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Influence of ambient temperature in the city of Portoviejo, Ecuador on the energy performance of photovoltaic modules

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ABSTRACT

The research analyzes the influence of the average temperature on the performance of specific photovoltaic solar modules under the environmental conditions of the city of Portoviejo, province of Manabí, Ecuador. The research is carried out using the qualitative methodology. Its main objective is to determine the influence of temperature on the energy performance of photovoltaic modules under the region's environmental conditions. Two electrical diagrams with different configurations were designed, which were analyzed and simulated using the MATLAB Simulink software. The results obtained show the direct relationship between the electrical parameters of voltage, current intensity, and power with the temperature value on the surface of the modules. It is concluded that the modules generate a higher value of voltage, electric current intensity, and electric power at a lower temperature, regardless of the level of solar irradiation they receive.

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1. INTRODUCTION

Electric power is one of the necessary factors for the development of today's society. Having quality, economical, and ecological electrical energy is a current challenge for many countries since it can solve some of humanity's problems and the environment [1]. The expansion of renewable energy sources is a step forward in the sustainable use of available natural resources in different countries [2], [3]. Internationally, several programs have been established as tools to encourage countries to use the potential of renewable natural resources to diversify their energy matrix. We can highlight the World Atlas of Renewable Energies of the International Energy Agency [4] and the initiative of renewable energy resources of the assistance program for energy management [5].

The progress of science and technology is a necessary factor in the choice of technologies, not only because they modify the efficiency of new energy systems but also because they allow the exploitation of previously unavailable resources [6]. For example, the installation costs of solar photovoltaic systems (SSFs) for electrical power production approach the level of the costs of other power generation systems that feed into the grids, producing what is known as grid parity [7]. In Colombia, they have investigated schemes with self-generation of electricity from solar sources in territories with moderate electricity costs and high solar radiation, thus achieving reasonable energy prices [8]–[10].

In study [11], a comparative analysis between the topologies of power filters to achieve the stability of the electrical system and its respective quality of energy in generation networks with renewable energy sources is presented. Chen *et al.* [12] propose a coordination control strategy of superconducting magnetic energy storage (SMES), an active superconducting fault current limiter (SFCL), and distributed generation units through wireless network communications to improve the stability of a microgrid under fault conditions. In Ecuador, some research has been carried out to integrate distributed generation systems using renewable energy sources (RES) in the national electricity system. In study [13], the competitiveness of integrating small-scale power versus voltage (PV) in Quito, Ecuador, is evaluated. These PVs will be used for the self-consumption of residential and commercial users affiliated with the "Quito Electric Company," which is the entity that manages the energy requirements in the city. Saltos-Ridriguez *et al.* [14] propose a methodological framework for optimal distributed generation planning to improve resilience in power distribution systems against volcanic eruptions by focusing on the occurrence of lahar.

In Ecuador, the use of RES has become widespread since issues related to the protection of the environment, and the conservation of natural resources have begun to intervene in political strategies. In this sense, the Ecuadorian government implemented the zero fossil fuel initiative in the Galapagos Archipelago to promote photovoltaic projects in the Puerto Ayora and Baltra islands for the environmental preservation of the ecological preservation archipelago [15]. This research work aims to determine the influence of temperature on the energy performance of photovoltaic modules under the environmental conditions of the city of Portoviejo, in the province of Manabí, Ecuador.

2. MATERIALS AND METHODS

The research is carried out using the qualitative methodology organized in three phases. In the first phase, a literature review related to the results obtained on the influence of temperature on the performance of photovoltaic modules was carried out. Gok *et al.* [16] conducted, in Canobbio, Switzerland, a study on the effect of temperature on the performance of photovoltaic modules integrated into buildings. They installed two crystalline silicon (c-Si) modules, one glass/back sheet and one glass/glass, with two different mounting configurations (ventilated and insulated). The installation was monitored for more than four years, concluding that, according to the parameters of the current-voltage (I-V) curve, the decrease in the performance of the glass/back sheet module in isolated conditions was mainly due to loss in fill factor with increasing resistance. However, the short-circuit current gain (Isc) was the main parameter of the higher energy performance obtained in an isolated glass/glass module regime.

In study [17], the simulation and evaluation of the performance of the interaction between the thermal and electrical losses in the interconnections of the modules and the influence of the tabulation on the power and temperature of modules installed in Qatar and Germany are carried out, comparing the impact of energy and temperature losses under different levels of irradiation and ambient temperature. Chandra *et al.* [18] carry out a technical and economic evaluation to determine that temperature and natural wind cooling significantly affect the performance of the photovoltaic module.

In the second phase of the study, different simulations were carried out to analyze the influence of temperature on the performance of photovoltaic panels with different configurations. Several authors report the results of simulations on photovoltaic solar panels to evaluate temperature's effect on their performance. Maffezzoni *et al.* [19] state that accurate and efficient electrothermal simulations of a solar photovoltaic system can be performed using system simulation software. These authors used a multiphysics model of a hybrid solar panel, a solar concentrator, and a cooling interface with heat recovery capacity that allows for predicting the temperature profile and the cells, allowing to obtain the electrical I/V characteristic of the entire system module. In study [20], the MATLAB Simulink software is used to simulate the performance of a hybrid water system that uses photovoltaic solar panels and wind turbines and that works with the values of the climatic parameters measured over five years. Kumar *et al.* [21] describe the electrical PV output characteristics of photovoltaic systems under different shading conditions using MATLAB simulation, concluding that the output graph of the PV system is affected by shading from clouds, nearby buildings, and trees.

Ecuador's legal and constitutional framework in the electricity sector was analyzed in the third and last phase. The regulations and norms established on implementing photovoltaic systems and the environmental, economic, and social impacts. The study was carried out in the province of Manabí in Portoviejo, the head canton of the region. In addition, two electrical diagrams with different configurations were designed, which were analyzed and simulated using the MATLAB Simulink. Figure 1 shows the diagram of the circuit used in the first test, which comprises a photovoltaic solar cell. The temperature and exposure time values change in this simulation, but the irradiation values do not change.

Figure 2 shows the schematic of the circuit used in the second test. It is made up of a photovoltaic array of 18 modules (2 branches in parallel with nine modules connected in series in each branch). This connection diagram allows you to modify the temperature and irradiation values. It consists of different components, including a display to view the alphanumeric values, two constants to enter the irradiation and temperature values, and measurement devices. In addition, it has a mathematical operator that allows multiplication between the value of the current and the voltage to obtain the value of the electrical power.

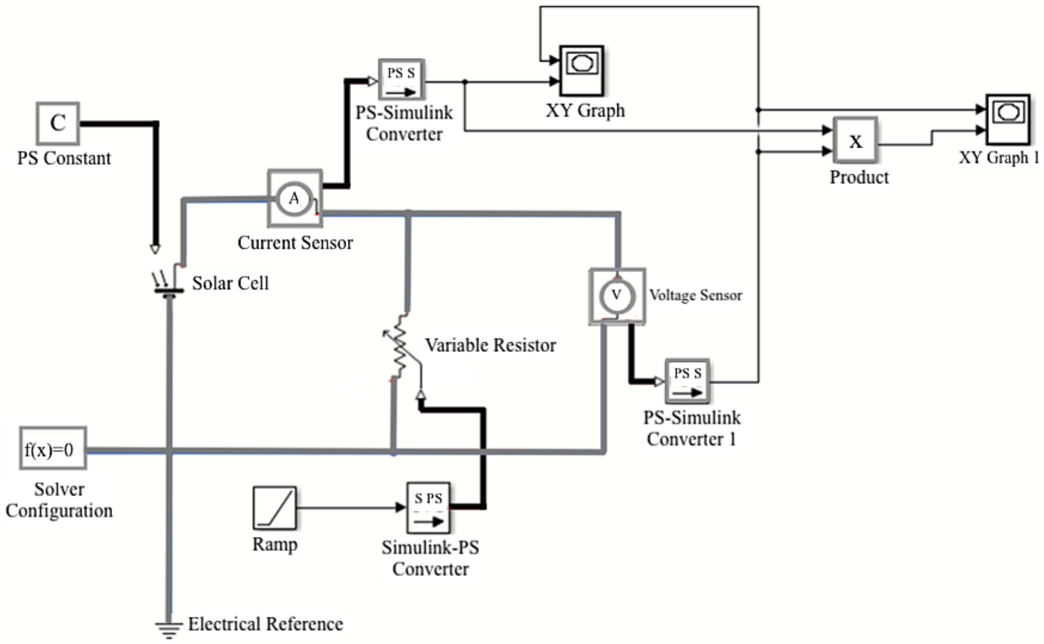

Figure 1. A circuit diagram made up of a photovoltaic solar cell

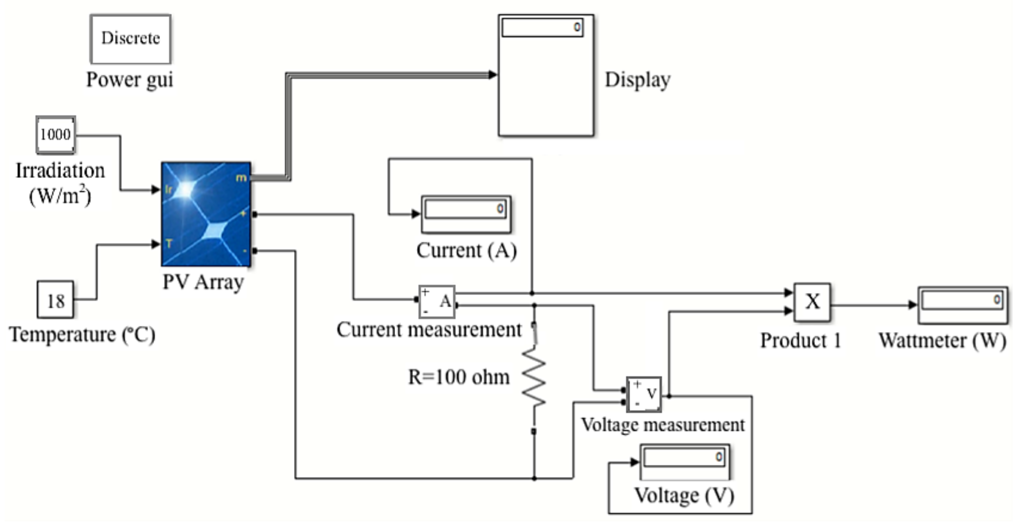

Figure 2. A photovoltaic array of 18 modules formed the circuit diagram used in the second test

Figures 3 to 5 show the results of the simulations that allow obtaining the values related to power losses and voltage drops that occur when the temperature value of the module increases. The temperature values used in the simulations ranged between 18 ºC and 32 ºC, while the irradiation values used in the study were 1,000 W/m², 3,000 W/m², and 4,845 W/m². These irradiation levels simulate three different atmospheric situations; a value of 1,000 W/m² corresponds to a very cloudy day; there is no direct incidence of sunlight on the modules or solar panels. The value of 3,000 W/m² corresponds to a partially cloudy day, and the value of 4,845 W/m² simulates a day with a clear sky where there is a direct incidence of the sun's rays on the modules. This last irradiation value corresponds to the average value in the city of Portoviejo [22].

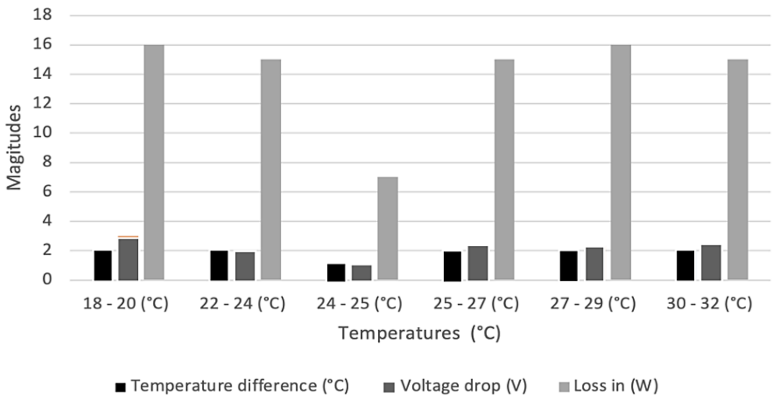

Figure 3. The behavior of the simulations carried out corresponding to the voltage drop, losses, and temperature difference at 1,000 W/m²

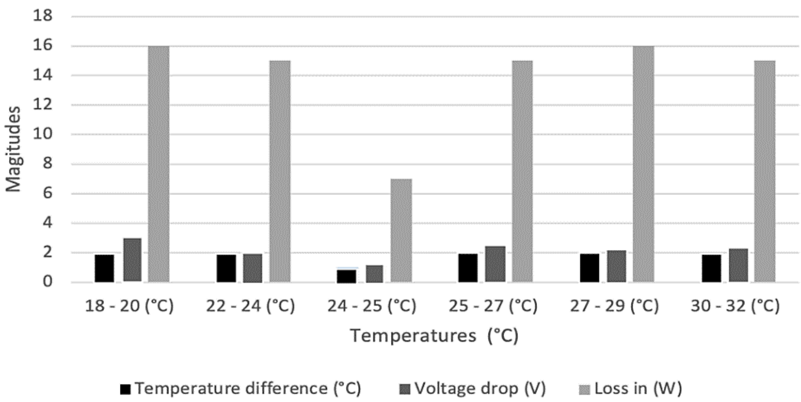

Figure 4. The behavior of the simulations carried out corresponding to the voltage drop, losses, and temperature difference at 3,000 W/m²

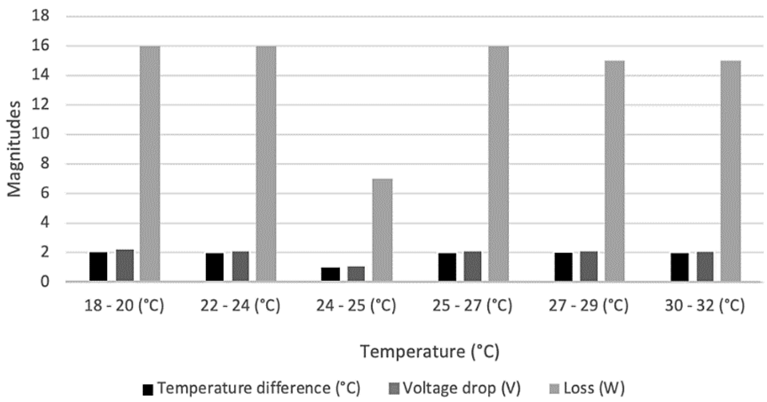

Figure 5. The behavior of the simulations carried out corresponding to the voltage drop, losses, and temperature difference at 4,845 W/m²

The behavior of the simulations shown in Figures 3 to 5 show that the temperature value at which the photovoltaic modules are found has a considerable influence on the efficiency and performance of the solar panel and, therefore, of the entire solar array photovoltaic. For example, suppose the temperature value of the modules goes from 24 to 25 ºC, regardless of the level of irradiation it has. In that case, the voltage drop is 1.1 V, and the average power loss reaches 7 W.

3. RESULTS AND DISCUSSION

In the analysis carried out, the relationships between the electrical parameters of voltage, current intensity, and power with respect to the temperature value that the photovoltaic modules had on their surface were also considered. Figure 6 shows the characteristic curve of the relationship between current and voltage with respect to temperature in the configuration of the photovoltaic solar array of the second test, observing that the change in temperature affects the voltage value more than the value of the current intensity. Figure 7 shows the characteristic curve of the relationship between electrical power and voltage with respect to the temperature level at which the surfaces of the photovoltaic modules are found, noting that when the temperature value increases, the values decrease power and voltage values.

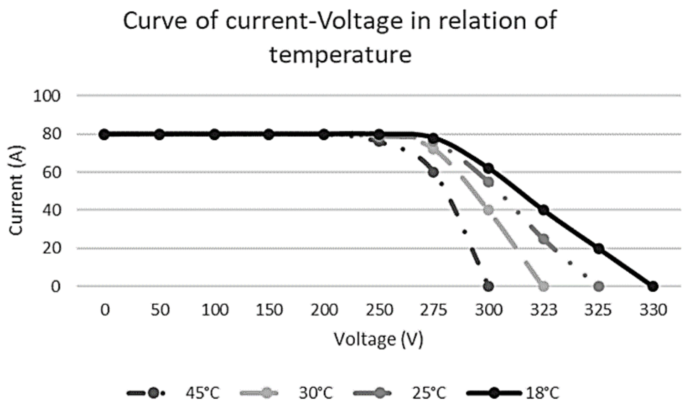

Figure 6. The characteristic curve of current and voltage with respect to temperature

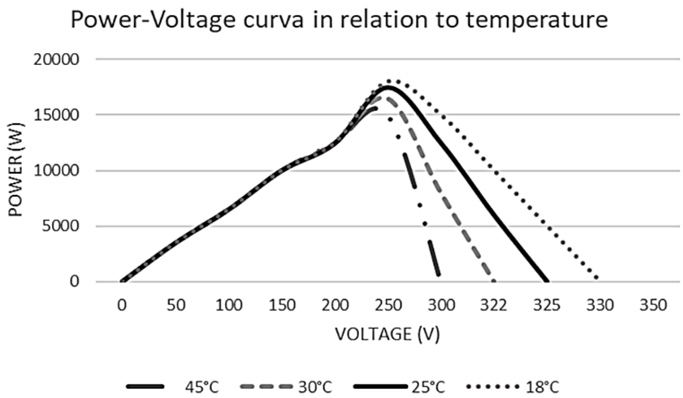

Figure 7. The characteristic curve of electrical power and voltage with respect to temperature

Figures 8 to 10 show the reduction reached by the electrical parameters of voltage, current intensity, and power when the temperature value on the surface of the modules increases. The curves represented in Figure 8 show the relationship between the voltage generated in the photovoltaic array and the value of the module temperature, showing that the modules generate more voltage, regardless of the level of solar irradiation. For example, at a temperature of 20 ºC and using the different irradiation levels defined in the study, voltage values exceeding 330 V are obtained. With irradiation of 1,000 W/m², a voltage level of 335 V is obtained, and with irradiation of 4,845 W/m², the voltage level reaches 357 V. However, at a temperature of 45 ºC, the modules generate less voltage since with irradiation of 1,000 W/m² a voltage value of 300 V is obtained and with 4,845 W/m² the voltage level reaches 322 V.

Figure 9 shows the relationship between the value of the current generated by the solar plant and the temperature of the modules, evidencing that at a lower temperature, the modules generate more power regardless of the level of solar irradiation to which it is subjected. For example, at a temperature of 18 ºC and using the different irradiation levels defined in the study, current intensity values that exceed 3.3 (A) are obtained. With irradiation of 1,000 W/m², the current intensity value that circulates at the solar plant's output is 3.32 (A), while with irradiation of 4,845 W/m², the current intensity reaches 3.53 (A). On the contrary, the solar plant delivers less electric current at a higher temperature. As the magnitude of the current intensity is directly proportional to the electrical power, the latter has the same behavior as shown in Figure 10.

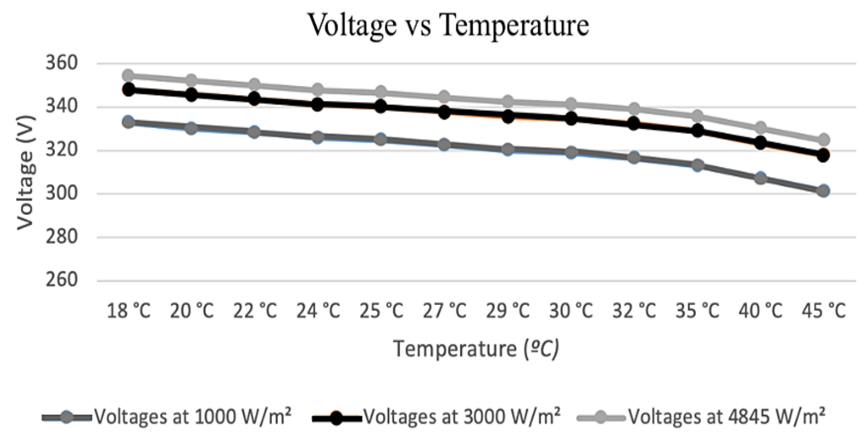

Figure 8. The behavior of voltage vs. temperature at different levels of irradiation

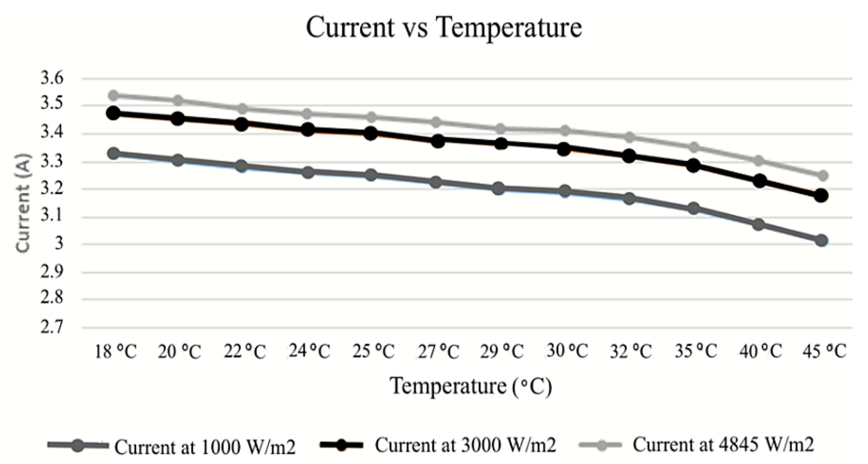

Figure 9. The behavior of current vs. temperature at different levels of irradiation

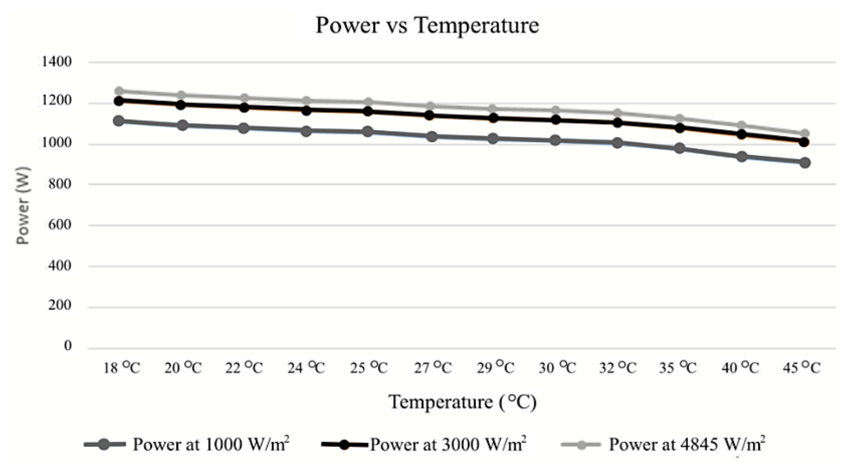

Figure 10. The behavior of power vs. temperature at different levels of irradiation

3.1. Analysis of current regulations

Ecuador was one of the first countries in Latin America and the Caribbean to promote, facilitate and promote projects involving the use of renewable sources of non-conventional energy through the implementation of different laws and regulations with economic and fiscal incentives [23]–[28]. As of 2012, to promote the use of other technologies with renewable energy sources such as biomass and wind power, photovoltaic solar systems were excluded from economic and tax incentives, so currently, the projects that are carried out using solar energy do not have such incentives [26], [27].

According to [29], Ecuador's energy matrix currently has 65% of total electricity generation using renewable energy sources and 35% using fossil fuels. The nominal power installed in the renewable energy plants amounts to 5,299.09 MW. Of this value, 96.22% corresponds to hydroelectric plants, an established power amounting to 5,098.75 MW. The use of biomass is 2.73%, 144.30 MW of electrical power, and photovoltaic plants contribute 27.63 MW, which is equivalent to 0.52%. In addition, wind energy provides a capacity of 21.15 MW, 0.40%, while biogas represents 0.14% with 7.26 MW of installed power.

According to Maldonado and Yanez [30], Ecuador is one of the few countries globally that recognizes nature as an entire entity, where the constitutional principle that must be developed within the legal system is generated. That is why the Ecuadorian constitution specifies that the electrical energy produced by photovoltaic solar systems is clean and renewable energy and contributes to mitigating environmental damage due to the frequent use of fossil fuels [31], [32]. The environmental impact of a photovoltaic plant is found in the extraction and transport of primary materials and the transformations and productions that arise from the manufacture of the modules and devices that make up the photovoltaic system.

In our study area, located in Portoviejo, the environmental impact is given by the imports of the panels, equipment, and accessories of the photovoltaic systems to be installed and the transfer to the region of location the same [33]. The province of Manabí is located in a humid and very hot climatic zone according to the zoning of the Ecuadorian Construction Standard (NEC) [34]. The incident solar radiation in Portoviejo guarantees that for each kWp of power installed in the photovoltaic system, about 36 MWh of electrical energy can be generated in the life cycle of said systems. In addition, in the city of Portoviejo, the estimated average commercial price is 0.08 US cents, and an approximate actual cost is 0.30 US cents per kWh generated [35].

4. CONCLUSION

As the city of Portoviejo is located in a humid and very hot climatic zone and in correspondence with the results of the simulations carried out, it can be affirmed that the photovoltaic systems installed in the region can be implemented with natural aeration. In addition, compliance with the established technical standards must be guaranteed to achieve an adequate installation of the modules, equipment, devices, and conductors that are part of the photovoltaic system to avoid overheating due to the circulation of the intensity of the current and the changes of temperature. On the other hand, the results obtained show that the solar radiation that affects the studied site is high, which causes the photovoltaic modules to heat up and thus decrease their efficiency. Finally, the study shows that high-temperature values directly influence the performance of photovoltaic modules, producing voltage drops and electrical power losses at the output of the photovoltaic system.

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