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Effect of coloring covers on the electrical parameters of a photovoltaic module

Efecto de cubiertas colorantes sobre los parámetros eléctricos de un módulo fotovoltaico

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Abstract

The efficiency of a photovoltaic module can be affected by different factors, including irradiance and temperature, so the environmental conditions to which it is subjected have a great impact on photovoltaic generation. The present work deals with the analysis of the electrical parameters of a photovoltaic module when it is exposed to the elements and the cells are covered with a layer of plastic material, in this case cellophane, characterized by being thin and having some transparency. The analysis was carried out with pink, red, orange, yellow, lemon green or light green, green, blue and purple cellophane. In addition, a nano-ceramic gray coating to polarize crystals was added to the tests. This with the purpose of observing if a coating is capable of filtering light for the convenience of the module's operation, improving its performance. The results obtained show that the pink coating is the one that has the least impact on the parameters, while the nano-ceramic gray film has the greatest impact.

Photovoltaic energy, Transmittance, Coating, Parameters

Resumen

La eficiencia de un módulo fotovoltaico puede verse afectada por distintos fatores, entre ellos la irradiancia, y la temperatura, por lo que las condiciones ambientales a las que este se someta son de gran impacto en la generación fotovoltaica. El presente trabajo trata del análisis de los parámetros eléctricos de un módulo fotovoltaico cuando este se expone a la intemperie y se recubren las celdas con una capa de material plástico, en este caso celofán, caracterizado por ser delgado y poseer cierta transparencia. El análisis se llevo a cabo con celofán de color rosa, rojo, naranja, amarillo, verde limón o verde claro, verde, azul y morado. Además, a las pruebas se añadió un recubrimiento nano-cerámico para polarizar cristales de color gris. Esto con el propósito de observar si un recubrimiento es capaz de filtrar la luz a conveniencia del funcionamiento del módulo, mejorando su rendimiento. Los resultados obtenidos muestran que el recubrimiento de color rosa es el que menos impacta en los parámetros mientras que la película gris nano-cerámica es la que mayor impacta.

Energía fotovoltaica, Transmitancia, Recubrimiento, Parámetros

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1 Introduction

One of the most important and widely used renewable energy sources is solar energy, harnessed in solar thermal and photovoltaic systems, which has been improving over time (Hassan *et al*., 2022). The operation of photovoltaic technology is based on the photoelectric effect, which refers to the emission of electrons when light strikes a surface. Understanding light as a particle, when it is directed towards the surface of a material, such as a conductor, there is a collision between the light particle and the atoms that make up the material. In order for an electron to escape from the material, the electron must first absorb sufficient energy from the incident radiation during the collision to overcome the attraction of the positive ions of the surface material that produces a potential energy barrier, which keeps the electrons inside the material (Bawazeer *et al*., 2023). The interaction caused by a photon is illustrated in Figure 1.

Thus, if two conducting electrodes, an anode and a cathode, and a voltage source, such as a battery, are connected, the light hitting the surface of the cathode causes emission of negatively charged electrons, which, by their nature, are pushed towards the anode. The flow of electrons is the photocurrent and this varies as a function of voltage, frequency and light intensity (Sears *et al*., 2009).

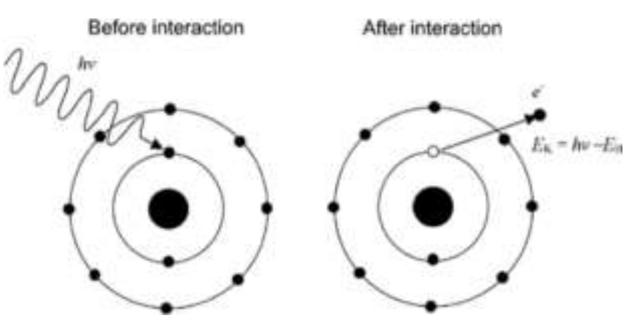

Figure 1 Representative schematic of the photoelectric effect, Bawazeer *et al*, 202

Approximately, standard solar cells use only half of the solar spectrum, where infrared rays do not contribute to electrical generation. That is, photovoltaic generation requires radiation with wavelengths ranging from 200 to 800 nm, which comprise the visible spectrum (ranging from 400 to 780 nm) and a small part of the UV spectrum, as shown in Figure 2. (Elsarrag *et al*., 2015).

	Wavelength	Spectrum	%
Photovoltaic	~200–800 nm	UV & visible light	58
Thermoelectric	~800–3000 nm	IR	42

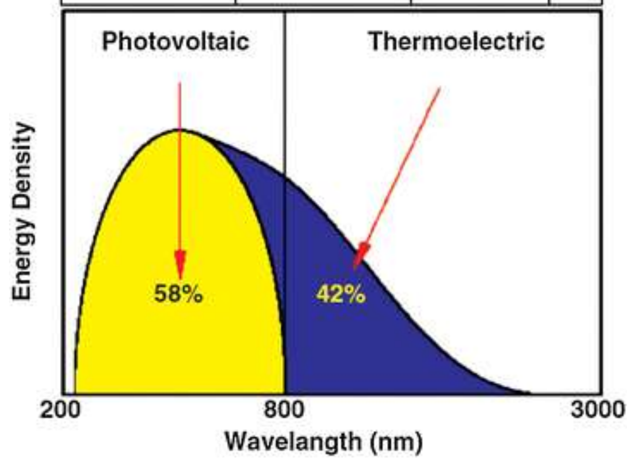

Figure 2 Utilization of the solar spectrum by solar systems, Elsarrag *et al*, 2015

For the maximum utilization of photovoltaic technology, it is sought that the module works at the maximum power point, referred to the net power that the module generates (Shang and Col., 2018).

However, it is difficult for the module to work at its maximum capacity due to different factors, among which are the environment, maintenance, installation and its operation (Shaik and Lingala, 2023). The generation of the module depends mainly on the amount of irradiance it receives, i.e., the transmittance of the module surface, defined by Paudyal *et al*. (2017) as the degree of solar radiation passing through a surface (in this case, the module encapsulation which is usually made of plastic or glass). Dirt or shading, are factors that reduce transmittance, thus causing the module performance to drop.

On the other hand, heating of the modules causes the energy band to decrease, also decreasing the power output (Shaik and Lingala, 2023). To determine the net power generated by a module, manufacturers use standard test conditions in their laboratories that are commonly 1000 W/m^2 and 25 °C, conditions that are impossible to find anywhere on the planet, so once the modules are exposed to the elements they will generate less power than indicated by the supplier due to heating and irradiance interruption (Hassan *et al*., 2022).

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To address these issues, solar panels should be installed taking into account location, panel orientation in the azimuthal plane, tilt, environmental conditions, and the efficiency of the technology used (Danner and Meer, 2021). Regarding the heating of the panel, different cooling systems are studied such as, ventilation, thermal collectors placed on the back of the panel to jointly produce thermal energy, water spray cooling on both sides of the panel, and geothermal cooling for air conditioning (Jakhar, 2016). Another method studied by Mohamed (2022), is a nano-ceramic coating installed on a module to reduce infrared transmission. Mohamed compared this method with water spraying and found that while water spraying improves the performance of the module, the nano-ceramic film reduces it.

On the other hand, Sudhakar *et al*. (2013), studied the effects on the performance of photovoltaic modules using different colored coatings, to filter the light, since the color of the light depends on the wavelength, taking into account that sunlight is white when including the wavelengths of the visible spectrum. He used purple, blue, green, yellow, orange and red films and observed that the red color generated more electricity than the other colors where "Contrary to popular belief, longer wavelengths of visible light, those with less photon energy, are more efficient in photovoltaic cells than shorter, more energetic wavelengths".

The colors that make up the visible light spectrum are; violet (390 - 455 nm), blue (455 - 495 nm), green (495 - 575 nm), yellow (575 - 595 nm), orange (595 - 625 nm) and red (625 - 780 nm), therefore, these wavelengths are exploitable for photovoltaic technology (Sudhakar *et al*., 2013).

The present work is divided into 4 chapters. The first chapter introduces the topic with the theoretical concepts relevant to the study conducted. Then, Chapter 2 explains the materials and procedures used in the analysis performed, specifying the technique used for taking measurements. In the third chapter, the results are discussed, where the performance of the PV module without any cover is compared against the performance of the module using different color covers. Finally, Chapter 4 contains the inferences drawn from the evaluation of the module performance according to the roof colors that stood out for their effects.

2 Methodology

The development of this experiment was carried out using eight different colors of cellophane film including; pink, red, orange, yellow, lemon green or light green, green, blue and purple. And a nano-ceramic polarizing film for car and windows color gray. Table 1 shows the characteristics described by the supplier about the nano-ceramic film.

Brand	Alaska
Model	Ceramic Film IR 7090
Description	Nano Ceramic Smart Film IR 90% and UV 99% Blocking
Benefits	– Protection against solar radiation – Reduces air conditioning consumption – Drastically reduces the heat sensation on the skin. – Does not alter the visibility and luminosity of its crystals. – Reduction of harmful UV rays by 99%. – Reduction of IR rays, which cause most of the heat, by 90%. – Greater protection of clothing and furnishings
Width	75 cm
Thickness	1.5 mm
Transmission	96% visible light
Rejection	86% of heat and 99% of UV light

Table 1 Characteristics of IR 7090 nano-ceramic film *(https://articulo.mercadolibre.com.mx/MLM-921249021-pelicula-inteligente-nanoceramica-proteccion-de-calor-90-ir-_JM#position=3&search_layout=grid&type=item&tracking_id=4d612f9a-6fe7-480f-96b3-91d4a1b176d4).*

The equipment required for the measurements was a hand-held pyranometer, an infrared thermometer, a multimeter for solar panels and photovoltaic modules JAM72S10 410/MR 410 W. The two previously cleaned modules were placed in a sunny place without shade and then covered one of the PV modules with cellophane paper of each color, leaving both modules exposed to the elements for 10 minutes between each color change, to observe the changes in cell temperature. The modules were placed at the same inclination and with the same orientation side by side. After this time, measurements were taken, such as electrical parameters, cell temperature, ambient temperature and irradiance taken from different points. Figures 3 and 4 show the cellophanes placed in the module.

Figure 3 Purple, green, orange and red cellophanes, installed in the MFV
Own Elaboration

Measurements were taken on both panels simultaneously to analyze how their efficiency increased or decreased with each color used, compared to the module that had nothing interfering with its operation.

Figure 4 Blue, pink, yellow and lime green cellophanes installed in the VFM
Own Elaboration

The irradiance was taken from three different points, below the cellophane, in front of the VFM and the direct irradiance, parallel to the surface of the module as shown in Figure 5. This was done to obtain the tone coefficient or transmittance of each cellophane used, as well as the degree of light reflection received by each color.

Figure 5 Irradiance measurement
Own Elaboration

As for the nano-ceramic film, it was necessary to measure and cut it to fit the size of the module (1 m x 2 m), this is shown in figure 6.

Figure 6 Installation of nono-ceramic film in photovoltaic module
Own Elaboration

Finally, measurements were performed following the above procedure for each cellophane. The tests were carried out for 5 days, with a series of measurements for each color per day and the results were averaged.

3. Results

The results of this study are composed of; the hue coefficients, light reflection with and without coating, temperature and electrical power generation, obtained from the measurements taken of the module with and without cellophane. The average of the results of each coefficient per color is shown in Table 2.

Coefficients					
Color	Tone	Reflection		P (W)	T (°C)
		With cellophane	Without cellophane		
Pink	0.72	0.13	0.08	0.80	0.93
Red	0.80	0.14	0.10	0.72	0.93
Orange	0.75	0.16	0.09	0.70	0.93
Yellow	0.82	0.13	0.08	0.82	0.95
Lemon green	0.81	0.12	0.09	0.79	0.92
green	0.66	0.11	0.09	0.64	0.92
Blue	0.64	0.13	0.10	0.66	0.95
Purple	0.65	0.13	0.09	0.61	0.90
Polarized	0.55	0.21	0.11	0.58	0.95

Table 2 Coefficients obtained between the module with and without coverage
Own Elaboration

It can be observed from Table 2 that in general, light colors have higher transmittance, while dark colors intervene more in the passage of light, as expected. It was also observed that the reflection of the surface of the module with cellophane is always greater than the reflection of the surface of the module without it.

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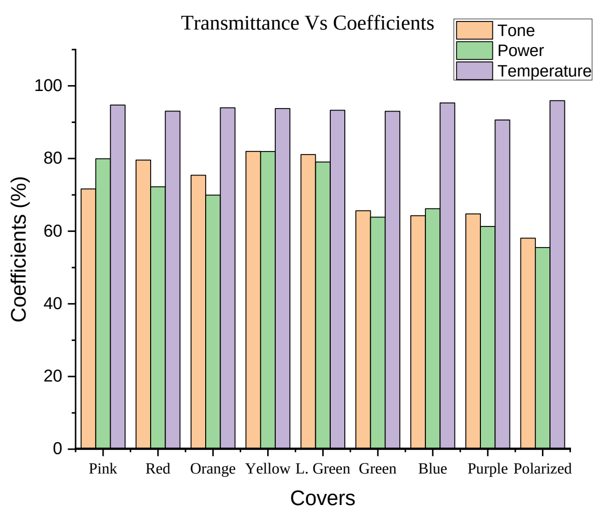
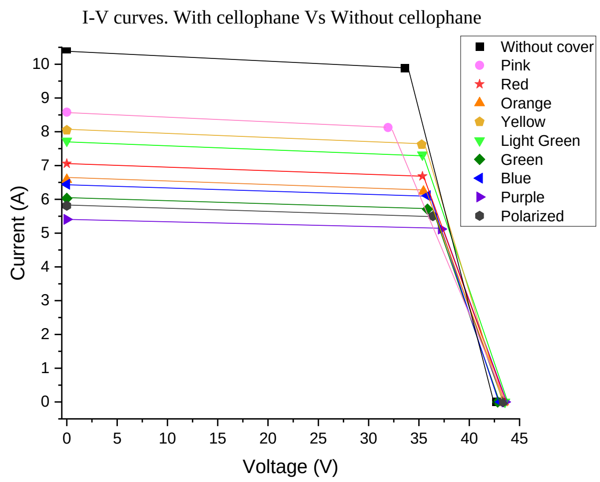
This means that the light that could be absorbed by the module is affected by the covers due to the part that is reflected since it is not completely transmitted. Also from table 2 it was found that the most reflective coating corresponds to the nano-ceramic polarized coating. All this analysis indicates that the photovoltaic power generation is affected in different amounts depending on the color of the coating. Regarding the cell temperature, it was observed that it is affected by any color coating, in which the green cellophane presented the lowest temperature coefficient.

Graph 1 shows graphically the relationship between the transmittance of each color as a function of; the tone coefficient, the photogenerated power, and the cell temperature. By making a visual comparison of each coefficient it is possible to observe that colors with higher transmittance have the highest power generation, while darker colors show lower cell temperature coefficients. In this analysis, the exception corresponds to the nano-ceramic film, which presented the highest cell temperature.



Graph 1 Transmittance Vs tone coefficient, power and cell temperatura
Own Elaboration in OriginLab.

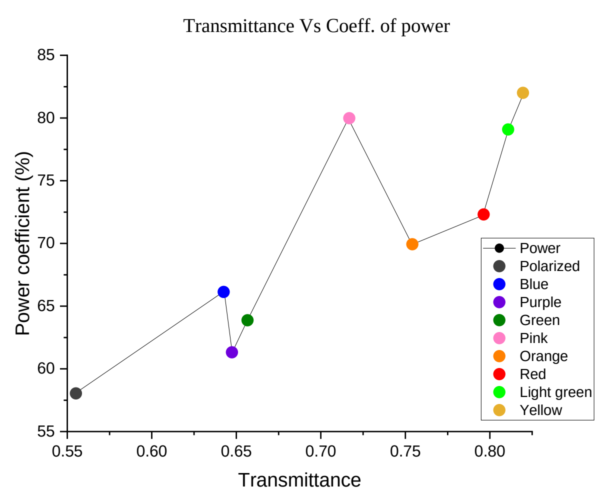
Graph 2 contains the I-V curves of the photovoltaic module covered by each color of cellophane, making the comparison with the results of the I-V curve without cellophane.



Graph 2 I-V curves of the module with cellophane and the module without cellophane
Own Elaboration in OriginLab

From graph 2, it is remarkable the decrease in the maximum power generation, which may well be due to the irradiance obstruction. The colors with the lowest maximum power drop are pink, yellow and lime green, respectively, while the colors purple, nano-ceramic polarized and green are the ones that decrease the electrical power to almost half of the generation of the module operating without cellophane.

The coefficient of photogenerated power for each cellophane color was also plotted as a function of transmittance and can be seen in graph 3. In this graph it can be seen that the relationship between power and transmittance is increasing, that is, the higher the transmittance, the higher the photogenerated power. From this result, it is worth noting the behavior of the power of the module with the pink cellophane, which shows a photogenerated power almost as high as that of the yellow color, where the latter has the highest transmittance.



Graph 3 Transmittance Vs power coefficient
Own Elaboration in OriginLab

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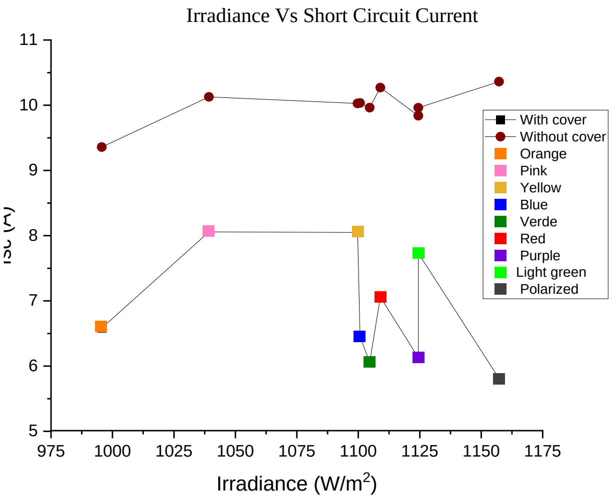
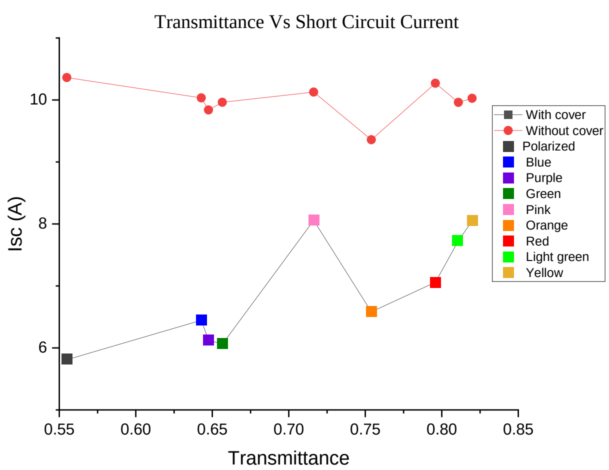
Graph 4 shows the average incident irradiance measured for each color of cellophane as a function of the short-circuit current of the photovoltaic module, results that were also compared without the use of cellophane in each case.



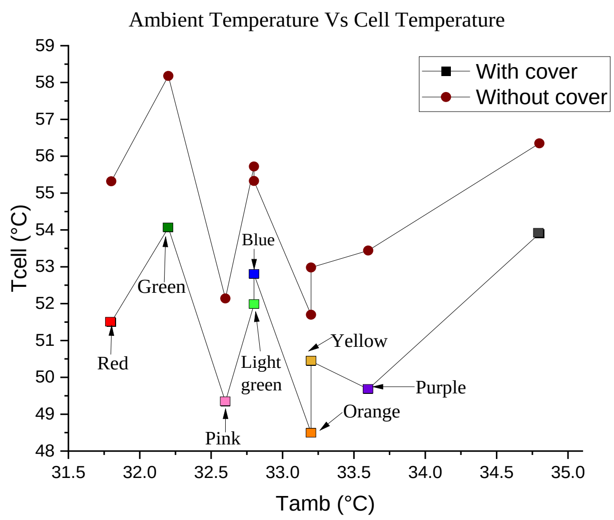
Graph 4 Irradiance Vs short circuit current with and without cellophane
Own Elaboration in OriginLab

From graph 4, in general, it is observed that the curve obtained from the module without cover shows higher short circuit current, which indicates that all the cellophanes contribute in some way to the reflection of the radiation that could be absorbed in the module. On the other hand, among the different cellophanes, it is observed that the dark shades provide the lowest currents, indicating that they are the most reflective, in which the nano-ceramic film registers the lowest short-circuit current.



Graph 5 Transmittance Vs short-circuit current with and without cellophane
Own Elaboration in OriginLab

In order to give an idea of the portion of radiation transmission to the module for each color, graph 5 shows the transmittance of each cellophane used against the short circuit current, compared to the short circuit current measured without the intervention of the covers. From graph 5 it can be inferred that a lower pitch coefficient is equivalent to a lower short circuit current and vice versa. In this case, as in the case analyzed in graph 4, it is also observed that the current generation is affected to a lesser extent by the use of pink, yellow and light green cellophanes, compared to the current photogenerated by the module without cover, while the nano-ceramic polarized, blue, green and purple cellophanes, affect in a greater manner. To understand the effects of the colored coatings on the cell temperature of the module, Figure 6 plots the ambient temperature against the cell temperature of the module with and without cellophane.



Graph 6 Ambient Temperature Vs Cell Temperature
Own Elaboration in OriginLab

Analyzing graph 6, it is clear that the use of a cover in all cases decreases the cell temperature due to the part of the radiation that is reflected. In the case of cellophane, the more reflective colors such as orange, red and pink, present a greater difference between the cell temperature with and without cellophane despite being at the same environmental conditions. While in the case of the nano-ceramic film, in spite of having the highest degree of reflection, the difference between the cell temperature without coating and that of the module using the coating is minimal, this may be due to the fact that, it is dark gray and haves a low tone coefficient, it absorbs more infrared radiation.

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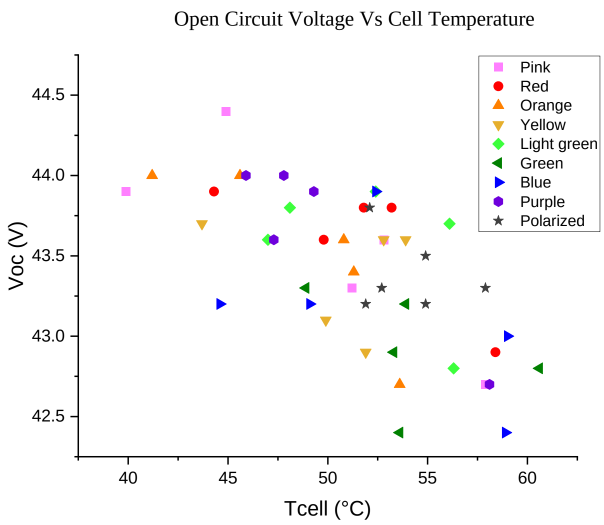
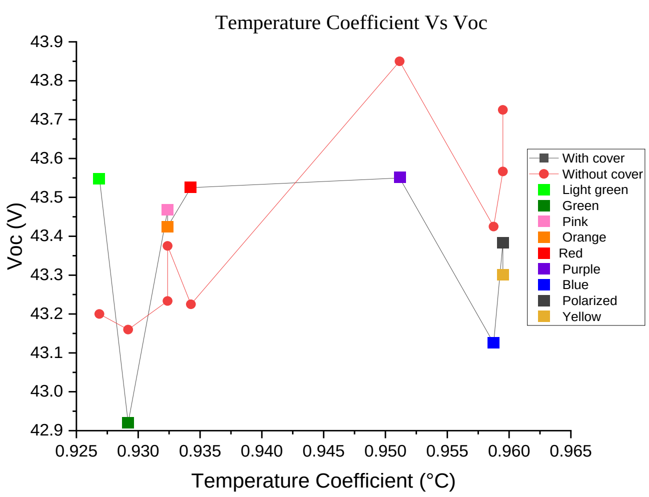
It should be noted that this result does not agree with the description given by the supplier (Table 2), since it indicates that the film is capable of reflecting up to 86% of infrared radiation. Figure 7 is a scatter plot of cell temperature versus open circuit voltage measured during the 5-day test.



Graph 7 Open circuit voltage Vs Cell temperatura
Own Elaboration in OriginLab

Through graph 7 it is verified that the open circuit voltage is inversely proportional to the cell temperature, so that the higher the cell temperature, the lower the open circuit voltage and vice versa.

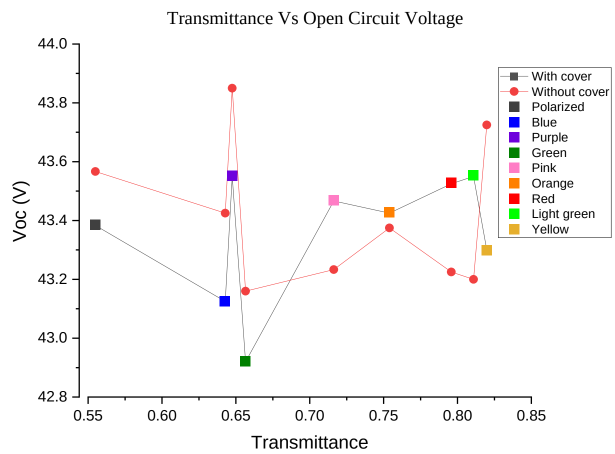
Taking this into account, graph 8 shows the curves generated for the module with cover and the module without cover according to the temperature coefficient of each shade and the average open circuit voltage obtained.



Graph 8 Open Circuit Voltage Vs Temperature Coefficient
Own Elaboration in OriginLab

From graph 8 it is observed that some of the colors such as lime green, pink, orange and red, with lower cell temperature coefficients, tend to generate higher open circuit voltage than the module without cover, on the other hand, the covers with higher temperature coefficient, which are the covers in which the cell temperature is almost not reduced, the open circuit voltage tends to be lower than that of the module without cover.

These results coincide if the transmittance of each sheath is analyzed against the generated circuit voltage. This analysis is shown in Figure 9.



Graph 9 Open circuit voltage Vs Transmittance
Own Elaboration in OriginLab

Then, from graph 9 it can be understood that coatings with higher transmittance tend to generate higher open circuit voltage. This reflects that although in all cases using colored coatings, the cell temperature decreases, not in all cases, the decrease in cell temperature found between the module with and without coating is sufficient to show an elevation in voltage generation.

The placement of coatings on the surface of the PV module ultimately affects the electrical parameters of the module, and the color of the coating has an influence due to the transmittance of sunlight it allows to pass into the module. Thus, higher coating transmittance tends to have less effect on short-circuit current generation, open circuit voltage, and, therefore, photo power generation. However, no coating is able to improve the net electrical power generation of the module tested.

In spite of this, the coatings do contribute to the decrease of the cell temperature due to the light reflection they cause, but only in the shades that present higher transmittance, there will be an increase of the open circuit voltage, that is, light colors, dark colors will tend to present lower open circuit voltage in spite of having lower cell temperature than the module without coating.

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4. Conclusions

In this work, an investigation was carried out on the impact that coloring films have on the electrical parameters and cell temperature of a photovoltaic module. The analysis showed that the color that least affected the performance of the module was pink, with a transmittance of 72%, surface reflection of 13% and electrical power generation of 80%, since in all the comparisons analyzed it was presented in the points closest to the electrical parameters of the module without a cover, this may be because it is one of the colors with the longest wavelength, like red, but with greater transmittance than this.

In terms of power coefficient, as well as short circuit current generation, the yellow color was the best, being the lightest color with a transmittance of 82%.

On the other hand, the light green cellophane with a transmittance of 81% was the most efficient in terms of cell temperature decrease and open circuit voltage increase.

Likewise, the coating with which the module had the worst performance was the nano-ceramic film, with a transmittance of 55%, surface reflection of 21% and power generation of 58%, in addition to having the lowest cell temperature reduction, with a coefficient of 95%.

This means that this type of film used to reduce the temperature inside automobiles does not represent a viable option to reduce the temperature of photovoltaic cells despite the characteristics described by the supplier.

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