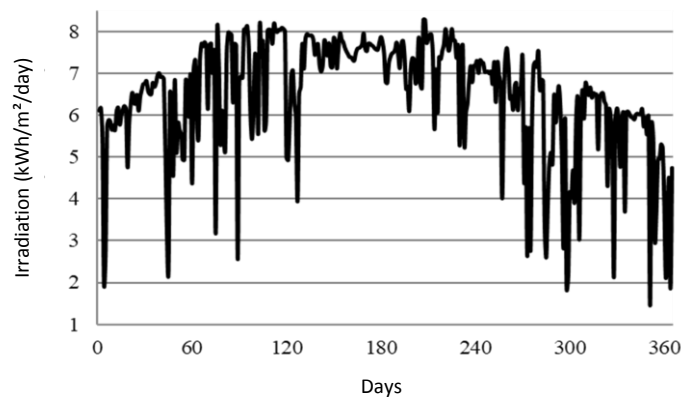


Fig 2. Example of annual irradiation distribution in a desert region of Algeria

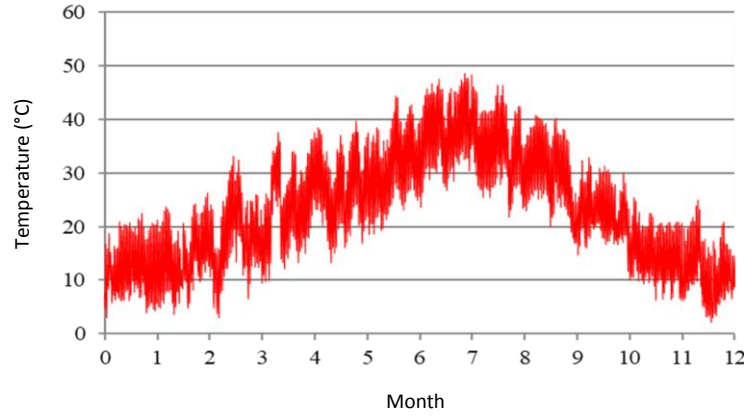


Fig 3. Example of annual ambient temperature in a desert region

In this work, the PV solution raises the air pollution effect issue on energy productivity by the soiling accumulation on PV modules glazing (Semaoui et al., 2020). In desert regions, the wind restless the dust particles exist in the sand and with time these particles deposited on the surfaces (Fig. (4)).

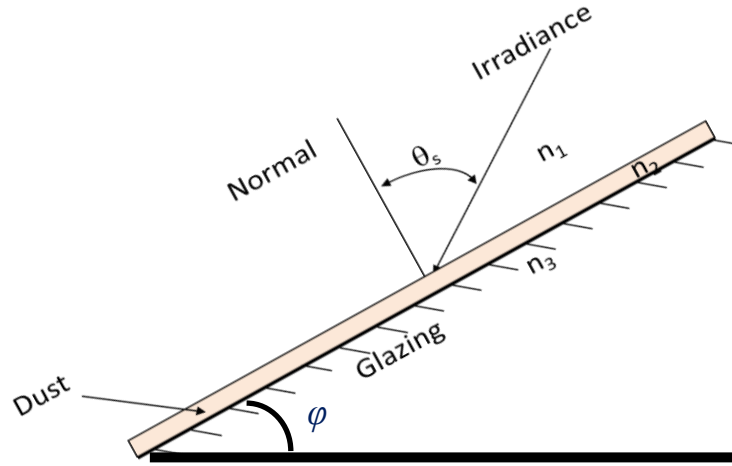


Fig 4. Descriptive diagram of dust deposition on the inclined plane

Where, n_1 , n_2 and n_3 are the indices of different midst (air, dust, and glass). θ_s and ϕ are respectively incident and tilt angles.

This natural phenomenon constitutes an obstacle that quantitatively prevents the radiation penetration in the PV cell material (Semaoui et al., 2015). For this purpose, a study is conducted to analyse the effect of dust accumulation on the optimal inclination of PV generator in a desert region.

This study is based on the models of incident global solar irradiance on the inclined plane and dust accumulation phenomenon as a function of inclination and exposure duration. Figure (5) shows the calculation protocol adopted through the simulation program.

The total solar radiation on a panel with the tilt angle can be expressed by using the following model (See Eq. (1)) (Semaoui et al., 2014):

$$GT(\phi) = GB(\phi) + GD(\phi) + GR(\phi) \quad (1)$$

Where $GB(\phi)$, $GD(\phi)$ and $GR(\phi)$ are respectively, direct, diffuse and reflected irradiances.

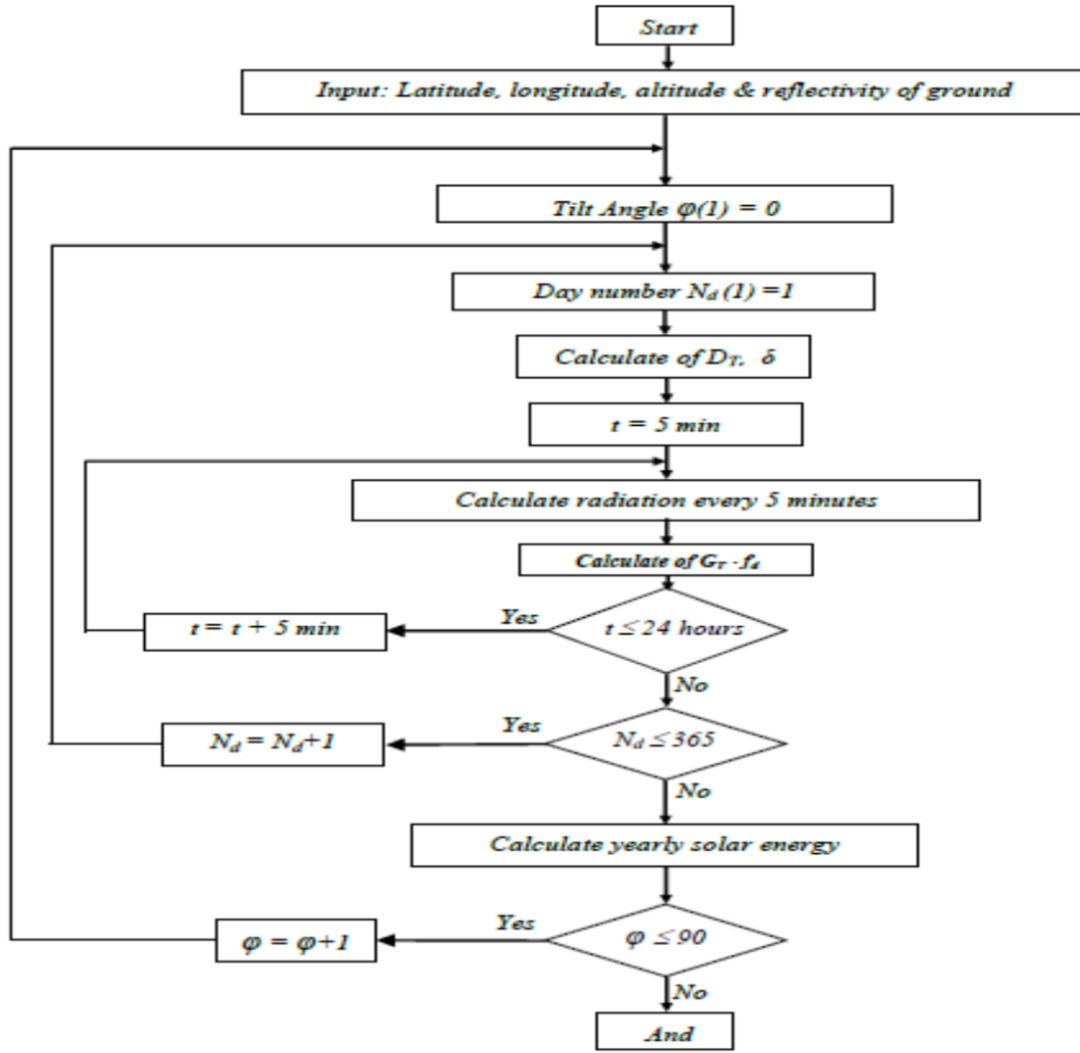


Fig 5. Calculation protocol flowchart

The final absorbed solar radiation by PV panel is the product of the received one and transmittance with dust factor (See Eq. (2)) (Ruidong et al., 2017):

$$GT(fd) = GT \cdot fd(\varphi) \quad (2)$$

Where $fd(\varphi)$ is the relationship between dust factor and the tilt angle.

By substituting the absorbed radiation affected by dust into the output power, PV output model is derived by considering the dust factor.

3. RESULTS AND DISCUSSIONS

The dust seriously affects the productivity of the PV generators (Fig. (6)). On the other hand, reduces the absorption of incident energy, which affects the cell's efficiency. The trend curve of measured point clouds describes the dependence of energy losses with the optical transmittance. This curve has specific shape. It was found that this shape is due to the optical reaction of dust due to the inclination and orientation factors.

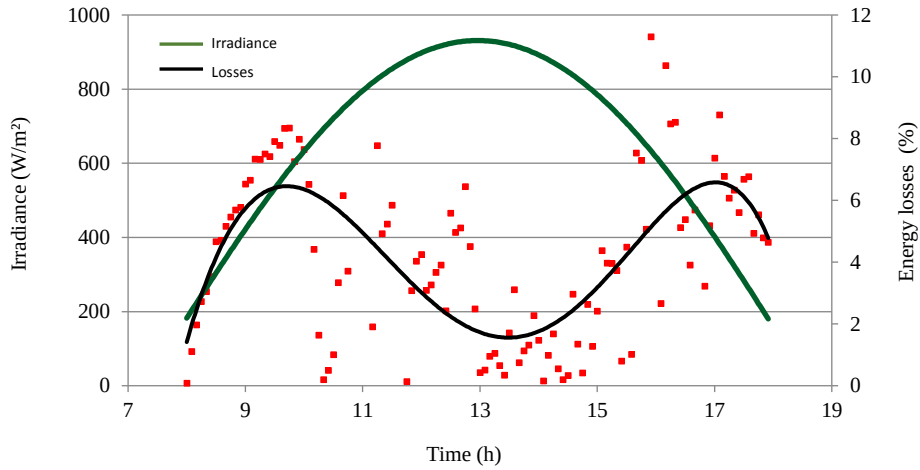


Fig 6. Example of energy losses evolution of dusty PV generator

3.1 Dust effect on tilt angle

Figure (7) illustrates the dust effect on glass transmittance of PV module in a direct way, and particularly on tilt angle which directly affects on the dust accumulation. Of course, all factors have an influence on the energy amount absorbed by the PV module.

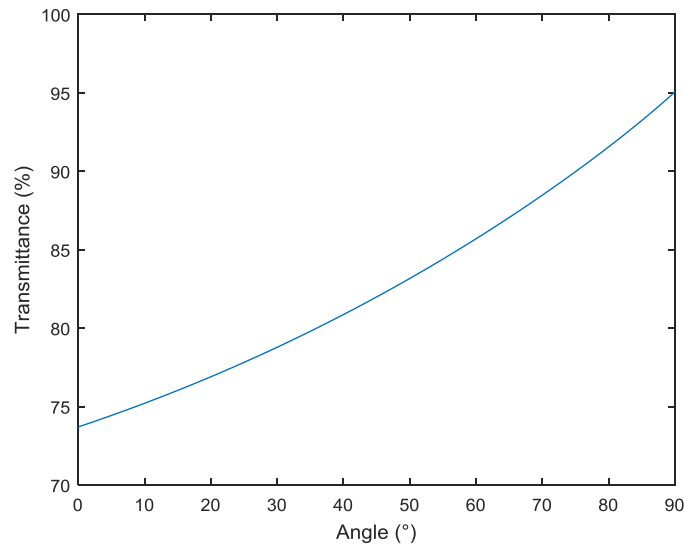


Fig 7. Transmittance versus tilt angle

3.2 Optimal tilt angle with dust accumulation

Figures (8) and (9) successively show the annual global irradiation evolution for different inclinations with and without dust. The optimal inclination is between 30° and 40° for the irradiation evolution without dust on the glazing.

On other hand, for the case of the irradiation evolution with dust on the glazing, the optimal inclination exceeds 40°. This provides a compromise between an inclination that prevents the dust accumulation, and at the same time promotes a normal incidence of electromagnetic waves on the PV modules surface.

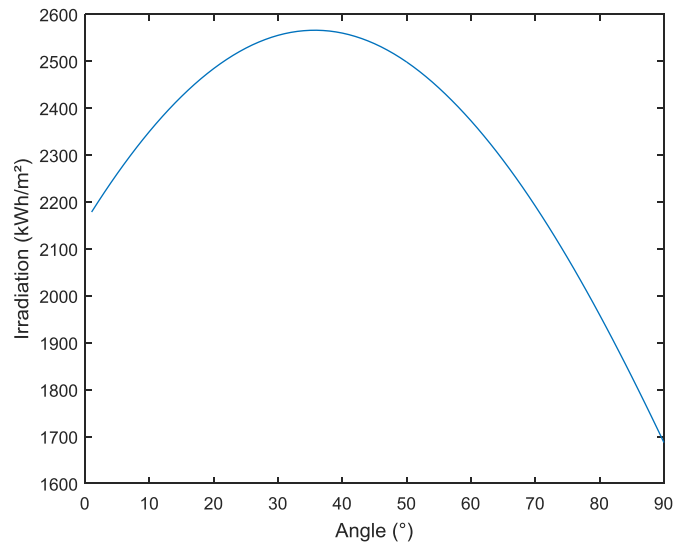


Fig 8. Irradiation evolution without dust versus tilt angle

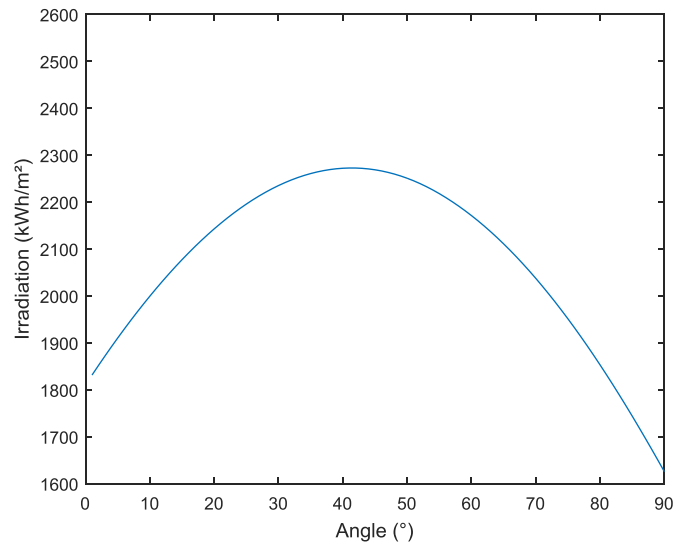


Fig 9. Irradiation evolution with dust versus tilt angle

4. CONCLUSION

The factor of dust deposition is included in the optimum tilt angle of a fixed-type of soiled PV panel in order to maximize the output power. The effect of dust deposition on the reduction in transmittance is investigated mathematically with using simulation software to verify the optimized tilt angle. We observe that the optimal tilt angle shifts with the effect of dust, approximately from 36° to 43° of course with the attenuation of the annual cumulative irradiation. This is due to a trade-off between an inclination angle that favors normal incidence and one that simultaneously minimizes dust accumulation, which affects transmittance.

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