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Design Of A Photovoltaic System For An Educational Institution On The Colombian Caribbean Coast

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Abstract: This article presents the design of a photovoltaic system in an Educational Institution on the Colombian Caribbean coast. The design is carried out with data obtained from sensors installed in the establishment, from which consumption values were obtained in different blocks of classrooms. A photovoltaic test panel was also installed, which, using a parallel circuit with a load and sensors, allowed to obtain values of voltages, current and power supplied from the said element, which were of great importance to have a reference of radiation obtained during the entire measurement period of the place. The system presented allows the generation of energy according to the environmental conditions and the requirements of the Institution.

Keywords: photovoltaic generation, solar system design, sustainable energy.

I. INTRODUCTION

A photovoltaic system is defined as the working set of parts and pieces that produce electrical energy from renewable energy, in this case, solar energy, and that can be used by any electrical device. The main characteristic of this type of project is sustainable development that fundamentally supports the integration of natural resources with clean technology, applying it to basic electricity consumption, such as homes, businesses, and schools.

The main benefit of implementing this project is that solar energy allows the building of the educational institution to generate its own electrical energy, store it or sell it by entering it into the traditional grid. Another important benefit is that the ecological culture is encouraged to students and citizens, promoting the use of sustainable and responsible energy with the environment, as well as the fact of updating the electricity network of the institution.

Background

Colombia is a very advantageous country geographically compared to others since it has large areas of land with great solar radiation, so it is not alien to the implementation of solar systems. The process of solar energy in Colombia is described in Table 1 taken from (Velasco Muñoz, 2019)

Table 1 Solar energy in Colombia

50s decade	Colombia joins the International Renewable Energy Agency (IRENA), which is a great commitment to implement clean energy production technologies.
60s decade	Santa Marta was the first place in the country where solar heaters were installed in the homes of banana workers. They still exist but are out of use.
80s decade	Solar heaters of Israeli origin were installed in some universities in Santander and Bogotá.
90s decade	In Medellín, Manizales, and some neighborhoods of Bogotá, the use of solar heaters were massively applied. It reaches the Atlantic Coast, which made it possible to regulate the use of solar heaters through ICONTEC.

The UPME (Mining and Energy Planning Unit from its Spanish initials) indicates "In Colombia, in addition to the widespread problems of increased consumption, with a rise in electricity prices that reach values close to 500 COP / kWh" (UPME, 2021). According to the UPME, there is a matrix dependent on hydroelectric plants, which have 69.18% of the total installed capacity.One of the places with the greatest use of electricity in the towns are schools, due to the constant use of elements in the daytime to reduce or increase the ambient temperature and also with lighting.In order to reduce the cost of electricity consumption and negative climatic factors, it is sought to implement a photovoltaic system that, based on a feasibility analysis and study of electricity consumption, meets the quality conditions based on the dimensioning of the power of the Educational Institution.

Conceptual framework

Photovoltaic solar technology consists of the direct conversion of solar radiation into electricity. This conversion is carried out through the solar cell, the basic unit in which the photovoltaic effect occurs (Velasco Muñoz, 2019). PV systems are designed around the photovoltaic cell, which is typically made of a semiconductor material such as silicon. Since a typical photovoltaic cell produces less than 5W at approximately 0.5 VDC, the cells must be connected in series-parallel configurations to produce enough power for high-power applications. These modules, depending on the intended power output, can have maximum power outputs ranging from a few watts to more than 400 W. Typical array output powers range from 100 watts to amounts in kilowatts. But photovoltaic arrays with power output in megawatts and gigawatts are becoming increasingly common (Photovoltaic Systems Engineering, 2017).

There are two types of PV systems, grid-connected and stand-alone. PV systems interconnected with the electricity grid can supply excess photovoltaic energy to the grid or use the grid as a backup in case of insufficient photovoltaic generation. These systems need to incorporate adequate interconnection circuits so that the PV system disconnects from the grid in case of grid failure (Gyorvari & Vokony, 2017).

Since photovoltaic arrays only produce energy when they are illuminated, there are also isolated PV systems, that use an energy storage mechanism so that it is available at a later time. Most commonly, the storage mechanism consists of rechargeable batteries, but it is also possible to employ more exotic storage mechanisms (Modi et al., 2021). When using a battery storage mechanism, it is also common to incorporate a charge controller into the system, to prevent the batteries from reaching an overcharge or over-discharge condition.

The functions of the inverter are DC / AC conversion, modulation of the output alternating wave, and regulation of the RMS value of the output voltage. These inverters are generally of the single-phase type with a frequency of 60 Hz and with different power ranges and nominal input and output voltages. Depending on the requirements of the load, there are several inverters available. Selecting the right inverter for a particular application depends on the load waveform requirements and the efficiency of the system. The selection of the inverter will also depend on whether the inverter will be part of a grid-connected system or an autonomous system (Arellanes et al., 2017).

II. METHODOLOGY

For the design of the photovoltaic system, in this case, connected to the conventional electrical grid, the steps described in Figure 1 were taken into account.

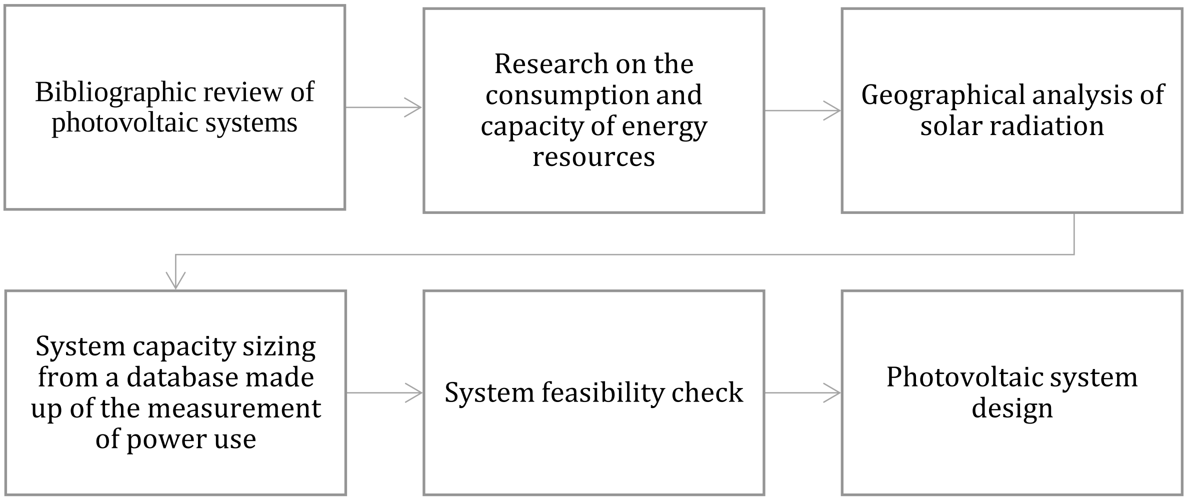


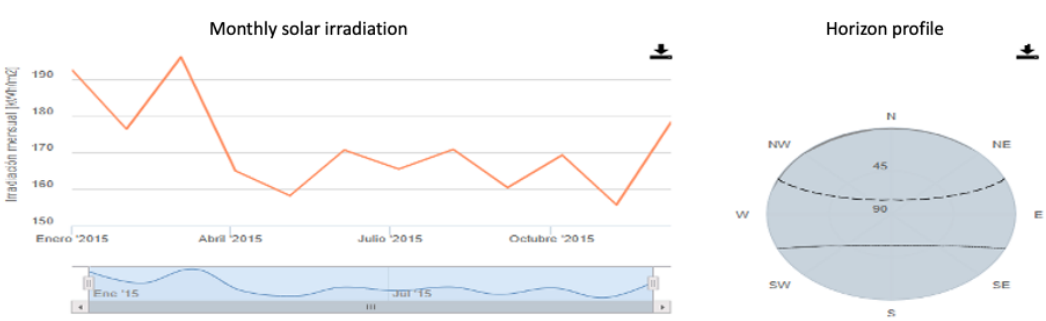
Figure 1 Design methodology

III. PROPOSED DESIGN

The design of the system initially included a bibliographic review and a field visit to the Educational Institution, in order to gather information and plan the design strategy. Below are the parameters of some of the phases described in the methodology.

Radiation analysis at the installation site

For the present analysis, the database that provides reliable data from the Photovoltaic Geographical Information System (PVGIS) web platform was taken into account. As a verification method, a parallel circuit made up of a photovoltaic panel, a load, and a circuit whose job was to measure the current and voltage supplied by the photovoltaic panel was implemented. The Educational Institution is located at latitude 9.316378 and longitude -75.284914, this is how the PVGIS platform is accessed, it allows monthly, daily and even hourly data studies to be carried out data through the solar radiation tool. Figure 2 shows the information for the months of the last year available on the platform and the daily data for the last three months of that year.



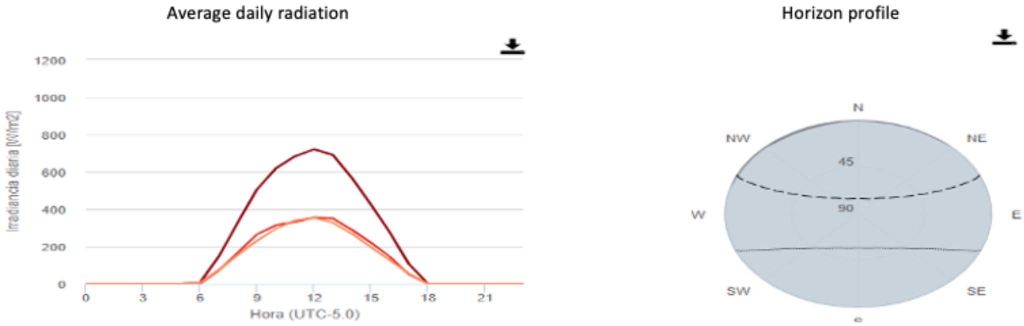


Figure 2 Solar radiation at the location of the Educational Institution

For the verification of the radiation obtained by the PVGIS platform, a measurement circuit was implemented consisting of a 200W polycrystalline photovoltaic module from the Powest brand, an open-source Arduino Uno microcontroller board, Arduino Shiel Ethernet W5100 module, Voltmeter composed of a voltage division circuit and a load which consists of a theoretical 3ohm resistance of 200watts. Figure 3 shows the values obtained with the equipment implemented in October 2019.

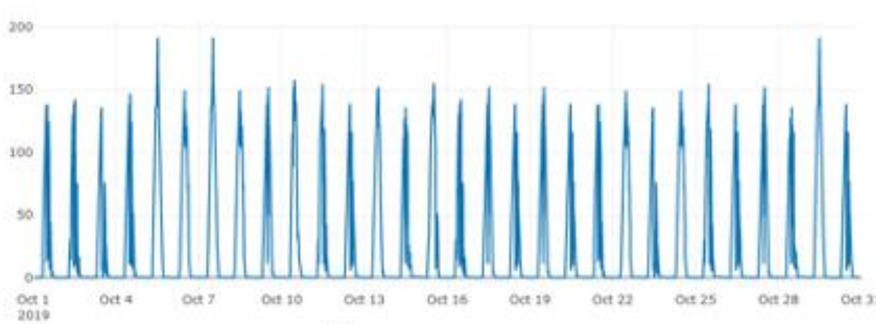


Figure 3 Power generated by the photovoltaic module during the month of October.

From the graphs obtained by the measurements of the photovoltaic module regarding the load, and the study of the data obtained from the database of the PVGIS platform, it can be seen that the place where the implementation of the photovoltaic system is to be carried out has a large source of solar radiation, which allows us to affirm that the system will generate a large amount of energy. The analysis allows determining the average Peak Solar Irradiance of 1000w / m2.

The next thing in the design that must be considered is the orientation and inclination that the photovoltaic modules must have so that they have the highest possible radiation collection. To give an optimal orientation to the modules, we use the cardinal points, which indicate that, from the East, the sun rises approximately, and that from its apparent movement, the sun sets in the west. Figure 4 shows the cardinal position of the sun according to the date in the Educational Institution.

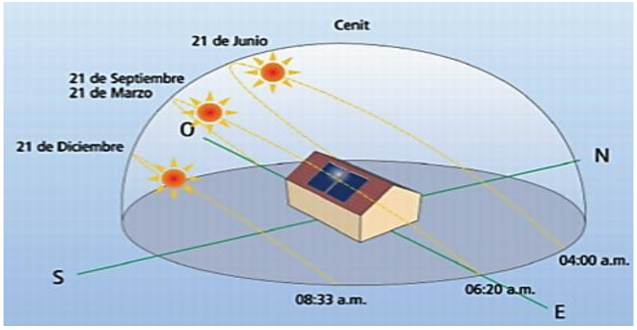


Figure 4 Cardinal position of the sun according to the date

With the help of a digital compass, the North, South, East, and West of the installation site were identified, another important step is to give it orientation in view towards the equatorial line, this is essential since, if our modules are oriented towards the east or to the west, we would only have a short radiation capture time. For a photovoltaic module to be able to take advantage of the greatest possible radiation, it is extremely important to give it an ideal inclination so that it can be exposed to solar radiation for as long as possible.

β= 3.5+ (0.69*Latitude of the place)

Where beta (β) is the optimal inclination for the photovoltaic module.

β= 3.5+ (0.69*9.316378)

β= 9.93°

β= 10°.

Which results in an angle of 10 °. For reasons of reducing dirt or retention of material that can reduce the performance of the modules, a 15 ° angle of inclination is chosen.

Analysis of the installation point and interconnection of the place

When studying the interconnection between the generating plant and the establishment's electrical distribution board, there are no problems that could cause losses due to long interconnection cable runs, not exceeding 20m. Figure 5 shows the model of the installation and interconnection point.

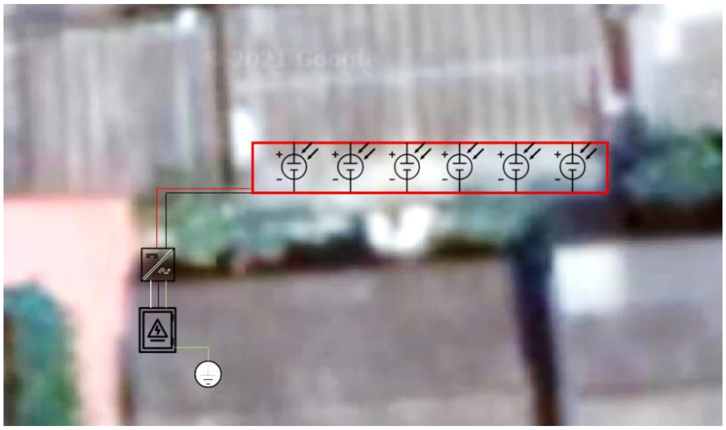


Figure 5 Model of the installation and interconnection point

Analysis of the optimal structure according to the type of roof of the place

The space where the system will be implemented is a flat concrete floor, which facilitates the installation of the modules. For this type of structure, you will need certified aluminum for panels made to measure according to the size of the modules and the optimum angle already known. Figure 6 shows the metallic structure of the proposed panel.

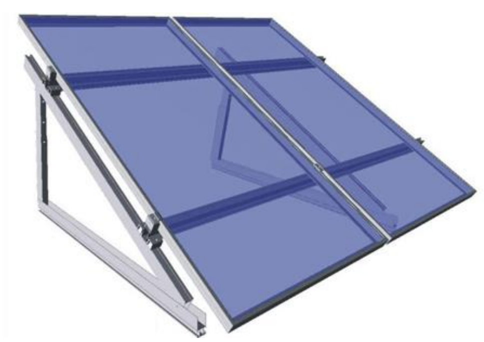


Figure 6 Metal structure of the panel

Analysis of loads or energy consumption

The energy consumption analysis varies according to the client's profile and can be classified into three types: residential, commercial, and industrial. In our case, the profile is adapted to a commercial profile, where only for a certain time, consumption is generated.

For the energy consumption analysis of the establishment, various methods can be used, in this case, two were chosen: one could be defined as theoretical and the other practical.

- In Theoretical Consumption

A list is made of all the electrical appliances connected to the establishment's electrical circuit. Questions of the estimated time of use of each appliance are asked, consumption is verified in the technical sheet of each appliance and at the end multiplications and sums of the total consumption are made, which gives us a theoretical daily consumption as a result.

- In Practical Consumption

An alternating current measurement module, commercially known as a clamp meter, was configured on the Arduino microcontroller board. Lines were added to the code for their correct calibration and data collection at the time of the photovoltaic module measurements, measured every 15 minutes, the same period as the photovoltaic module measurements. Table 2 shows the energy consumption in classrooms.

ENERGY CONSUMPTION CLASSROOM BLOCK PESTALOZZIANO SCHOOL					
EQUIPMENT	**QUANTITY**	**POWER**	**TIME**	**SIMULTANEITY**	**CONSUMPTION**
Ceiling fan	8	15W	6	100%	720 Wh
Sound system 330W	2	40W	2	50%	80 Wh
Epson Projector	2	405W	2	50%	405 Wh
Lighting	8	15W	2	50%	120 Wh
				TOTAL CONSUMPTION	**1.325 Wh**

Table 2 Energy consumption in classrooms

Design and sizing

Knowing the amount of electrical energy necessary for the school's consumption, we proceeded to design how the solar panels will be in the space selected for their installation. When sizing a photovoltaic system, the following steps should be taken into account:

- Sizing by available space

It is not more than the number of modules that can be located in the desired space for the installation of the photovoltaic system, where a margin of 0.75m must be left on each edge of the place to avoid possible lifting of the modules due to strong flows of air, it is also important to maintain a minimum separation between modules of at least 0.005m. After carrying out the measurements, the calculations were performed:

  - Latitude of the place:9.316378
  - Distance (North - South) = 2.2mts
  - Distance (East - West)= 15mts
  - Optimum inclination of modules (β) = 10 °.
  - Module dimensions = 1665 x 1002 x 35mm.

For this scenario, the modules were installed from east to west, due to the limited space between north to south.

  - Distance (North-South) = 1.45mts
  - Distance (East-West) = 14.25mts

It should be noted that the distance between north and south is shorter than the length of the modules, but for this particular case, it is not affected since the structure of the plate provides the remaining space for the proper installation of the modules.

Ns = Dis (E-O) / A+Sep

Where: Ns; is the number of modules in series possible to install, Dis (E-O); available distance between east and west, A; width of the photovoltaic module and Sep; the separation between each module.

Ns=14.25mts/1.002mts+0.005mts

Ns=14.226

Ns=14 photovoltaic modules

- Sizing by energy substitution

To be able to size the system, it is vitally important to know the daily or monthly consumption of the circuit, also to obtain from a reliable source, the month with the lowest radiation in the place. To obtain the month with the least solar radiation, the following data were obtained:

Year	**Month**	**H(i)_m**	Latitude (decimal degrees): 9.316

2015	Jan	190.75	Longitude (decimal degrees): -7
2015	Feb	175.46	Radiation database: PVGIS-NS
2015	Mar	195.94	
2015	Apr	165.64	H(i)_m: Irradiation on planed at an angle (kWh/m2/mo)
2015	May	159.26	
2015	Jun	172.36	PVGIS (c) European Communities, 2001-2021
2015	Jul	166.9	
2015	Aug	171.81	
2015	Sep	160.69	
2015	Oct	1678.9	
2015	Nov	154.68	
2015	Dec	176.51	

Table 3 Calculation of the month with the lowest solar radiation.

As it can be seen on the table, the month of November has the lowest radiation index, with an amount of 154.69kWh / m2 / month, which, when dividing the amount of radiation by the days of the month, an average of 5,156kWh / m2 per day, which will be of great importance to calculate the PSH (Peak Sun Hour), of the month.

$$\mathrm{PSH} = \frac{\text{Global irradiation}}{1000\mathrm{W/m^2}}$$

$$\mathrm{PSH} = \frac{5.156\mathrm{kWh}}{1000\ \mathrm{W/m\hat{}2}} \ = \ 5\mathrm{H}$$

With the PSH, we proceed to carry out the calculations for the sizing of the system. The next step is to calculate the percentage of energy to be replaced, which in this case would be 100%, which indicates that our system must supply the total monthly consumption of the block, we will take as the consumption value, the theoretical value, which is 1,325kWh /

day. So that our system can provide the required amount of consumption, we use the following formula:

P=E/PSH*P.R.

Where: P; is the peak power of the system, E; is the expected energy to be replaced, PSH; peak solar hour and P.R. Performance Ratio.

P=1.325kWh/day/5h*0.7896

P= 335.6Wp.

With the peak power of the system, the number of photovoltaic modules is calculated to meet the consumption need by the following equation:

#Mod= P/Pm

Where: P; is the peak power of the system and Pm; the nominal power of the photovoltaic module.

#Mod= 335.6W/325W

#Mod= 1.04 ➔ #Mod=2

The quantity of two modules is taken, since, by having greater production, a minimum voltage is also generated for the correct operation of the inverter and apart from that, it would be certain that the modules will be able to supply the energy need. Additionally, as support, it can be seen that all the calculations were carried out under the month with the least amount of radiation, which gives certainty that in the other months, the system will be able to supply the expected consumption.

System electrical production analysis

It is very important to know the amount of energy that the photovoltaic system will be able to generate. This value will be calculated with the PSHs obtained from the worst month from the PVGIS database, multiplying the HSPs by 365 days a year, in this way the total PSHs for the year will be obtained.

$$\text{PSH (year)} = \text{PSH} * 365$$

$$\text{PSH (year)} = 5 * 365$$

$$\text{PSH (year)} = 1.825$$

Having calculated the peak solar hours of a year, the amount of kWh that the system will generate can be calculated

$$P\ (year) = Pp * PSH\ (year) * P.R$$

$$P\ (year) = 335.6W * 1825h * 0.7896$$

$$P\ (year) = 0.482\ kWh/year$$

Analysis and selection of components

In today's market, there are large numbers of photovoltaic module designer brands. For the selection of modules, just an analysis will be made in a list of brands and the efficiency that this particular module can generate will be checked, this way it can be considered that we will obtain a module with more profitability in production compared to others. The type of module that is thought for this design is of the polycrystalline type, it is true that the monocrystalline ones provide more efficiency compared to the polycrystalline ones, but within the trade, the polycrystalline has a variety of brands and more existence, this is because they are a little cheaper than monocrystalline modules, despite not having the same efficiency, which does not exceed 8%, the market is more inclined towards polycrystalline modules.

The brands that were taken into account are the following:

- TALES SUN
- LOGI SOLAR
- POWEST
- YINGLI SOLAR
- TRINA SOLAR

All of these comply with the RETIE certification (Technical Regulation of Electrical Installations) and the EN 61215 standard. For warranty reasons and not so much for efficiency, since, in most brands, the efficiency of one to another was negligible, and more for the nature of guarantees and technical support, the brand TALES SUN was chosen with a nominal power of 325W.

- Inverter selection

For the selection of the inverter, a 1.5kW inverter was chosen, suitable for the load required by the establishment. It is also vitally important not to underestimate the inverter, since, being exposed to overloads, its useful life would be short.

Due to the limitation of the number of modules required to meet the electrical need of the establishment, a study was carried out of the inverters that were capable of operating under a minimum voltage range which the photovoltaic system can generate. It must also be recognized that being a competitive market, many brands are almost on par in technology to others. The GROWATT brand inverter with a power of 1.5kW was chosen, whose inverter has an MPPT input with minimum and maximum voltages of 50 to 500 VDC and a minimum operating voltage of 80 VDC.

It should be noted that the selected inverter is capable of providing statistics of interest to evaluate the performance of the photovoltaic system, this can be done through the inverter interfaces such as RS485, USB, or WIFI connectivity, a plus that the brand of the selected inverter gives us. , is an app called Shine Phone, which is a friendly way provides us with data from the photovoltaic system.

- Bidirectional meter

This meter is selected for its compliance with the most recent standards, of which the IEC62052-11 (203), IEC652053-21 (2003), and compliance with CREG resolution 030 of 2018 stand out.

IV. CONCLUSIONS

This work shows the design of a photovoltaic system in an Educational Institution on the Colombian Caribbean coast. The design is carried out with data obtained from sensors installed in the establishment, from which consumption values were obtained in different blocks of classrooms, thus allowing to validating or contrast data from external sources with data taken directly in the field. The presented system allows the generation of energy through a sustainable generation system according to environmental conditions and the requirements of the Institution, which benefits from costs associated with energy consumption.

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