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# DESIGN OF A PHOTOVOLTAIC SOLAR SYSTEM TIED GRID FOR THE ECONOMY AND ADMINISTRATION BUILDING AT THE SURCOLOMBIANA UNIVERSITY

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**ABSTRACT**

In this document, the design of a photovoltaic solar energy installation was carried out in order to supply part of the electricity demand of the economy and administration building at the Surcolombiana University. Site choice and sizing was made based on available installable area. Subsequently, the generation projection was calculated by applying correction factors and meteorological data available at the Institute of Hydrology, Meteorology and Environmental Studies, comparing the generation with the demand of the economy's building according to the consumption obtained from the network operator. To simulate the behavior of the projected system, three specialized software packages were used: Prospect from Solargis, System Advisor Model from NREL, and PVsyst from PVsyst SA. Finally, the installation and maintenance costs of the system are established, and the investment return point is found.

**Keywords:** autogenerator, peak-sun hour, solar panel, unconventional source of energy.

## 1. INTRODUCTION

By means of solar rays, enough energy can be obtained to supply part of the energy demand of a place, an installable area the size of Spain would be enough to supply the daily energy demand of the entire planet [1].

The consumption of electrical energy in the world grows at a rate of 1.8% annually [2], and it is estimated that by 2030 it will be necessary to supply about 198,721.8 TWh with electrical energy from different sources; traditional energy sources that represent 90% of the world energy generation matrix [3], among which are oil, gas, coal, nuclear and hydro, these sources have an impact on the carbon footprint considerable.

Taking these figures into account, it is imperative to look for alternatives that allow meeting the increase in energy demand without incurring a high price per kWh. To provide a truly widespread primary energy source, solar energy must be captured, converted, and stored profitably [4], reducing carbon dioxide emissions.

The global capacity of solar energy has been increasing in recent years. Various factors have influenced the unstoppable increase in the use of photovoltaic solar energy; the decrease in costs, such as in the price of solar panels and the improvement in production techniques [5], in addition to the increase in investment and advances in technology have driven the development of many projects that impact the advancement of renewable energies.

Hence the idea of proposing a design for a photovoltaic solar energy installation that feeds part of the electricity demand of the Surcolombiana University, which is in line with the global trend to promote and encourage the consumption of renewable energy, and especially energy clean, such as solar or wind to contribute to the reduction of CO2 in the atmosphere [6]; the place chosen to carry out the project is the economy and administration building.

Globally, the use of solar energy has increased in recent years, this due in large part to the increased competitiveness of solar photovoltaic energy, along with increasing demand and increased awareness of an energy to alleviate pollution and carbon dioxide emissions. Currently there are some important projects in the country such as the Celsia solar farm [7], the solar installation of Electrohuila SA ESP at the Promisión building and control center building [8], Nutresa solar installation [9], among other projects that have been carried out in the country.

This project seeks to take the first step in the university towards the use of unconventional and environmentally friendly energies, the project proposes a design and simulation of the installation of a solar system that will generate savings in the university's energy bill.

## 2. MATERIALS AND METHODS

### 2.1 Choice of Place

In the first stage, the place chosen for the design of the photovoltaic solar system was located, this is the economy and administration building located at the headquarters of the Surcolombiana University, on Avenida Pastrana Borrero - Carrera 1, in the city of Neiva, Huila, Colombia. The coordinates of the economy and administration building of the Surcolombiana University are 2°56'41.2" N 75°18'01.0" W. Figure-1 shows the location of the place, obtained from Google Maps.

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**Figure-1.** Location of the economy and administration building.

Subsequently, in order to determine the maximum installable capacity in the network to which the project will be connected, availability is verified on the network operator's website. The transformer number and the account number are taken from the energy bill. The result is shown in Figure-2.

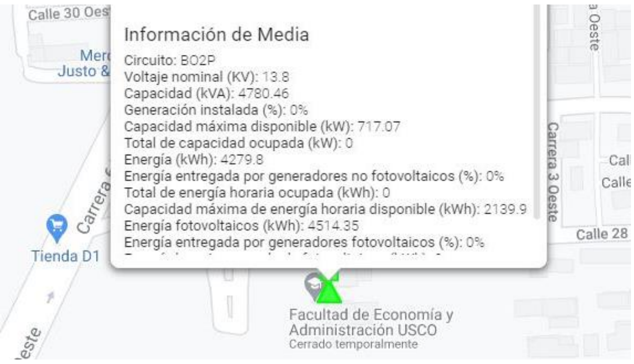


**Figure-2.** Availability information.

Because the T00093 transformer is particular since the transformer is a level 2 connection asset (its measurement and connection point are at this level), the limits of the system that is proposed to be installed will be limited to the average information as showed in the Figure-2, that is, the maximum available capacity in kW that can be installed is 717.07 kW.

## 2.2 System Sizing

For the sizing, the calculation of the generation and its losses due to panel degradation is carried out, this is calculated as follows.

According to the roof of the building shown in Figure-3, zone 1 and zone 2 are chosen for the assembly of the system, this is obtained from the architectural plans of the building [10].

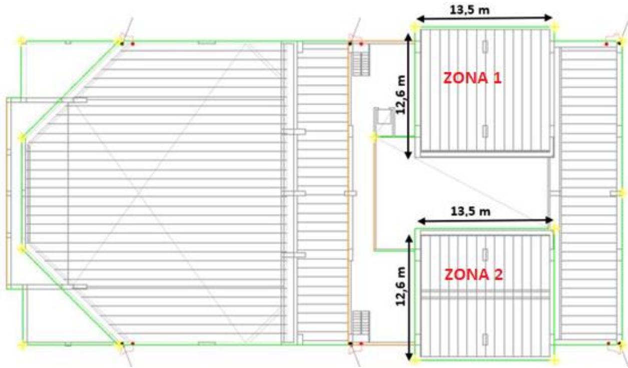


**Figure-3.** Areas to be used, top view.

Each chosen roof area is 13.5 meters long and 12.6 meters wide, 1 meter is cut on each side to leave an area for the transit of personnel at the time of inspection or maintenance of the panels. Then the effective area is 11.5m x 10.6 m, which gives 121.9 $m^2$ of useful area for installation.

Since the roof space is limited, the solar panel technology that offers the highest W/$m^2$ ratio will be used. For this reason, a monocrystalline technology panel is selected which, although it represents a greater investment, also has greater efficiency compared to other technologies, such as polycrystalline and amorphous panels. The most efficient monocrystalline commercial panel on the market at the time of the search for this project is the LG NeON2 LG340N1C-A5 with dimensions 1686 x 1016 x 40 mm, which gives an area of 1.71297 $m^2$ per panel. Given the dimensions of the panel to be used, it was determined to distribute the panels in 10 rows and 7 columns, the arrangement of the panels is shown in Figure-4.

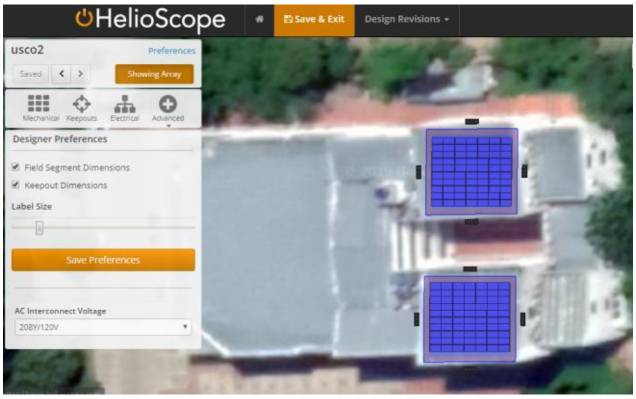


**Figure-4.** Roof panel distribution.

According to the chosen layout, 70 panels per zone can be installed in the calculated area, obtaining a power of 47.6 kW per zone calculated according to (1), and a total power of 95.2 kW according to (2).

$$P_{\text{zone}} = N_{\text{panels}} * P_{\text{panel}} \quad (1)$$

$$P_{\text{total}} = P_{\text{zone}} * 2 \quad (2)$$

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where $N_{\text{panels}}$ is the number of panels, and $P_{\text{panel}}$ is the power of each panel.

The database provided by Institute of Hydrology, Meteorology and Environmental Studies was used to extract the irradiation and Peak Sun-Hour (PSH) data at Neiva city, obtaining an average of 4.6 PSH. With this value the daily, monthly, and annual energy produced by the system is calculated from (3). An annual energy of 79.92 MWh is obtained.

$$Energy = PSH * P_{\text{panel}} * N_{\text{panels}} \quad (3)$$

The above calculation corresponds to the theoretical energy. To calculate the expected real energy, the performance ratio (PR) must be considered, which expresses the relationship between the real performance and the nominal performance of the photovoltaic installation [11]. In this way it indicates what proportion of the energy is available for the supply after having discounted the energy losses (for example, due to thermal losses and losses due to wiring) and the own consumption for the operation. The PR is defined as shown in (4).

$$PR = \frac{\text{Real performance in kWh per year}}{\text{Calculated performance in kWh per year}} \quad (4)$$

Because for the calculation of the PR it is necessary to have the value of the real generation and it is not possible to have this value, a reference PR of 86% will be taken. This value is taken according to the annual generation data of two real photovoltaic solar systems studied: the Promisión building solar system and the Electrohuila S.A. control center building. These share similar characteristics to the projected solar system, such as the same panel technology, the same inverter and a nearby location, approximately 1 km away, in this sense, the real energy is calculated according to (5), obtaining an annual energy of 68.73 MWh.

$$Energy_{\text{Real}} = 0.86 * Energy \quad (5)$$

Finally, the energy loss corrections due to panel degradation are made. Photovoltaic modules are manufactured for a useful life of 25 years, but year after year they suffer a progressive loss of performance, this due to prolonged exposure to the elements, this loss occurs at a rate of 0.5% per year according to the datasheet of the panel. In other words, the generation of the panel will decrease year after year at a rate of 0.5%, at the end of its useful life, the projected system will generate 1,619,104 kWh throughout its useful life.

To give a perspective of the current demand of the building of economy and administration and the production expected by the photovoltaic system, a series of graphs that describe its behavior are presented (Figure-5). The data for consumption in a specific year were obtained from the regional network operator Electrohuila SA (The data correspond to the electrical energy account number 1673839, account associated with the economy building, whose meter is remotely managed and with an hourly profile). While the generation projection was obtained by calculating the production of the proposed system, considering the monthly solar irradiation data, consulted on the website of Institute of Hydrology, Meteorology and Environmental Studies [12].

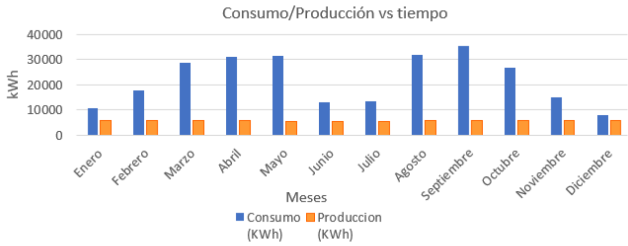


**Figure-5.** Consumption/Production vs time.

From Figure-5, the calculation of the monthly percentage of energy that the proposed plant is capable of supplying is made, this is shown in Table-1.

**Table-1.** Consumption vs Production.

| Month | Consumption (kWh) | Production (kWh) | Percentage |
|---|---|---|---|
| 1 | 10,638.28 | 5,956.19 | 56% |
| 2 | 17,885.14 | 5,771.98 | 32% |
| 3 | 28,881.70 | 5,649.17 | 20% |
| 4 | 31,081.70 | 5,673.73 | 18% |
| 5 | 31,556.46 | 5,587.76 | 18% |
| 6 | 13,091.23 | 5,587.76 | 43% |
| 7 | 13,586.30 | 5,526.36 | 41% |
| 8 | 32,093.33 | 5,710.57 | 18% |
| 9 | 35,469.10 | 5,894.78 | 17% |
| 10 | 26,724.79 | 5,894.78 | 22% |
| 11 | 15,029.38 | 5,649.17 | 38% |
| 12 | 8,067.98 | 5,649.17 | 70% |
| Average percentage in academic period | | | 24% |
| Average percentage in vacation period | | | 52.5% |
| Annual average percentage | | | 33% |

The proposed solar photovoltaic system was drawn in the Autocad design software (student version), given the size of the system, it is presented divided into two sections as shown in Figure-6 and Figure-7.

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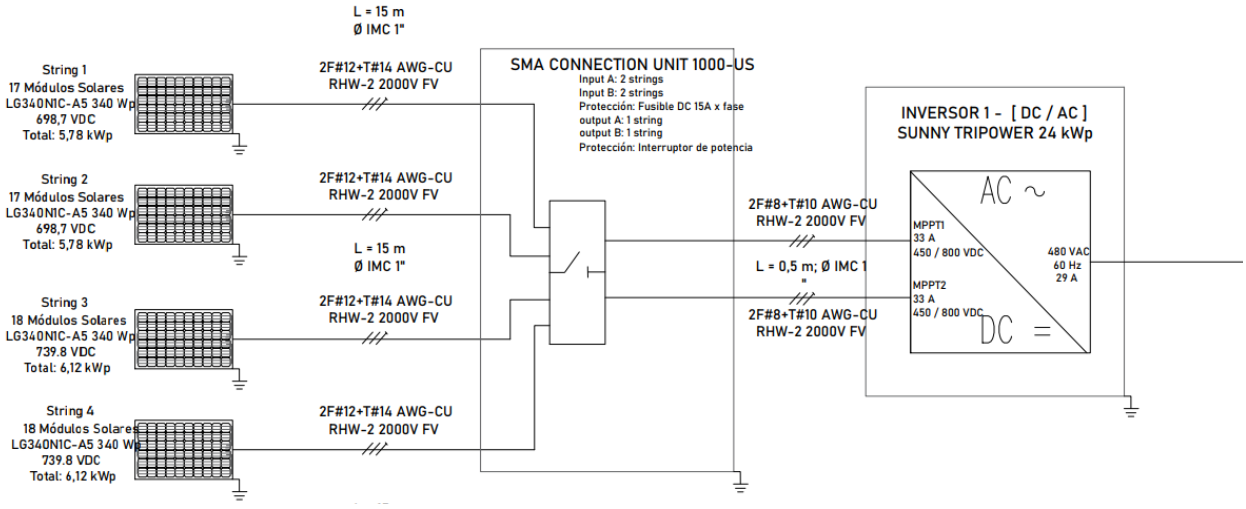


**Figure-6.** One-line diagram (section 1).

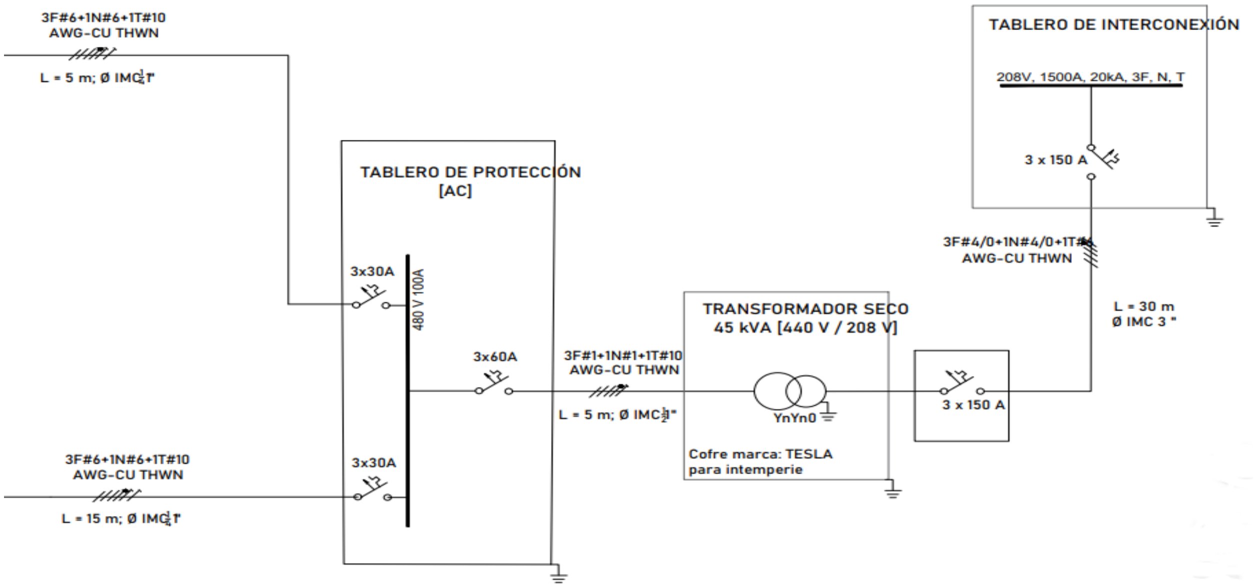


**Figure-7.** One-line diagram (section 2).

Since the two zones are identical, Figure-6 represents the two proposed zones. In each one of them the installation of 70 panels is projected, distributed in 2 strings of 17 panels and 2 strings of 18 panels, as shown in Figure-6. These are entered into the SMA CONNECTION UNIT 1000-US combination box, in groups of two strings of equal length, that is, two strings of 17 for input A, and two strings of 18 for input B. At the output of the unit as a result of the combination there will be two outputs each with a string, which are entered into the SUNNY TRIPOWER 24000 inverter to make the change from direct current to alternating current. This corresponds to each of the zones. The output of each inverter is entered into a busbar that will oversee combining the two systems as shown in Figure-7.

As a result of this combination, a 480V three-phase system will be obtained. Since the electrical network of the building to which the solar system is to be connected is at a voltage level of 208V, a power transformer is used to reduce the voltage to the desired level. Then a connection is diverted to the main electrical panel of the economy and administration building.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Simulation

To simulate the behavior of the projected photovoltaic solar system, three specialized software packages are used, Prospect from Solargis, System Advisor Model (SAM) from NREL and PVsyst from PVsyst SA. In each of the simulators, the characteristics that make up the solar system were entered, such as type and number of panels, inverter, transformer, and meteorological data, thus obtaining the condensed results in Table-2.

**Table-2.** Simulation results.

| Simulator | Generation (MWh) | Parameters entered | | | Limitations | Deviation from calculation (%) |
|---|---|---|---|---|---|---|
| | | Orientation | Modules | Inverter | | |
| SAM | 69.65 | Yes | Yes | Yes | It does not allow simulating more than one inverter with multiple MPPTs. | 1.59 |
| PVsyst | 73.60 | Yes | Yes | Yes | It does not allow to simulate strings of different sizes in the same area, the inverter used cannot be found in its database. | 7.34 |
| Prospect | 68.69 | Yes | No | No | It does not allow you to select the equipment to use. | 0.15 |

### 3.2 Emissions Calculation

In order to calculate how many tons of carbon dioxide would be ceased to emit with the implementation of the proposed solar system, (6) is used.

$$\mathrm{E}_{\mathrm{missions}} CO_2 = \mathrm{G}_{\mathrm{enerated}} \mathrm{E}_{\mathrm{nergy}} * \mathrm{E}_{\mathrm{mission}} \mathrm{F}_{\mathrm{actor}} \quad (6)$$

According to XM and in accordance with the data provided by the Ministry of Mines and Energy, and the mining-energy planning unit, the $CO_2$ emission factor for electricity generation is equal to 0.164 $kgCO_2/kWh$ [13]. In this sense, for 1,619,104 kWh that corresponds to the projected generation, a total of 265,533 $kgCO_2$ would cease to be emitted throughout the useful life of the solar system, or what is equal to 265,533 tons of $CO_2$.

### 3.3 Cost Calculation and Return on Investment

To know the value of the proposed solar system, the quotation was made with specialized companies that distribute this type of elements, among which there are panels, inverters, AC and DC protections, wiring, canalization, transformer, the structure that will support the panels, and connectors. To this were added the costs associated with RETIE certification, labor and operation and maintenance, for which it was obtained that the value of the projected solar system will be $226,907,182 COP.

With the value of the solar system over the total energy generated, the equivalent price of the kWh generated is calculated, this will be $140.14 COP. A projection was made of the price of kWh by the network operator in the next 25 years and the cost that would be incurred when consuming energy from the network operator versus the cost of energy by self-generation and it was obtained that after 6.37 years will recover the investment made in the project. At the end of its useful life, an energy saving of COP $1,965,222,261 is expected.

## 4. CONCLUSIONS

The area chosen for the installation of the solar system has optimal characteristics for its operation. Since the available installable area on the roof has better characteristics, compared to the other existing buildings in the university headquarters, such as roof size, ease of access and better incidence of solar radiation on the place, which includes possible obstacles between the sun and the surface with shadows throughout the day.

By dividing the installation into two zones or subsystems, greater reliability is obtained, since this allows the other subsystem to work normally in the event of a fault in one of the two zones. On the other hand, if maintenance is required, this can be carried out in a staggered manner per subsystem, which would allow to always keep at least half of the installation generating normally.

A photovoltaic solar system was designed to generate 68.56 MWh per year and 1,619,104 MWh throughout its useful life. The energy demand of the economy and administration building was also characterized, as a result, it was observed that for the academic period the projected solar system will contribute an average of 24% of the total demand of the building and 52.5% in the holiday period. Thus, the system contributes an average of 33% of the building's annual demand.

The performance of the solar system was simulated in three specialized software packages. The software that most closely approximated the calculated value is Prospect, with a deviation of only 0.15%. However, all three yielded values very close to the one calculated theoretically. According to experience, despite not giving the most accurate result, the System Advisor Model simulation tool turned out to be the one with the greatest versatility since it allows entering all the parameters of the calculated system, such as panels, inverter, and meteorological data of the place with the same reference of the proposed equipment.

The impact on the carbon footprint that the project would have throughout its useful life was calculated, obtaining a decrease of a total of 266,148.32 $kgCO_2$, or what is equal to 266.148 tons of $CO_2$. This provides a positive environmental impact, since by supplying part of the demand for the university building with photovoltaic solar energy, there would be no negative impacts associated with traditional energy generation. By not producing emissions of $CO_2$ and other polluting gases to the atmosphere that contribute to climate change, the greenhouse effect is reduced, there will be cleaner air that leads to a better quality of life for people.

The cost analysis associated with the installation was carried out. It was obtained that the total cost of the project in its useful life is $226 million COP, and the price of the kWh generated will have a value of $140.14 COP, this is much lower than the value of the current rate of the network operator, which is approximately $500 COP, without considering the increase of this in the next 25 years. With the values obtained, it was found that the investment will be recovered in 6.37 years, that is, there is an internal rate of return of 21.06%. At the end of the useful life of this project, a saving of $1,965,223,261 COP is expected for energy, this is around 9 times the initial investment.

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