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Proposal of Photovoltaic System for House

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Abstract

In this work, the design project of a photovoltaic system to feed a house is shown, based on a demand study and its general characteristics, the available area for the assembly of the modules, the geographic location, and the meteorological data of the place. With this information, the relevant calculations were carried out to ensure that the installation provides the energy necessary to cover the consumption of the home and, also, delivers the excess energy to the grid. The PVsyst software was used to design the photovoltaic system. To check the advantages of implementing the photovoltaic arrangement, the benefit-cost relationship was evaluated, conducting an environmental impact analysis taking into account the reduction of CO_2 emissions into the atmosphere and the tons of fossil fuel left to burn when generating electricity. With this power source, making it convenient to carry out the installation.

Contents

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1 Introduction

The increase in the excessive dependence on fossil fuels to obtain electricity has caused the depletion of its reserves and severe damage to the environment, due to the emission of harmful gases that occurs in the burning of coal, oil, and gas. natural, effects that are elements that accelerate climate change, being a threat to the human species. Betting on the use of renewable energy sources (FRE), currently, as the alternative allows us to solve the immediate need of man to replace fossil fuels and provide a better-quality service, in addition to achieving the energy sustainability of the House.

The sun is the source that provides all the energy to the earth. The incidence of its radiation allows the processes of photosynthesis, transforming the energy of the solar rays into chemical energy, essential for plant and animal life. The photosynthetic process has allowed the formation of fossil fuels. The sun is at the genesis of the winds and is the engine that moves the hydrological cycles.

Directly, the energy of the sun appears in the form of solar energy itself, hydraulic, or wind energy (Thekaekara, 1973). The solar energy received at the earth's surface has been calculated in an amount equivalent to 178,000 Tera Watt (TW) -year (Tacuri, 2008). In 1990, this amount was estimated to be 15,000 times greater than global consumption. However, about 30% of this energy is reflected in space, 50% is absorbed, converted into heat, and forwarded to the Earth's surface; of this 50%, 49,000 TW-year are forwarded as heat energy in the form of electromagnetic radiation, and 40,000 TW-year as heat energy itself.

The remaining 20% allows winds to form (~ 350 TW), feeds hydrological cycles (~ 35,000 TW), and only a very small part of solar energy is used by photosynthesis, thanks to which the Planetary biodiversity exists (100 TW). Geothermal energy also considered renewable and from the cosmic formation process, can be subtracted from the Earth's crust up to a value of 30 TW a year. The energy of the tides, created by the attraction of the moon, can also deliver a small part of the usable energy of the order of 3 TW-year. Estimates of the potential of renewable energies (primary biomass, solar energy, hydraulic energy, wind energy, and geothermal energy) show that their contribution will be multiplied by ten, reaching up to 10 or 15 TW-year.

Studies have been carried out in Ecuador, which offer information on the solar potential from the databases provided by NASA, free of charge (NASA, 2015), and studies have been carried out in territories and especially the province of Manabí (Rodriguez & Vázquez, 2018), where the solar potentials of each municipality including Manta have been studied. The energy, economic and environmental performance of a small 3.4 kWp plant has been calculated, which is connected in the distributed generation model at the Faculty of Sciences, Mathematics, Physics, and Chemistry (FCMFQ), of the Technical University of Manabí (UTM) (Vázquez *et al.,* 2018).

This growth in renewable energy will depend above all on its costs, taxes on non-renewable energies, and energy policies (Tacuri, 2008). The objective of the research is to design a photovoltaic plant based on the load and demand study carried out in a house in the canton of Manta, evaluating the social, environmental, and economic benefits of the installation of photovoltaic systems in a house, in addition to simulating the design of the photovoltaic power station using the PVSYST software.

Production is based on the physical phenomenon called the 'photovoltaic effect', which consists of converting sunlight into electrical energy using semiconductor devices called photovoltaic cells. These cells are made from pure silicon (one of the most abundant elements, the main component of sand) with the addition of impurities from certain chemical elements (boron and phosphorus), and are capable of generating a current of 2 to 4 amps, at a voltage of 0.46 to 0.48 Volts, using light radiation as a source.

The cells are mounted in series on solar panels or modules to achieve an adequate voltage. Part of the incident radiation (insolation) is lost by reflection (bounces) and part by transmission (passes through the cell). The rest can jump electrons from one shell to the other creating a current proportional to the incident heat stroke. An anti-reflective coating increases the efficiency of the cell (Tacuri, 2008).

Solar energy, together with wind, hydro, geothermal, and biomass, are considered the energy sources of the future, since unlike conventional resources they are practically inexhaustible, as well as being an ecological option. Photovoltaic systems are a very interesting option, from technical and economic perspectives, since the region where our country is located has abundant solar radiation throughout the year. Photovoltaic (SFV) systems began to be installed in the early 80s, last century. An example is that of It occurred in Japan, with a power of 1.2 MW (Agredano, 2008).

In 1995 the world installed capacity, in large plants or photovoltaic plants, was 600 MW; 16 years later, there was an installed capacity of more than 70 GWp in this type of facility (ren21, 2020). In 2019, the electric power purchase agreements (PPA) signed by the private sector-led to record growth of more than 43% from 2018 to 2019 in new capacity for renewable electricity generation (REN21, 2020).

As an example, in Cuba, the development of SFV represents an energy generation alternative that contributes to the reduction of dependence on fossil fuels, especially oil, which is becoming increasingly scarce and its burning emits large volumes of CO2 into the atmosphere, which causes high rates of environmental pollution. Also, given its geographical location, it has favorable natural conditions to achieve significant results in the use of this type of system. Cuba has average solar radiation above 5 kWh / m2/ day, with an approximate variability of ± 10% throughout the island, a very positive aspect, unlike other higher latitudes (Rodríguez *et al.,* 2013). The direct component of the radiation is between 65% and 80%, the diffuse component being relatively high, which enriches the solar spectrum in the wavelengths of blue (Stolik, 2014).

To increase the availability of energy, decrease costs, guarantee higher quality and reliability of services, use of photovoltaic systems connected to the network should be made and, within this modality, prioritize the installation of systems in places close to the loads. In some cases, due to the limited area available, the roofs of the installations are used to locate the photovoltaic array, this practice is very common in the world, for example Bangladesh is the world's largest market for photovoltaic systems for the residential sector, although Rapid development is also seen in countries such as Uganda, Kenya, and Tanzania in Africa, Brazil, and Guyana in Latin America and China, India, and Nepal for Asia (Stolik, 2014).

In Ecuador, until 2011, photovoltaic installations totaled less than 3 MW, in some 9,000 low-power photovoltaic systems, almost all remote not connected to the grid (CONELEC, 2012). Regarding the energy situation in the residential sector, currently, 74,478 homes do not receive electricity, which represents 1.9% of the country's households. Of these, 21,194 are located in mountainous areas with difficult access, making it essential to execute a Rural Electrification Program with Renewable Energy Sources (CONELEC, 2012).

Plans establish the electrification of more than 20,000 homes in rural areas within three years, with the corresponding benefit for some 80,000 inhabitants. The present work is aimed at carrying out the design of a photovoltaic system, capable of satisfying the energy demand of a home and delivering a percentage of the energy generated to the grid, as a way to promote the implementation of this technology.

2 Materials and Methods

A house in the canton of Manta was selected to carry out the design and proposal of the installation, for this, the characterization of the house was carried out, bearing in mind that the mounting of the photovoltaic system will be carried out on the surface of the living place; it is located at 23.1 ° north latitude and 82.42 ° west longitude, with an ideal north-south orientation for the design of a photovoltaic system.

3 Results and Discussions

A house in the canton of Manta was selected to carry out the design and proposal of the installation, for this, the characterization of the house was carried out, bearing in mind that the mounting of the photovoltaic system will be carried out on the surface of the living place; it is located at 23.1 ° north latitude and 82.42 ° west longitude, with an ideal north-south orientation for the design of a photovoltaic system.

Characterization of the house

The house is made up of a portal, three rooms, a living room, a dining room, a bathroom, and a kitchen. Among the predominant electrical charges are refrigerators, televisions, ventilation equipment, lighting, and computers, among others. The service is single-phase two-wire at 110 V. For the design, several methodologies allow selecting the capacity of the photovoltaic system to be connected, that is, the peak power (kWp) that will be necessary to supply the load.

A variant is developed using measurements made in the home itself and the other is from the monthly billing that exposes the energy consumption in kWh. To carry out this work, the electrical consumption of the house for the year 2019 is available, with which the load graph observed in table 1 is constructed, to more easily analyze the monthly energy behavior.

Table 1
Demand for housing per month

Equipment	Average power (W)	Quantity	Monthly time (h)	Monthly consumption (kW-h)
Lighting	100	15	6	252
Average to connect cell phones	5	6	4	3.36
Average to turn on computers	230	2	4	51.52
Air conditioning	400	3	4	134.4
Televisions	300	3	10	252
Refrigerators	350	2	24	470.4
Washing machine	2,200	1	3	79.2
TOTAL	3,585	32	55	1,242.88

The second step is to determine the available area in the place of installation. The plate of the house has a surface area of 85 m2, of which the part corresponding to the eaves, the portal, and that occupied by a water tank are neglected, resulting in an available area of 72 m^2. Around the house, there are no obstacles that can cast shadows on the photovoltaic modules.

Calculation of the maximum photovoltaic power to be installed taking advantage of the entire available area

To determine the photovoltaic power to be installed, it was necessary to have the incident solar radiation on the inclined plane in the area where the study is carried out. Although in Ecuador, solar radiation does not present significant variations throughout the territory, it considerably influences the expected productivity of the photovoltaic system. But when it comes to photovoltaic systems connected to the grid, destined to generate electricity during its useful life cycle (25 years), it is necessary to ensure adequate energy use of the system from the design stage.

This requirement is achieved to the extent that the technology is planned to be installed in the area where the best solar potential exists, thus favoring the economic recovery of investment in the shortest period. For this reason, it is necessary to make an estimate as accurately as possible, taking into account the historical data of the place.

Several meteorological studies can be used to know the solar potential. The Geographic Information System of Renewable Energy Sources (SIGFRE) (Rodríguez *et al.,* 2013) was used to obtain the real data on solar radiation in the place where the house is located, which guarantees the best selection of the photovoltaic system necessary to cover the load thereof. Figure 1 shows the annual average radiation values of Cantón Manta, taken from (Rodriguez & Vázquez, 2018).

Figure 1. Annual average solar potential of the Manta canton
Source: (Rodriguez *et al.*, 2019)

Specific productivity is another aspect to consider to obtain the necessary photovoltaic power to cover the household load. This is more than an indicator that simplifies the calculation of the energy generated for one year for each installed kWp, based on an incident solar potential, and is determined by equation 1 (Rodríguez *et al.*, 2017).

$$Pesp = Ps.Ac.\eta t.\eta c.number\ of\ days \qquad (1)$$

Where:
Pesp → One-day specific productivity (kWh / kWp / day)
Ps → Solar potential (kWh / m2)
Ac → Area required for 1 kWp photovoltaic (6.4 m2 / kWp)
ηt → Efficiency of use of the modules (14%)
ηc → Efficiency depending on the climatic variable (90%)

Design of the photovoltaic system

To perform the simulation of the photovoltaic system connected to the grid to be installed in the home, one must start from the specific conditions of the installation and the electrical production that can be expected from the photovoltaic system connected to the grid, among many other parameters of interest. To simulate the photovoltaic system, a project must be presented in which some characteristics and parameters have been analyzed, such as: the modules, their arrangement, possible shadows that may hinder solar radiation, among others.

The aspects that were analyzed in the design were:

a) Select the meteorological data to be used. The project form and the corresponding meteorological data to be used were prepared.

b) Define the orientation of the photovoltaic panels. The panels were oriented to the south, the azimuth, and an angle of inclination equal to the latitude of the place, 23 or to achieve the best use of the energy emitted by the Sun.
c) Specify the profile of obstacles (if present). In this step, the incidence of shadow by an obstacle was not taken into account due to its nonexistence.
d) Define the closest shadows (if they occur). It is not important to pay particular attention to this point since the home does not have any building nearby and no trees that cause shade by its arrangement.
e) Design of the system as a whole, that is, select the modules, the inverters, and their connection type.

The selected modules were the DSM-250 of national production. The arrangement is made up of 21 modules. The inverter model selected for installation was the German-made Sunny Boy SB 1700, with 1.6 kW of nominal power. The decentralized generator-converter type configuration will be used, working one inverter for each row of modules. Therefore, 3 such inverters will be used. The inverters have a built-in protection system capable of connecting and disconnecting from the grid in the event of an anomaly.
To generate 5.3 kW, 21 solar modules are needed, distributed as follows: three rows, each consisting of seven 250 Wp modules connected in series and a 1.6 kW inverter for each string of modules, the arrangement obtained is you can see it in figure 2.

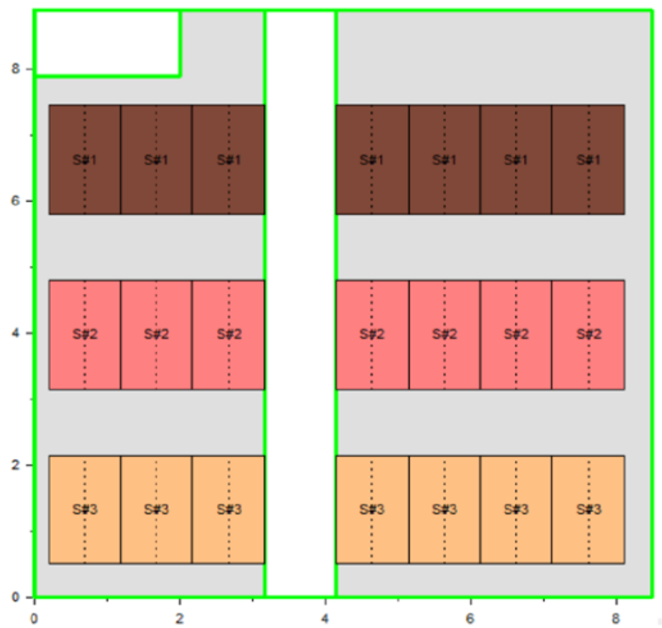

Figure 2. Location of the module chain

a) A safety and protection system was proposed for the installation against atmospheric electric shocks. Using the rolling sphere method, it was obtained that to protect the entire area occupied by the house, it is only necessary to use a lightning rod. The design of the ground mesh resulted in the location of a vertical electrode at 1.8 m depth, obtaining a grounding resistance of 0.93 Ω, thus meeting the necessary protection requirements.
b) Measurement and control equipment. These systems need devices to monitor their operation at all times, so it is necessary to have computer systems and communication devices, such as:
c) Datalogger communication equipment (Sunny WebBox RS 485). This device offers various possibilities for displaying parameters, files, and processing the installation data. Its function is to continuously collect the inverter data and store the production data of the photovoltaic system.
d) Radiation and temperature sensor (Sunny SensorBox RS 485). It is in charge of measuring solar irradiation. It is mounted outdoors next to the solar generator. The measurement of the module

temperature is carried out by means of a temperature sensor, which includes, through the measurement of solar irradiance and the module temperature, the theoretical power can be calculated and compared with the actual power of the inverter. the way you can easily detect the failures of the Generator

e) Accessories. They are the support materials for the assembly or installation of the photovoltaic system, the connection cables, overcurrent protections, and the supports for the modules.
f) Energy meter. Necessary to count the energy produced that is injected into the network and that which is consumed from it.

System simulation results

Once the photovoltaic system has been designed, the photovoltaic system is simulated using the PVSYST. The PVSYST is a computer tool to support the design, in addition to simulating photovoltaic installations, either isolated or connected to the grid, it makes it possible during the simulation to determine all kinds of characteristics and parameters of the installation, the modules, their arrangement and possible shadows that can get in the way of solar radiation, among other parameters (Perzon *et al.,* 2005; Akbarzadeh & Wadowski, 1996). The program has an extensive database, consisting of a collection of meteorological sheets from much of the world and a wide range of panel models and inverters from different manufacturers, organized by manufacturers or by their nominal power, to perform simple simulations of this type of facility with data from real manufacturers; Also, it allows you to add meteorological and component data that is not included in its database.

The PVsyst results in a complete report with all the information of the project with its general components and most important data. Also, it describes it from the technical-informative point of view. The first data it presents is the production of the system, which is a total of 7.88 MWh / year with a specific production of 1,501 kWh / kWp / year and a performance factor of 72.8%.

Environmental impact of the proposed photovoltaic design

Taking into account the objectives pursued with the implementation of photovoltaic technology, it is feasible, after carrying out the design of the installation, to analyze the economic and environmental benefits it provides, given the need to mitigate the use of fossil fuels and thus mitigate the effects of environmental pollution. Hence the importance of evaluating the insertion of this technology in the national energy matrix, taking into account the CO_2 reduction obtained with its implementation (Páez-Osuna, 2001; Evans *et al.,* 2005). By performing an energy analysis, the amount of fuel stopped burning can be determined to produce the same amount of energy, and it is calculated using equation 2 (Martinez, 2014).

$$Fuel\ saved\ =\ Eg\ (1000) \qquad (2)$$

Where:
E → is the energy generated in kWh / year (7 881 kWh)
g → is the specific fuel consumption (it is taken from the generator sets, choosing the worst condition, or that is, the one that will save less and is equal to 236 g / kWh).

By using expression 2, it is obtained that the fuel-saving that favors the insertion of the photovoltaic system connected to the grid is 1.9 t / year. With this value it is possible to obtain the amount of CO2 that is no longer emitted into the atmosphere, using equation 3.

$$CO2\ not\ emitted\ =\ Fuel\ saves.k.\rho \qquad (3)$$

Where:
k→ Coefficient that allows relating the unburned fuel with the tons of CO2 → not discharged into the atmosphere (3,119 kg / l).
ρ→ Fuel density (0,9781 kg / l).

In total, thanks to the installation of the photovoltaic system, 6 t / year of CO_2 are no longer emitted, which contributes positively to the country's environmental improvement.

4 Conclusion

The project for the installation of a grid-connected photovoltaic system was prepared, which is made up of a total of 21 solar panels, arranged in 3 rows, each consisting of 7 modules and an inverter. The simulations showed that the arrangement delivered all the energy that the load demanded, generating 7.88 MWh on average per year, saving in turn 1.9 tons of fuel and avoiding the emission of 6 tons of CO2 into the atmosphere.

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