Article Journal of Technical Invention
December 2023 Vol.7 No.20 1-8

Dry cleaning analysis for photovoltaic modules

Análisis de limpieza en seco para módulos fotovoltaicos

ESCOBEDO-MÁRQUEZ, Diana Laura†, RENTERIA-RAMIREZ, Rodolfo Enrique, CASTILLO-CAMPOS, Nohemí Alejandra and ÁLVAREZ-MACÍAS, Carlos*

Tecnológico Nacional de México, División de Estudios de Posgrado e Investigación, Campus Laguna, Coahuila, México

ID 1st Author: *Diana Laura, Escobedo-Márquez* / **ORC ID:** 0009-0005-9859-8251, **CVU CONAHCYT ID:** 1188232

ID 1st Co-author: *Rodolfo Enrique, Rentería-Ramírez* / **ORC ID:** 0000-0002-2513-8191, **CVU CONAHCYT ID:** 1155773

ID 2nd Co-author: *Nohemí Alejandra, Castillo-Campos* / **ORC ID:** 0009-0001-2490-4325, **CVU CONAHCYT ID**: 1271718

ID 3rd Co-author: *Carlos, Álvarez-Macías* / **ORC ID:** 0009-0009-7454-5809, **CVU CONAHCYT ID**: 165872

DOI: 10.35429/JOTI.2023.20.7.1.8 Received June 12, 2023; Accepted November 24, 2023

Abstract

For a photovoltaic module to work in optimal conditions, it is necessary a correct cleaning, as electrical power losses due to dirt on the module´s surface are estimated to be as high as 30-40% in dry and sandy climates. In this work, the design and construction of a dry cleaning system was made using a cylindrical brush with nylon bristle of 100 cm in length and 12 cm in width, the bristle have 0.3 mm diameter. The angular speed of the system is 10.58 π radians per second. The objective is to analyze the impact of the cleaning system on the electrical properties of a photovoltaic module. For the experimental analysis, the brush was adapted to a conventional electric motor, and the cleanings was on the frontal cover of the photovoltaic modules. The module was exposed to the environmental conditions of a desert climate, to perform periodic cleanings and record temperature and irradiance variables. The result of the research shows the analysis of the electrical properties of the module to determine the influence of the type of cleaning and its impact on the conversion efficiency.

Photovoltaic energy, Dry cleaning, Electrical parameters

Resumen

Para que un módulo fotovoltaico opere en óptimas condiciones es necesario una correcta limpieza, ya que las pérdidas de potencia eléctrica debidas a la suciedad en la cubierta del módulo se estiman hasta 30-40% en climas secos y arenosos. En este trabajo se realiza el diseño y construcción de un sistema de limpieza de tipo seco usando un cepillo cilíndrico de cerdas de nylon con dimensiones de 100 cm de largo por 12 cm de ancho, las cerdas tienen un diámetro de 0.3mm, la velocidad angular del sistema es de 10.58 $\boldsymbol{\pi} rad/seg$. El objetivo es analizar el impacto del sistema de limpieza sobre las propiedades eléctricas de un módulo fotovoltaico. Para el análisis experimental el cepillo se adaptó a un motor eléctrico convencional y las limpiezas se realizan sobre la cubierta frontal de los módulos fotovoltaicos. El módulo se somete a condiciones ambientales de un clima desértico para realizar la limpieza paródicamente registrando las variables de temperatura e irradiancia. El resultado de la investigación muestra el análisis de las propiedades eléctricas del módulo para determinar la influencia del tipo de limpieza y su afectación en la eficiencia de conversión.

Energía fotovoltaica, Limpieza seca, Parámetros eléctricos

Citation: ESCOBEDO-MÁRQUEZ, Diana Laura, RENTERIA-RAMIREZ, Rodolfo Enrique, CASTILLO-CAMPOS, Nohemí Alejandra and ÁLVAREZ-MACÍAS, Carlos. Dry cleaning analysis for photovoltaic modules. Journal of Technical Invention. 2023. 7-20: 1-8

* Correspondence to Author (e-mail: calvarezm@correo.itlalaguna.edu.mx,)
† Researcher contributing as first author.

1. Introduction

Solar Photovoltaics is a technology that generates direct current (power measured in watts or kilowatts) by means of semiconductors when they are illuminated by a beam of photons. [1] This technology has grown considerably in recent years. The Energy Regulatory Commission (CRE) estimates that by 2030 there will be an installed capacity of solar photovoltaic systems in Mexico equivalent to 6,905 MW. [2] Despite this, this technology presents variability in the production of electrical energy due to external factors that impact the electrical parameters of the photovoltaic module, reducing the generation of electrical power. These factors are the irradiance received, orientation, temperature, shading, thermal performance of the module and soiling. Flores Rivera (2018) [3] indicates that the most impactful soiling is formed on the module by environmental factors such as birds, wind, environmental pollution and dust. Dust is a determining factor that causes a reduction in the transmission of incident solar radiation reaching the PV cells [8]. A dust deposit of 4 g/m2 reduces the power conversion by 40% [4]. The effect is severe when modules are installed in desert areas with frequent dust storms, as the dust lodges on the module surface as dirt.

It has been proven by different studies that dirt on a module affects the module efficiency, an investigation by Jiang (2011) found by indoor experimentation that the reduction of a module's efficiency was increased by 26% by a dust layer of about 0 to 22 g/m2 [5]. Furthermore, Elminir (2006) reported a decrease in power output of up to 70% after exposing the panels to the elements for 6 months in Egypt [4]. Taking this into account, it is important to clean the roof of the modules, so this has become an issue that draws attention, as it seeks to maintain the efficiency of the modules, especially in desert regions, where despite having large amounts of irradiance, the climate is severe, facing most of the year hot days, and little rainfall.

Al Sheheri (2017) attributes that the constant drop in efficiency of PV modules installed in arid regions is due to dust permeating the surface and insufficient rainfall to clean them naturally, leading to the use of other cleaning techniques [6].

These techniques can be classified into two main categories: wet cleaning, which involves the use of water to remove dirt, and dry cleaning, which encompasses all methods that do not require water and are generally based on physical processes, such as brushing or vibration. The forms of cleaning that can be used for PV module maintenance can be categorised as follows: manual cleaning, mechanised cleaning, hydraulic cleaning and cleaning robots installed Al Shehri (2017) [6].

In this work, a dry cleaning system for modules based on a nylon bristle brush is constructed to analyse the impact of electrical parameters when subjected to dust and cleaning. The paper is structured as follows; in section 1 an introduction to situate the reader in the field of research, section 2 covers the construction of the prototype which is divided into: the design and construction, the coupling of an electric motor, section 3 corresponds to the experimental development of the dry cleaning. Section 4 is a review of the results obtained in the project, while section 5 shows the preliminary conclusions.

2. Methodology

A. Design and construction of the dry cleaning system.

For the construction of the prototype it was necessary to design it virtually. Figure 1 shows the 3D model in the SolidWorks programme.

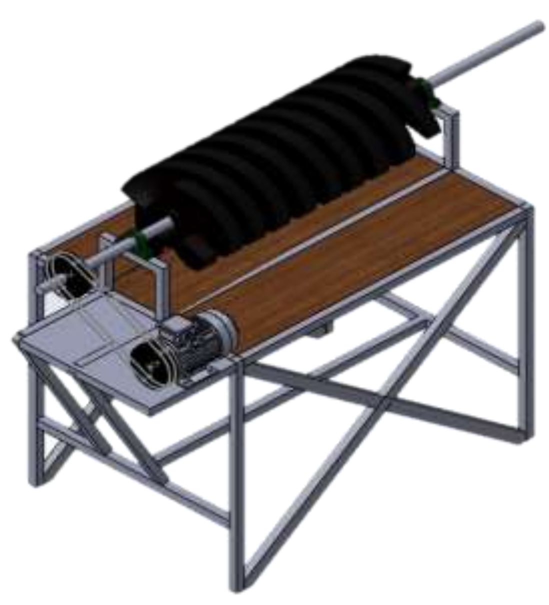

Figure 1 3D model of the dry cleaning prototype
Own Source, made in SolidWorks

The cleaning prototype made in SolidWorks has the assembly table or base, the nylon bristle roller and an electric motor. The dimensions of the brush are 100 cm by 12 cm wide, this, taking into account the axis and the length of the bristles. The base is 120 cm long, 84 cm wide and 90 cm high. This was followed by the construction of the system. The most important aspect of a cleaning system must be that the device is able to clean the photovoltaic modules and for this reason, figure 2 shows the union of 2 cylindrical rollers with nylon bristles in the form of a spiral, which will perform the functions of dry sweeping covering the width of the module.

Figure 2 Union of the two cylindrical rollers
Own Source

This roller is made of nylon bristles that have a diameter of 0.3 mm (this is the thinnest material available on the national market, to avoid scratching the module). The shaft was manufactured using one inch diameter (25.4 mm) stainless steel tubing. To support the system, diagonally arranged PTR bars were assembled and welded to provide stability to the base, as shown in figure 3.

Figure 3 Support assembly for stability of the system base
Own Source

Subsequently, supports were placed along the table surface to provide support for the bases that were installed to fix two one-inch diameter bearings.

In addition, a metal base was designed and fabricated and suspended from the top of the table to house the electric motor, which will provide the desired rotation of the roller. This base has additional braces to ensure stability during operation. The complete mechanism is shown in figure 4.

Figure 4 Roller system assembled on the stand
Own Source

At the end, wooden bases with a thickness of one inch were placed on top of the base structure and five castor wheels were added to support loads of up to 100 kg each. These castors will make it easier to move the modules on the table during the dry-cleaning process.

B. Coupling of a conventional electric motor to provide the brush rotation

In the system, the use of a conventional electric motor was implemented to obtain the rotation of the nylon bristle brush and to be able to apply a rotating sweep to clean the surface of the modules. In the work of Arrubla (2020), a motor rotation speed of 115 rpm was determined. Other studies show that at low revolutions for a rotary sweep it is possible to remove the most volatile dust and dirt without damaging the surface of the modules [7]. The electric motor selected is a Marathon 1075 Rpm, single phase, ½ HP, 110v single phase motor, shown in figure 5.

Figure 5 Electric motor selected for system coupling
Source: https://www.marathongenerators.com

This section also presents the equations to describe the transmission of the motor power, the bristle pressure on the PV module and finally the angular and linear velocity of the system.

i) Speed reduction mechanism

The brush rotational speed setting was obtained from equation 1, to calculate the output speed generated by the motor.

$$N1 \ x \ D1 = \ N2 \ x \ D2 \qquad (1)$$

Where
N1 = Engine speed
N2 = Engine output speed
D1 = Drive pulley diameter
D2 = Diameter of the driven pulley

The expected output speed is 300 rpm taking into account the research of Arrubla (2020) [7], it is expected that by increasing the rotational speed less cleaning cycles will be required and for this purpose a driven pulley of 11" diameter was chosen.

ii) Pressure of the bristles on the PV module

The pressure was determined using a horizontal board under the nylon brush to obtain the optimum height of 16 cm, from the base to the nylon bristles, sufficient to sit the module on the wood and allow the nylon bristles to rub against the module to apply the cleaning. The pressure was determined using the equation 2.

$$P = \frac{F}{A} = \left[\frac{N}{m^2}\right] = Pa \qquad (2)$$

Figure 6 shows the picture of the method.

Figure 6 Experimental tests to obtain the pressure exerted by the roller on a Surface
Own Source

iii) Angular and linear velocity of the system.

The angular velocity (ω) is a measure of rotation and determines the speed with which the angle can vary over a period of time.

The angular velocity (ω), which can be measured in radians per second, is a measure of rotation and determines how fast the angle can vary over a period of time. It is calculated by means of equation 3.

$$\omega = \frac{\theta}{t} \qquad (3)$$

Where
$\theta \ = \ number \ of \ revolutions \ in \ RPM$
$t \ = \ tiempo \ en \ que \ el \ cuerpo \ da \ vueltas$

Linear velocity, (V), is the speed at which a point moves along a circular path. This is why angular velocity and linear velocity are related equation 4.

$$V = \omega R \qquad (4)$$

3. Experimental development of dry cleaning in a module

A 50W polycrystalline module of the EPCOM brand (Fig. 7) was used for cleaning. The module was installed on the roof of the renewable energy laboratory of the TecNM Campus Laguna, in the city of Torreón, Coahuila. The module was placed with a southward orientation and an inclination of 25° corresponding to the latitude of the study area.

Figure 7 Polycrystalline photovoltaic module, Epcom 50W
Source Manufacturer's datasheet Annex 1

For this study, the PV module was left installed outdoors for 12 days for each cleaning. This cleaning frequency value is based on the work of Castillo (2022) [8], who used a 410 W JaSolar module in the same location, during this period of time he found a 25% reduction in efficiency, so it was decided to perform cleaning at the frequency of every 12 days [8].

All measurements were obtained near solar noon every 12 days, and environmental measurements were also taken, all before and after cleaning. Irradiance was measured with a Tenmars pyranometer (SM-206). For correct measurement with this instrument, the pyranometer must be calibrated and positioned parallel to the module surface. Wind speed was measured with an AMPROBE model TMA10A anemometer.

Figure 8 Measurement of environmental parameters
Own Source

To determine the ambient temperature, the Weatherlink application was used to consult the values obtained from the weather station located at the Instituto Tecnológico de la Laguna. For the measurements of the electrical parameters of the module, an ELEJOY WS400A multimeter was used for modules and the IV curve was obtained with a Prova 200A curve tracer, equipment shown in figure 9.

Figure 9 Equipment for measuring the electrical parameters of photovoltaic modules
Own Source

The electrical parameters were obtained before and after cleaning the photovoltaic module. As mentioned before, the dry cleaning was performed on the module cover after being exposed for 12 days to the weather and dirt, and the analysis showed an average power reduction of 32%. Figure 10 shows the technique performed for the dry cleaning process with the constructed system.

Figure 10 Photovoltaic module in dry cleaning process with cylindrical roller
Own Source

4. Results

A. Design and construction of the dry cleaning system.

Figure 11 shows the final prototype built with dimensions of 1.20 x 84 x 90 cm, which allows the cleaning of modules with dimensions up to 100 cm wide, dimensions of commercial modules.

Figure 11 Final prototype of a dry cleaning system for photovoltaic modules
Own Source

ISSN 2523-6792

B. Results of the coupling of a conventional electric motor to provide the brush rotation.

The result of the equations to describe the reduction of the transmission speed of the motor, the pressure of the bristles on the photovoltaic module and finally the angular and linear speed of the system are presented.

i) Calculation of the rotational speed.

To determine the rotational speed N2, equation 1 was used, where N1 corresponds to the speed of the motor, being 1200rpm, the motor speed reduction mechanism communicates with a 3" drive pulley with which N2 was determined, i.e.

$$N2 = \frac{N1xD1}{D2} = \frac{(1200)x(3)}{(11)} = 327.27\,rpm$$

ii) Calculation of the sow pressure on the photovoltaic module

To obtain the pressure of the roller on the module surface, equation 2 was used. The force of 9.62 N was obtained from the weight of the roller, whose mass is 0.98 kg, which is applied over a total area while the system is rotating. The total area was determined by adding the three sections where pressure is exerted when the module is placed, being 0.05 m^2. Then

$$P = \frac{9.62}{0.05} = 194.31Pa$$

iii) Calculation of angular and linear system velocity.

To determine the angular velocity it is necessary to know the number of revolutions the roller turns per minute, which is 327.27 rpm, which converted to radians is

$$\theta = 327.27\,rpm\,x\,2\pi rad = 654.54\pi rad$$

that using equation 3 the final angular velocity becomes

$$\omega = \frac{654.54\pi rad}{60\,seg} = 10.909\,\pi rad/seg$$

To obtain the linear velocity, equation 4 is the relationship between the radius and the linear velocity, which is directly proportional. The radius of the pulley is 13.97cm, so that

$$V = \omega R = 10.9\,\frac{\pi rad}{seg}\,x\,13.97cm = 478.77m/s$$

C. Results of the experimental development of dry cleaning in a module exposed to environmental conditions for a desert climate.

Figure 12 presents a comparison between the I-V characteristic curves of the electrical behaviour of the module before and after the cleaning process.

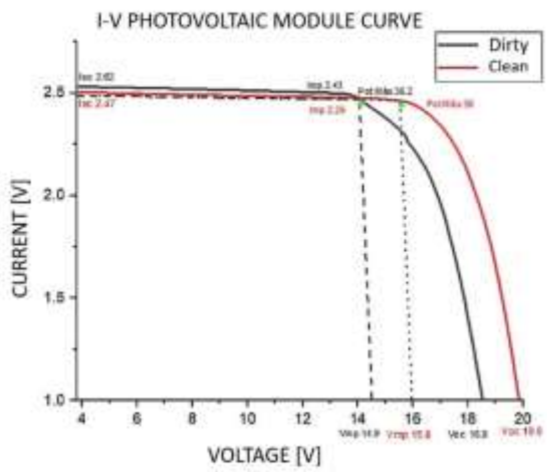

Figure 12 Comparison of I-V curves of dirty and clean PV module
Own Source

From figure 12 it is possible to observe a decrease in peak power, where the peak power current decreases very slightly, showing how dirt directly affects the current generation of the modules. This suggests that cleaning the module allows the incident radiation to penetrate the module cells without being covered by dust.

On the other hand, it can be observed that the open circuit voltage has a more noticeable variation, being more influenced by temperature. On the study day, the environmental conditions before and after cleaning were similar. The radiation was 1172 $W/m2$, the ambient temperature was 31 °C before cleaning.

After cleaning, the irradiance received in the module increased to 1200 $W/m2$ and the ambient temperature increased to 33°C, although the cleaning was done in less than 15 minutes, this time was enough to affect the measurements. The cell temperatures of the module were also recorded, before cleaning it was 58.13 °C and after cleaning it decreased to 41 °C.

From these data, it can be deduced that the accumulation of dust acts as a layer that interferes with the incident radiation on the module, which causes an increase in the module temperature. The removal of this dust layer resulted in a 29% decrease in module temperature.

5. Annexes

Annex 1 corresponds to the technical data sheet of the photovoltaic module used for the analysis.

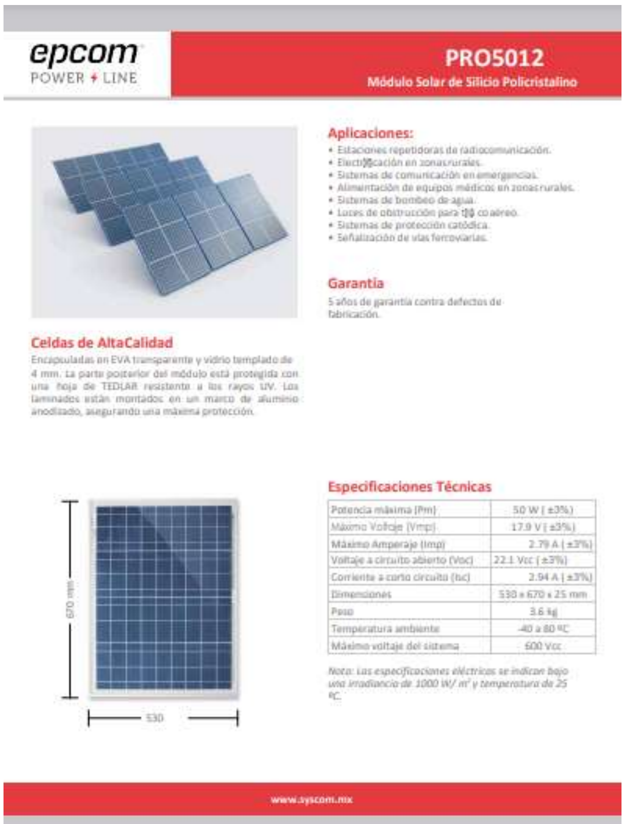

Figure 13 Datasheet Epcom 50W module. Manufacturer's datasheet

6. **Acknowledgements**

The authors would like to thank the Tecnológico Nacional de México for the financial support, as well as PRODEP. CONAHCYT is also thanked for the support through grant 812614.

7. Conclusions

In this work, a dry cleaning system with dimensions of 1.20 x 84 x 90 cm was designed and built, which allows cleaning modules with dimensions up to 100 cm long up to 100 cm long and 200 cm wide, the dimensions of commercial modules.

In order to carry out its characterisation, it was necessary to couple a 1/2 HP electric motor and a speed reduction system with pulleys to reduce the rotational speed of the brush, resulting in 327.27 rpm per cycle.

The angular velocity of the cleaning system was also determined to be 10.90 πrad/sec. The force exerted by the roller on the module is 194.31 Pa, which is necessary to clean and remove the dust from the surface of the module. Its implementation showed that the cleaning of the PV module contributed to a decrease of the cell temperature by 7.13 °C.

It is concluded that the deposited dust acts as a layer that interferes with the radiation incident on the module by obstructing the radiation and causing the module temperature to rise. By cleaning and removing this dust the module temperature decreased by 29% directly impacting the open circuit voltage, this has a very noticeable variation and may be directly due to the module temperature. There was no difference between the current before and after cleaning, suggesting that the dust layer is not as thick or thick.

8. References

[1] Colegio Oficial de Ingenieros de Telecomunicación. (2002). Ibergraphi. https://www.coit.es/comunicacion/publicaciones/manualestecnicos/recursos/energia-solar-fotovoltaica

[2] Crecimiento de los sistemas fotovoltaicos en México en los últimos años. (2020, enero). Solarama Paneles solares México. https://solarama.mx/blog/crecimiento-de-los-sistemas-fotovoltaicos-en-mexico-en-los-ultimos-anos/

[3] Flores Rivera, N.M, Domínguez Ramírez, M. A. (2018). Medición de la eficiencia energética de los paneles solares de silicio. [Tesis de maestría, Centro de Investigación en Materiales Avanzados, S. C.Posgrado]. Nombre del repositorio. https://cimav.repositorioinstitucional.mx/jspui/handle/1004/215

[4] H, K., Iv, Elminir, A. E., Ghitas, R. H., Hamid, F., El-Hussainy, M. M., & Beheary, K. M. (2006). Effect of dust on the transparent cover of solar collectors. Energy Convers. Manag, 47(18–19), 3192–3203. https://doi.org/10.1016/j.enconman.2006.02.014.

[5] Jiang, Y., Lu, L., Ferro, A. R., & Ahmadi, G. (2018). Analyzing wind cleaning process on the accumulated dust on solar photovoltaic (PV) modules on flat surfaces. Solar Energy (Phoenix, Ariz.), 159, 1031–1036. https://doi.org/10.1016/j.solener.2017.08.083

[6] Al Shehri A, Parrott B, Carrasco P, Al Saiari H, Taie I, “Accelerated testbed for studying the wear, optical and electrical characteristics of dry cleaned PV solar panels,” Solar Energy, vol. 146, pp. 8–16, 2017. https://doi.org/10.1016/j.solener.2017.02.014

[7] M. Arrubla Irigoyen. (2020) Estado del arte del ensuciamiento y la abrasión asociada a los procedimientos de limpieza en la tecnología fotovoltaica, Pamplona [Tesis de Maestría, Universidad Pública de Navarra] https://academicae.unavarra.es/xmlui/bitstream/handle/2454/38670/ARRUBLA_IRIGOYEN_TFM.pdf?sequence=1&isAllowed=y

[8] N. A. Castillo Campos (2021) Estimación de frecuencia de ciclos de limpieza de módulos solares instalados en la laguna, Torreón, Coah. [Tesis de Ingeniería inédita, TecNM Campus Laguna]