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METHODOLOGY

FOR THE INTEGRATION OF PHOTOVOLTAIC SOLAR INSTALLATIONS IN HOTEL BUILDINGS IN THE CARIBBEAN

METODOLOGÍA PARA LA INTEGRACIÓN DE INSTALACIONES SOLARES FOTOVOLTAICAS EN EDIFICIOS HOTELEROS EN EL CARIBE

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ABSTRACT

The objective of this work is to propose a methodology for the installation of solar photovoltaic systems in hotel buildings in the Caribbean. The energy analysis of the building in question is proposed for the subsequent selection and sizing of the solar photovoltaic system to be installed, taking into account aspects such as the structural design of the panel supports, the calculation of the layout of the solar photovoltaic system and the design of the solar photovoltaic system's electrical network. The economic evaluation procedure for the company and the country is described. This methodology also studies the environmental impact of the implementation of this technology. Traditional calculation methods and software simulations are used to analyze the results obtained.

Keywords: methodology, photovoltaic solar systems, energy analysis, sizing, economic evaluation, environmental impact.

RESUMEN

El presente trabajo tiene como objetivo proponer una metodología para la instalación de sistemas solares fotovoltaicos en edificaciones hoteleras del Caribe. Se plantea el análisis energético de la edificación en cuestión para la posterior selección y dimensionamiento del sistema solar fotovoltaico a instalar, teniendo en cuenta aspectos como el diseño estructural de los soportes de los paneles, el cálculo de la disposición del SSFV y el diseño de la red eléctrica del SSFV. Se describe el procedimiento para la evaluación económica tanto para la empresa como para el país. Dicha metodología además estudia el impacto medioambiental que conlleva la implementación de esta tecnología. Para la realización de este trabajo se utilizan métodos de cálculo tradicionales y simulaciones mediante softwares para el análisis de los resultados obtenidos.

Palabras claves: metodología, sistemas solares fotovoltaicos, análisis energético, dimensionamiento, evaluación económica, impacto medioambiental.

INTRODUCTION

The consequences of global climate change in all areas of life are well known. This change is mainly caused by the increasing concentration of greenhouse gases (GHG), especially carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N2O). Recently, the importance of energy use in GHG emissions has been confirmed, as observed in the United States, where energy use has a share of 86% of total GHG production.

Much of the renewable energy obtained from wind, tidal, geothermal, biomass, and solar is converted into electrical energy to be distributed directly to the grid or meet independent demands. Currently, there is a worldwide interest in protecting the environment, mitigating the impact that man has generated on it, and rational use of natural resources. In line with the above, there is also a global interest in encouraging the use of renewable energies to reduce dependence on fossil fuels, mitigating the additional risks, such as progressive pollution and the increase in greenhouse gasses that they cause.

Solar energy is the most abundant energy source on Earth: renewable, available, accessible, and in much greater quantity than the energy needs of the world's population. However, its use presents technical and economic problems that make it challenging to use in practice.

The percentage of the sun's energy that reaches the Earth directly is used to some extent to heat water through solar collectors or to produce electricity through photovoltaic cells. These forms of energy production are the most environmentally friendly, thus reducing energy dependence on fossil and polluting energies such as oil (Guzman et al., 2016).

Solar photovoltaic systems are a promising alternative for the energy supply of buildings. They can be deployed in buildings regarding adhesion and architectural integration and present a consistent cost reduction. In a complementary way, photovoltaic generation shows social advantages, such as energy democratization and promoting the generation of jobs. In an optimal scenario, the economic resources destined to purchase energy could be oriented to finance equipment installation and maintenance companies (Marín et al., 2018).

Today there is a favorable global environment for renewable energy sources, a significant increase in the worldwide production of photovoltaic panels, as well as a strong decrease in their costs; more than 99% of photovoltaic energy connected to the electric grid predominates and parity of the cost of photovoltaic kWh with that of the conventional grid is achieved (Stolik, 2014).

Due to the economic situation of the country and the current energy deficit, the use of renewable energies, such as photovoltaic, has become a premise, leading to the development of large projects in this field. The objective of this work is to develop a methodology for the installation of solar photovoltaic systems in hotel buildings in the country.

DEVELOPMENT

The following section evaluates each aspect of installing a solar photovoltaic system using manual calculations, thus creating a methodology for future projects integrating solar photovoltaic systems in buildings. For this purpose, a sequence of steps was developed with a logical order later complemented with the necessary equations.

The expressions taken into consideration in this methodology were taken from (Becerra, 2019), (Monteagudo & Crespo, 2021), (ABB, 2019).

The methodology starts with an energy analysis of the facility, where the main saving opportunities will be detected and proposed to reduce energy consumption. Building resistance and panel support studies will be conducted according to site conditions. The site's electrical system's characteristics will also be considered. Afterward, the entire SSFV will be dimensioned, and its economic and environmental feasibility will be compared.

Energy characterization of the institution.

Energy review.

ISO 50 001 Energy Management System Model.

Analyze energy use and consumption.

Characterization of the electrical system of the place.

- Review of the electricity rate of the institution.
- Verification of the contracted power and the power factor.
- Lifting of installed loads.

- The behavior of the historical consumption of the institution and the installed loads.
- Characterization of alternative energy sources to the network.

Structural analysis of the site.

Review of previous structural studies carried out on the entity.

In the absence of said study, request it from competent entities.

Review of the orientation and coordinates of the site.

It appears that you're seeking a review of the orientation and coordinates of a site. However, the information you've provided is quite general, and I'm not sure if you have specific details or questions in mind. Nevertheless, I can offer some general guidance on what considerations are typically involved in reviewing the orientation and coordinates of a site:

Site Orientation

Solar Exposure: assess the site's orientation concerning the sun. This is crucial for understanding how sunlight will impact the site throughout the day and across seasons. A well-oriented site can maximize natural light and potentially benefit energy efficiency.

Wind Exposure: consider the prevailing wind direction. This is important for designing structures that take advantage of natural ventilation or, conversely, are shielded from strong winds.

Views and Surroundings: evaluate the site's orientation regarding views and surroundings. This can influence design decisions to capitalize on scenic views or mitigate undesirable aspects.

Coordinates

Geographic Coordinates: latitude and longitude provide the precise location of the site on the Earth's surface. This information is crucial for mapping, navigation, and understanding the regional climate.

Elevation: the site's elevation above sea level affects factors such as temperature and atmospheric pressure. It's particularly important for projects in mountainous regions.

Legal and Property Boundaries: ensure that the coordinates align with legal and property boundaries. This is critical for accurate land surveys, property ownership, and compliance with regulations.

Coordinate Systems: understand the coordinate system being used to ensure compatibility with mapping tools and databases.

If you have specific data or questions related to the orientation and coordinates of your site, please provide more details so that I can offer a more targeted and helpful response. Additionally, for any construction or development project, it's advisable to involve professionals such as surveyors and architects who can provide accurate assessments based on the specific context of the site.

Classification of the availability of the entity's areas for the possible installation of Photovoltaic Solar Systems (SSFV).

Study of shadows in the selected areas.

- By manual calculations.
- Through specialized software:

Pvsyst

sketch-up

Sunny Design

Selection of the SSFV to use.

The selection of a Photovoltaic Solar System (FVSS) involves considering several crucial aspects to ensure its effectiveness and efficiency. Firstly, a thorough evaluation of the geographical location is necessary to determine available solar radiation and optimize the system's performance. Additionally, the required energy generation capacity, coupled with the user's electricity demand, plays a pivotal role in selecting the PVSS capacity. The choice of solar panels, inverters, and energy storage systems should align with the project's specific needs, taking into account factors such as durability, efficiency, and maintenance. Financial considerations, including initial costs, tax incentives, and long-term savings, also play a key role in decision-making. In summary, the selection of a PVSS requires a comprehensive approach that considers location, generation capacity, component efficiency, and financial considerations to achieve an optimal and sustainable photovoltaic solar system.

Solar panel selection. Requirements to be taken into account.

- Dimensions to relate to the available area.
- The solar panel's mass relates to the place's structural characteristics.
- Electrical characteristics of the panel to relate to the possible demand to cover.
- Analysis of the area vs. power ratio of the panel.
- Photovoltaic solar panel technology to relate to the climatic characteristics of the site.

The structural design of the panel supports

Study of the climatic characteristics of the place

The characteristics of the climate influence the efficiency and performance of the photovoltaic solar system. It is important to have meteorological information for the area in which the project is focused. Especially to have the information on solar radiation presented to benefit the operation of the system it desires to implement (Benitez & Tello, 2018).

It is also important to know the influence of winds on structures for resistance calculations. These data can be found in meteorological centers or based on design software.

Selection of the type of structure

The structure is the element in charge of fixing the panels to the ground or roof of the installation, and they can be of the following types.

- Coplanar: For panels that are placed glued to the roof. They make better use of the space on the roof and are the most aesthetic solution with the least visual impact.
- Triangular structure: They are used to correct the inclination and orientation of the panels when the roof's position is not ideal, increasing the radiation received by the panels and consequently the electrical production.
- Solar trackers: These are mobile structures with one or two axes that vary the orientation of the panels depending on the solar position. They are more complex installations, but they can increase electricity production by up to 30% in locations with high direct radiation. There are several types:

- Two axes: They keep the surface of the panel perpendicular to the Sun.
- A polar axis: An axis's rotation is adjusted so that the normal to the panel's surface coincides with the terrestrial meridian that contains the Sun.
- An azimuthal axis: The rotation of an axis is adjusted to make the normal to the surface coincide with the local meridian containing the Sun.
- A horizontal axis: The rotation is adjusted on a horizontal axis and oriented in a north-south direction so that the normal surface of the panel coincides with the terrestrial meridian that contains the Sun.

- Static structures: In these structures, the module is fixed in one position and is not changed; they are the most used and suitable for ceilings and architectural integration.
- East-West gabled structure: Two modules are fixed, one facing East and one facing West, allowing a longer time to take advantage of solar radiation.

Selection of the angle of inclination of the module for the surface to be installed

As usual in photovoltaic systems, the orientation of the generator must be towards the southern horizon in the northern hemisphere (and towards the northern horizon in the southern hemisphere). The inclination of the generator must be such that it maximizes the annual production so that it will be between that which favors production in the winter months and that which favors generation in summer. A simple reroof positions the generator 10° less than the site's latitude. In any case, it is necessary that the slope is not less than 15° to allow the accumulated dirt to be removed by the rain (Perpignan, 2013; Santos et al., 2018).

Determine the azimuth of the solar modules

The panel's orientation is one of the decisions that directly influence the efficiency of the installation. This consists of properly positioning the solar panel about the star king. This topic has been extensively studied in recent years.

The orientation of the modules must be indicated from the azimuth angle of the deviation concerning the south direction (for the locations in the northern hemisphere) or the north direction (for locations in the northern hemisphere). The southern hemisphere (ABB, 2019).

Positive values of the azimuth angles show an orientation that tends to the west, while negative values tend to the east.

Good results are obtained when the modules are oriented southeast or southwest with a deviation of up to a maximum of 45 degrees toward the south direction.

Larger deviations can be compensated by utilizing a slight enlargement of the surface of the modules. (ABB, 2019)

- Structure support calculation:

For the dimensioning and calculation of the support structure, the following aspects are considered:

- Structure weight.
- Own the weight of the panel.
- Load on the beams.
- Wind load.
- Calculation of resistance of the joints.
- These calculations can be done by:

- Specialized software Autodesk Inventor Professional.

Different software is used for structural support calculations depending on the company or designer of the photovoltaic system. This software analyzes the structure through a hyperstatic system where static loads are reflected, such as that of the panel's weight, and dynamic loads are added, such as the force exerted by the wind, becoming variable. This software also carries out the proper calculations of the joints made in the structure, whether bolted or welded, apart from considering the counterweights and anchoring systems. In this methodology, he chooses to use the Autodesk Inventor system, which has been used as a precision calculation tool in several scientific articles in which photovoltaic modules are used as a source of energy:

- An analysis of solar-powered electric bi-hybrid vehicles compared to IC-powered vehicles using AI graph analysis.
- Dual-axis programming tracker with an adaptive algorithm for strong sunbeam scattering (Saymbetov et al., 2021).
- Implementation of the movement of manufacturers to the renewable energy laboratory: a case study of the automatic tracking photovoltaic model (Afif et al., 2019).
- Investigation of the optical and electrical performance of 3X truncated photovoltaic-thermal systems without low-concentration images (Chandan et al., 2020).
- Improving the performance of a desiccant-based cooling system by mitigating non-uniform lighting in coupled low-concentration photovoltaic thermal units (Chandan et al., 2022).
- SMOFIM: Smoked fish machine based on photovoltaic solar energy with exhaust filter reducing CO, CO_2, and HC pollutants to improve the fishing community's economy in TRISIK BEACH (Setiawan et al., 2018).
- Manual calculations.

The weight of the panel support structure is obtained by software based on the volume of the material used and its properties.

- Own the weight of the panels

The weight of the photovoltaic panels is considered an addition to the structure's weight. The weight of the panels must be determined manually.

Load on the beams

The load for each of the beams must consider the weight of the panel, accessories, and the gauge of the wiring used.

Load due to the action of the wind.

- Calculation of resistance of the joints.

The Dobrovolski book of machine elements is used as a bibliography to calculate the threaded joints in the panel support structure. The calculation method is for threaded joints without prior tensioning in their assembly.

It is evident that in addition to the tensile failure of the screw, other failures may occur, such as screw head shearing, screw thread shearing, nut thread shearing, bending, or crushing of the turns. Of the thread.

For the calculation of the turns in bending, it is assumed that these unfolded are a cantilevered beam, the concentrated force replaces the load distributed on the surface of the turn (equation 1)

$$\frac{P}{z} \quad (1)$$

Where (z-number of turns of the thread) and is applied to half of the working height of the loop (equation 2)

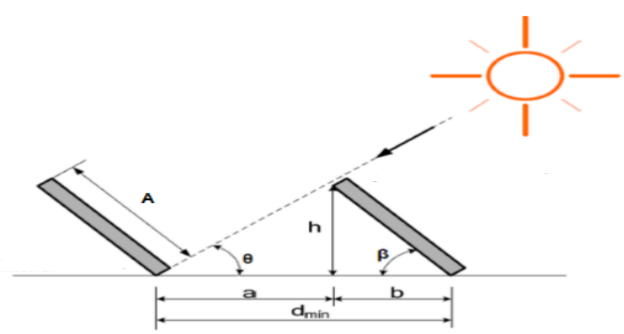
$$l = \frac{t'_2}{2}\Big) \quad (2)$$

Calculation of the provision of the SSFV.

- Determine the location of the photovoltaic modules projected on the area (Number of rows and columns and space between them).

The minimum separation distance between the different rows of solar modules that make up the photovoltaic generator is calculated so that no shadows are produced from some modules on others. Figure 1 shows all the measurements that must be considered for conventional static support structures (Bowler, 2019).

Fig 1. Measurements are to be taken into account for conventional static support structures.



Source: Becerra, (2019).

Where:

Minimum distance between panel edges to avoid shadows, (m).

-width of the panel (column of modules in parallel), (m).

-Component of panel height, (m).

-degree of inclination of the panel concerning the horizontal.

-the angle of the shadow concerning the horizontal.

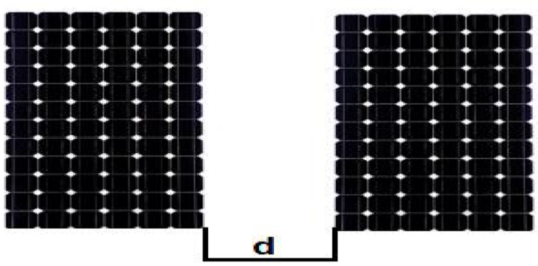
-distance from the upper edge of one panel to the lower edge of the other concerning the horizontal, (m).

-distance from the lower edge of the panel to its upper edge concerning the horizontal, (m).

Being d the minimum distance between the upper edge of one panel and the upper edge of the other for the horizontal, this can be normalized to a higher value if it is tiny, to ensure that interference between panels does not occur and facilitate access through the corridors for cleaning and maintenance (Bowler, 2019).

Figure 2 shows the minimum distance between panels in the row.

Fig 2: The minimum distance between panels in the row.



Source: Becerra, (2019).

This magnitude can also be normalized to ensure that interference between panels does not occur and to facilitate access through corridors for cleaning and maintenance (Bowler, 2019).

- Through specialized software:

For the study of shadows in the selected areas to obtain results of the layout of the photovoltaic system to be selected, it can always be done by manual calculations, but the quality of the calculation improves substantially when powerful software is used that performs the calculations with more precision and on a broader spectrum of the day. This software is widely recognized in the world, among which for their application as reliable shadow simulation tools are:

Pvsyst

- Analysis and design of photovoltaic solar systems using Pvsyst software.
- Design and analysis of a solar network system using PVsyst software for commercial applications.

Sketch-up

- Computer-aided design and simulation-based efficiency improvement of the first Egyptian solar city (Haggag et al., 2021).
- Feasibility evaluation of the adoption of distributed photovoltaic solar energy and phase change materials in multi-family residential buildings (Gassar & Cha, 2022).

Sunny Design

- Evaluation of outdoor photovoltaic technologies' performance and commercial software estimation in hot and dry climates (Othman & Hatem, 2022).
- Optimal planning of solar photovoltaic and battery storage systems for the residential grid-connected sector: review, challenges, and new perspectives (Khezri et al., 2022).

Design of the electrical network of the SSFV.

- Determination of the charge regulator.

The determination of the charge regulator is a critical aspect of the design and implementation of a solar power system. The charge regulator, often known as a solar charge controller, serves as a protective mechanism for the battery bank by regulating the voltage and current from the solar panels. This is crucial in preventing overcharging and deep discharging, which can significantly impact the lifespan and performance of the batteries. The choice of a charge regulator depends on various factors, including the type and capacity of the batteries, the solar panel configuration, and the overall system voltage. For example, in off-grid systems, where batteries are the primary energy storage, a charge controller with features like temperature compensation and multiple charging stages becomes essential to ensure optimal battery health. Additionally, the selection may involve deciding between PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking) controllers, each offering distinct advantages based on the system requirements. In summary, the determination of the charge regulator involves a comprehensive analysis of system components, battery characteristics, and specific operational needs to ensure the efficient and sustainable functioning of the solar power system.

- Calculate and select inverters according to the nominal power installed in the SSFV.

The number of inverters needed for the installation is determined by: Becerra, (2019) (equation 23).

The selection of the inverter and its dimensioning is carried out according to the nominal power of the photovoltaic generator. From the nominal power of the photovoltaic generator according to the distribution of solar energy radiation in the place of installation and according to the installation conditions. The designer will decide whether the inverter will be oversized ($P_{DC\ Máx\ Inverter} > P_{DC\ PV\ GEN}$)or undersized ($P_{DC\ Máx\ Inverter} < P_{–DC\ PV\ GEN}$) . In case the inverter is undersized, when the generated power is higher than normally estimated, the inverter will automatically limit the output power (ABB, 2019).

The maximum DC power rating of the inverter $P_{DC\ Máx\ Inverter}$, according to the efficiency of the inverter, defines the maximum power ratio of the AC inverter. The inverter's efficiency is influenced by the percentage of the output power defined by the inverter and the voltage of the photovoltaic array. (ABB, 2019).

- Calculation and selection of the battery bank.

Required battery capacity.

Determining the required battery capacity is a pivotal step in designing a reliable and efficient energy storage system, particularly in the context of renewable energy sources such as solar or wind power. The battery capacity is directly tied to the energy demands of the system and the desired level of autonomy during periods when renewable energy generation is insufficient. Factors influencing the required capacity include the daily energy consumption, the duration of energy storage needed during low generation periods (like nights or cloudy days), and the desired depth of discharge to prolong battery life. Additionally, the choice between lead-acid, lithium-ion, or other battery technologies will impact the overall capacity decision, considering factors such as cycle life, efficiency, and cost. It's crucial to strike a balance between providing enough storage to meet energy demands and avoiding excessive oversizing, which can lead to unnecessary costs and resource utilization. Ultimately, a careful analysis of the energy usage patterns, the renewable energy system's output variability, and the specific requirements of the application are essential for determining the optimal battery capacity to ensure a reliable and sustainable energy storage solution.

- Configuration of the photovoltaic strings (string).

Determination of the maximum number of photovoltaic modules in a chain.

The maximum number of photovoltaic modules connected in series that can be connected to the inverter is defined based on considering that the string voltage will always be below the maximum voltage at the inverter input.

If the string voltage exceeds the input voltage of the inverter, damage to the inverter may occur due to the overvoltage to which it is exposed (ABB, 2019).

Determination of the maximum voltage of the photovoltaic string $V_{OC\ MAX\ String.}$

The maximum open circuit voltage of the string($V_{OC\ MAX\ String}$) at the lowest temperature that can be expected at the PV installation site

Determination of the minimum number of photovoltaic modules in a chain:

In case the string voltage is less than the minimum, maximum power point voltage of the inverter, then the inverter may not be able to track or even generate losses during its operation.

The minimum number of photovoltaic modules connected in series that can be connected in the inverter is defined considering that it operates with the minimum string voltage in the maximum power point conditions (ABB, 2019).

The number of photovoltaic modules per string must not:

- Exceed the maximum number of photovoltaic modules per string.
- It must not be less than the minimum number of photovoltaic modules per chain.
- Determination of the maximum current of the photovoltaic modules.
- The short-circuit current is proportional to the cell temperature and has its maximum value at the maximum cell temperature.
- Maximum temperature at which the photovoltaic installation is expected to operate.
- Short circuit current of the photovoltaic module before the STC.
- Temperature coefficient of the photovoltaic module.

Determination of the maximum current in the chain:

In a series of module connections, the current does not add; the total current in a chain of PV modules connected in series equals the current generated by a single module. Based on the above, the maximum current of the photovoltaic string ($I_{SC\ MAX\ String}$) is equal to the maximum current of the photovoltaic module $I_{SC\ MAX}$ (ABB, 2019).

Determination of the number of chains:

Assuming that a correct dimensioning of the inverter was carried out according to the nominal power of the photovoltaic generator, as soon as the number of modules per string is defined, the number of strings per inverter must be verified.

For stand-alone MPPT string inverters, the maximum number of parallel-connected strings that could be connected to the single DC input channel of the inverter is defined based on the assumption that the short-circuit current of the string $I_{SC\ MAX}$ is always below the maximum input current of the inverter (ABB, 2019).

In the case of string inverters or a central inverter with a single MPPT, the maximum number of strings connected in parallel that could be connected to the inverter is defined based on the assumption that the is always below the maximum input current of the inverter.

In the case of the central inverter, the determination of the string number must also be carried out for the combiner box. In any case, the maximum current level of the components used in the combiner boxes (connectors, switch, and fuses) and the inverter must be adequate for the number of connection strings (ABB, 2019).

• Calculation of the projected SSFV generation through.

Software Pvsyst

Sunny Design.

For calculating the projected SSFV generation, there are several ways to execute this calculation, from using the peak solar hours term to using models based on the information presented by the manufacturer of the photovoltaic modules and inverters. Among the recommended programs to carry out this calculation with precision, we find the case of PVSyst and Sunny Design, as mentioned before. Can also be used:

Helioscope referenced by works:

- Advancement of specific simulation tools for floating photovoltaic solar systems: a comparative analysis of measured and simulated energy performance in the field (Manoj et al., 2022).
- Design and optimization of a mini-grid photovoltaic system for developing countries (Chaware et al., 2021).
- Simulation design and analysis of a 1 MWp grid-connected photovoltaic system floating on Lake Nasser.
- HOMER used in:
- Pre-installation analysis via “PVsyst” and “HOMER Pro” to design and simulate a 50 kW solar grid-connected photovoltaic system for electrification of rural areas of India (Ahirwar et al., 2021).
- Evaluation of the performance of a 20 MW photovoltaic plant in a hot climate using accurate data and simulation tools (Bentouba et al., 2021).
- Optimal design of a hybrid photovoltaic-wind system with the national grid using HOMER: a case study in Kerkennah, Tunisia.

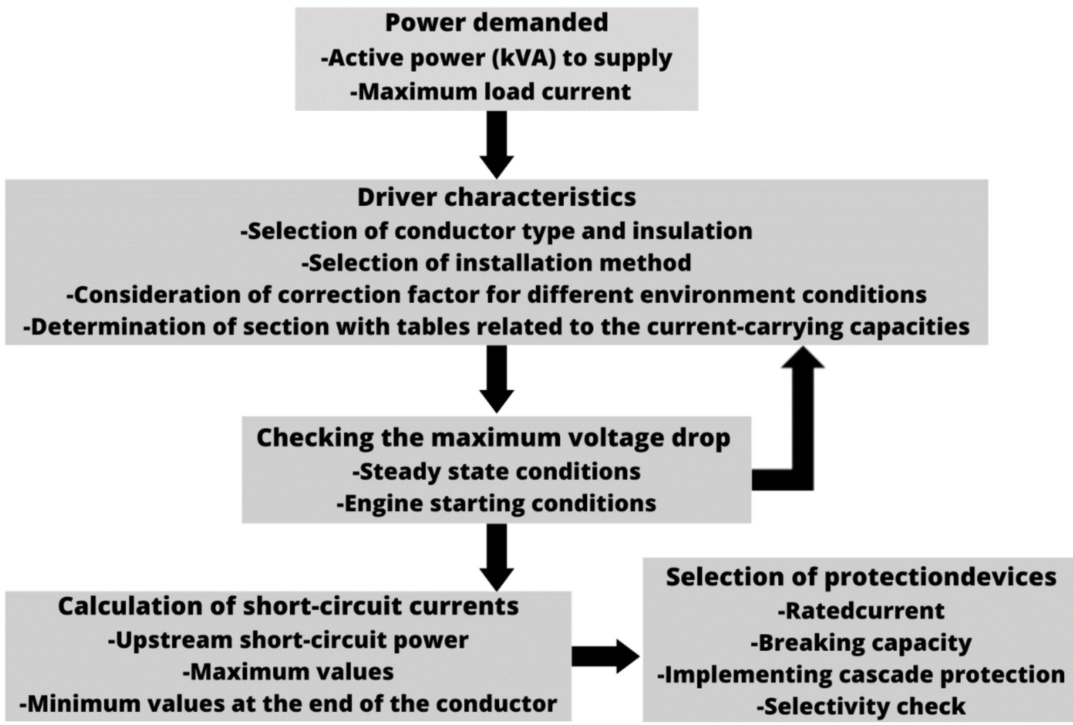
Wiring dimensioning of the electrical installation.

For the dimensioning of wiring and electrical protections, Cuban standard, NC 800: 2017, is used to dimension wiring and electrical protections. Cuban electrotechnical regulation for electrical installations in buildings.

Figure 3 shows the procedure described by the standard for sizing electrical wiring. The aspects considered according to the standard are power demand, conductor characteristics, verification of the maximum voltage drop, calculation of short-circuit currents, and selection of protection devices.

- Dimensioning of electrical protections.
- Sizing of electrical panels.
- Definition and sizing of the grounding system of the photovoltaic installation.
- Verification of the need to use the equipment for coupling between networks.

Fig 3: Diagram for cable area selection and protection device specification for a given circuit.



Source: Data obtained from NC 800: 2017.

For the dimensioning of the electrical protections, dimensioning of the electrical panels, definition and dimensioning of the grounding system of the photovoltaic installation, and verification of the need to use the equipment for coupling between networks, robust software is used. Among these can be found the Helioscope and the HOMER already mentioned in the calculation of SSFV generation. However, it can be used for this ETAP calculation, referenced by:

- Simulation and analysis of photovoltaic solar penetration in conventional energy systems.
- Performance study of the existing electrical network connected by a large-scale photovoltaic system.
- Design, analyze, and operate photovoltaic energy in a microgrid with an EESS.
- The design scheme for ring-based extra low voltage direct current photovoltaic microgrids for rural electrification (Kanniappen et al., 2022).

Analysis of costs and environmental impact.

Cost analysis for the institution.

For the development of the cost analysis, the criteria given by: Becerra, (2019), and Monteagudo & Crespo, (2021) are followed.

To carry out the economic evaluation, all expenses associated with the installation of photovoltaic technology will be taken into account in terms of panels, fixing tables, wiring, screws, and inverters; In addition to taking into account the following factors: the bank tax, inflation, discount rate and the useful life of the panels, to know more accurately the period in which the investment and profits will be recovered. What it will bring with it (Bowler, 2019).

All the economic calculations will be made for the lowest radiation conditions and peak solar hours, where the generation and delivery capacity of the SSFV will be minimum and for the maximum consumption recorded in one day.

Knowing the savings generated by the SSFV and the electricity rate applied to the institution, the monetary income can be determined by the following equation: Becerra, (2019)

Annual income.

For the determination of the income in the year, the days that are worked and the days that are not being taken into account, since the income on non-working days is associated with the generation of the SSFV that will be injected into the SEN network with a fixed sales rate. Knowing all these conditions, it is possible to proceed to the calculation of the annual income, defined as income from savings for those produced on working days and income from exports for non-working days (Bowler, 2019).

Savings income.

Saving income is a crucial financial practice that provides a safety net for unexpected expenses, facilitates investment in opportunities, and fosters financial discipline. It contributes to individual and societal financial stability, promoting economic growth and long-term wealth accumulation through interest and investment returns.

Export income.

Export income is crucial for economic development, providing growth opportunities, job creation, and economic resilience. It diversifies market reach, mitigates risks, strengthens foreign exchange reserves, fosters innovation, and enhances a country's global standing and diplomatic relations.

Total income.

Total income, whether at the individual, business, or national level, represents the cumulative earnings and revenue from various sources. It serves as a comprehensive indicator of financial health, influencing purchasing power, growth potential, and economic performance. Managing total income is crucial for strategic planning, investment, and overall financial stability.

Determination of the Simple Recovery Period (PSRI).

It is used in those cases where the annual savings are constant, and the PSRI in years will be: (Monteagudo & Crespo, 2021).

Due to the lack of depth of this evaluation, it is advisable to use the Simple Investment Recovery Period method only as a first quick filter of possible investments and to use more reliable methods to evaluate projects with good prospects in detail.

Calculation of simple interest

A capital placed in the bank generates a new capital, but always on the magnitude of the initial capital deposited and never on the magnitude of the interest earned (There is no capitalization). The following equation shows how simple interest is determined (Monteagudo & Crespo, 2021).

Calculation of compound interest.

A capital placed in the bank generates a new capital, but always on the magnitude of the initial capital deposited plus the magnitude of the interest earned (There is capitalization).

Evaluation of the value of money over time.

The evaluation of the value of money over time is a critical aspect of financial planning and economic analysis. Inflation, a key factor in this evaluation, erodes the purchasing power of money over time. As prices rise, the same amount of money buys fewer goods and services, impacting both individuals and businesses. This phenomenon underscores the importance of investing and earning returns that outpace inflation to preserve and enhance wealth. Moreover, the time value of money concept emphasizes that a sum of money today has a greater value than the same sum in the future due to its potential earning capacity or investment opportunities. Considering the effects of inflation and the time value of money is essential in making informed decisions regarding savings, investments, loans, and overall financial strategies. This evaluation is crucial for maintaining financial well-being, achieving long-term goals, and navigating the dynamic economic landscape.

Determination of cash flow.

The determination of cash flow is a fundamental financial analysis that provides insights into the liquidity and financial health of an individual, business, or investment. Cash flow represents the net amount of cash generated or consumed over a specific period, encompassing operational, investing, and financing activities. Positive cash flow indicates that more cash is flowing into the entity than out, providing flexibility for operations, debt servicing, and investment. Conversely, negative cash flow may signal liquidity challenges or high capital expenditures. Analyzing cash flow is crucial for assessing the sustainability of operations, as it directly impacts the ability to meet short-term obligations and pursue growth opportunities. Additionally, investors and creditors often scrutinize cash flow statements to gauge the financial resilience and solvency of an entity. Effective cash flow management involves optimizing receivables, payables, and investment decisions to ensure a healthy balance between inflows and outflows. In essence, the determination of cash flow is a key component of financial planning and decision-making, offering valuable insights into the overall financial viability and maneuverability of an entity.

Determination of the real interest rate (R)

It is the interest that considers the effects of inflation. Inflation or devaluation of money, reflected by increased market prices, can be included in the investment analysis by calculating a real interest rate (rate in constant currency) using the Ficher relation (Monteagudo & Crespo, 2021).

Determination of the net present value.

The determination of the net present value (NPV) is a crucial financial analysis that assesses the profitability and viability of an investment project. NPV calculates the present value of future cash flows by discounting them back to their current value using a specified discount rate. A positive NPV indicates that the projected cash inflows exceed the initial investment, signaling a potentially lucrative investment opportunity. This method takes into account the time value of money, recognizing that a dollar received in the future is worth less than a dollar received today due to factors such as inflation and opportunity cost.

The NPV analysis considers not only the magnitude of cash flows but also their timing, providing a comprehensive view of the investment's profitability over its life. It serves as a decision-making tool for businesses and investors, helping them prioritize projects or investments based on their potential to generate positive returns.

Moreover, a positive NPV suggests that the investment is expected to add value to the entity, contributing to wealth maximization. Conversely, a negative NPV implies that the project may not meet the required rate of return, warranting reconsideration or further evaluation.

In summary, the determination of NPV is a strategic financial analysis that accounts for the time value of money, enabling informed decision-making regarding the feasibility and desirability of investment projects.

Determination of the Internal Rate of Return (IRR).

It is the discount rate that reduces the Net Present Value to zero.

The IRR represents the percentage or interest rate earned on the unrecovered balance of an investment, such that, at the end of the evaluation period or useful life, the unrecovered balance equals zero (Monteagudo & Crespo, 2021).

Determination of the Real Period of Recovery of the Investment (PRI).

It is when the initial investment is recovered for a discount rate D considered.

Cost-Benefit Ratio (CBR).

It is determined as the ratio between the Net Present Value of the VPNC Costs and the Net Present Value of the VPNB Benefits.

SSFV price review.

To carry out the economic evaluation, all expenses associated with the installation of photovoltaic technology in terms of panels, fixing tables, wiring, screws, and inverters, besides taking into consideration the following factors as bank tax, inflation, discount rate, and the period of the useful life of the panels, to be able to know more accurately the period in which the investment will be recovered and the profits it will bring with him.

Cost analysis for the country.

To carry out the economic evaluation, all expenses associated with the installation of photovoltaic technology in terms of panels, fixing tables, wiring, screws, and inverters, besides having into consideration the following factors as bank tax, inflation, discount rate, and the period of the useful life of the panels, to be able to know more accurately the period in which the investment will be recovered and the profits it will bring with him.

The behavior of the market is analyzed to determine the amount of currency saved according to the amount of fuel not used for the generation of electricity provided by the photovoltaic installation.

Analysis Y input medium environmental.

- analyzing the issue of how much gas is left to burn down to produce the same amount of Energy.
- Therefore, from the fuel saved, it is possible to obtain the amount of CO_2 left to issue to the atmosphere in t/year.

Amount of fuel saved.

The determination of the amount of fuel saved is a critical metric that underscores the environmental, economic, and operational benefits of adopting fuel-efficient practices or technologies. By comparing the fuel consumption of a more efficient system or vehicle with that of a less efficient counterpart, the amount of fuel saved can be quantified. This reduction in fuel consumption contributes directly to environmental sustainability by lowering greenhouse gas emissions and mitigating the impact of transportation or industrial activities on air quality.

Economically, fuel savings translate into cost reductions for individuals and businesses, enhancing overall operational efficiency. This is particularly relevant in sectors heavily reliant on fuel, such as transportation, where fuel costs represent a significant portion of operating expenses.

Additionally, the conservation of fuel aligns with global efforts to address energy security and reduce dependence on finite fossil fuel resources. As the world shifts towards more sustainable energy practices, the amount of fuel saved becomes a key performance indicator for organizations committed to environmental responsibility and resource efficiency.

In conclusion, quantifying the amount of fuel saved is a multifaceted measure that reflects not only economic benefits but also environmental stewardship and a commitment to sustainable practices, making it a crucial consideration for both individual consumers and organizations alike.

Amount of CO_2 emitted into the atmosphere.

The quantification of the amount of carbon dioxide (CO_2) emitted into the atmosphere is a critical parameter in assessing the environmental impact of various activities and industrial processes. CO_2 is a major greenhouse gas responsible for climate change and global warming. Measuring and understanding the amount of CO_2 emissions is crucial for developing strategies to mitigate climate change and transition toward a more sustainable future.

Firstly, tracking CO_2 emissions allows governments, organizations, and individuals to identify major sources of pollution and implement targeted policies or practices to reduce carbon footprints. It serves as a key performance indicator in assessing progress toward environmental goals, such as those outlined in international agreements like the Paris Agreement.

Secondly, the amount of CO_2 emitted is directly linked to the combustion of fossil fuels, industrial processes, and deforestation. Monitoring these emissions provides insights into the effectiveness of efforts to transition to renewable energy sources, improve energy efficiency, and implement sustainable land use practices.

Furthermore, quantifying CO_2 emissions facilitates the development of carbon offset programs, where emissions in one area are compensated by carbon reduction or sequestration activities elsewhere. This contributes to the concept of carbon neutrality and promotes a balance between emissions and efforts to reduce or offset them.

In summary, the measurement and understanding of the amount of CO_2 emitted into the atmosphere are essential for informed decision-making, environmental policy development, and the global effort to combat climate change by reducing greenhouse gas emissions.

CONCLUSIONS

Photovoltaic solar systems are a promising alternative for the energy supply of buildings. Consuming energy obtained in the same place or very close to it is an ideal environmental and operational condition because it reduces losses due to transportation while promoting energy autonomy. In Cuba, the intensity of solar irradiation has a considerable value between 800 and 900W/m2 when it falls perpendicularly on a surface and more than 5kWh/m2 as the annual average value, which makes our country a propitious scenario for the use of photovoltaic solar systems for electricity generation.

For the selection and sizing of a photovoltaic solar system, a methodology is proposed that contemplates the method of manual calculations, including the most common computer tools for designing these systems, such as Pvsyst, Sketchup, Sunny Design, and Autodesk Inventor Professional.

The proposed methodology has as novelties the use of software already analyzed with a high level of effectiveness, which allows optimizing factors such as energy production and area to work, carrying out analysis of the effect of shadows and temperature in the system, and carrying out efficiency studies. Energy to achieve proper energy management and economic and environmental analysis that complements the study and allows us to see the effectiveness of the projects studied.

This research serves as a basis for future studies, allowing more precise analyses and covering all areas that govern energy management with its two main pillars: energy efficiency and renewable energy sources.

BIBLIOGRAPHIC REFERENCES

ABB. (2019). Photovoltaic plants Cutting edge technology. From sun to socket [Manual]. https://search.abb.com/library/Download.aspx?DocumentID=9AKK107492A3277&LanguageCode=en&DocumentPartId=&Action=Launch

Afif, R. A., Pfeifer, C., & El-Khozondar, H. J. (2019). Implementation of the maker movement to renewable energy laboratory: A case study of the auto-tracking photovoltaic model. 2019 IEEE 7th Palestinian International Conference on Electrical and Computer Engineering (PICECE), 1-4. https://doi.org/10.1109/PICECE.2019.8747226

Ahirwar, P., Kori, A. K., & Kapoor, S. (2021). Pre-Installation Analysis via "PVsyst" & "HOMER Pro" to Design and Simulate a 50kWp Solar Grid-Tied PV System for Rural Area Electrification, The structuralIndia. 2021 5th International Conference on Electrical, Electronics, Communication, Computer Technologies and Optimization Techniques (ICEECCOT), 388-394. https://doi.org/10.1109/ICEECCOT52851.2021.9708056

Becerra, R. M. (2019). Anteproyecto de sistema solar fotovoltaico en la Delegación Provincial de Materiales de la Construcción. Cienfuegos. Universidad de Cienfuegos.

Bentouba, S., Bourouis, M., Zioui, N., Pirashanthan, A., & Velauthapillai, D. (2021). Performance assessment of a 20 MW photovoltaic power plant in a hot climate using real data and simulation tools. ***Energy Reports***, *7*, 7297-7314. https://doi.org/10.1016/j.egyr.2021.10.082

Chandan, Baig, H., ali Tahir, A., Reddy, K. S., Mallick, T. K., & Pesala, B. (2022). Performance improvement of a desiccant-based cooling system by mitigation of non-uniform illumination on the coupled low-concentrating photovoltaic thermal units. ***Energy Conversion and Management***, 257, 115438. https://doi.org/10.1016/j.enconman.2022.115438

Chandan, Dey, S., Sujan Kumar, P., Reddy, K. S., & Pesala, B. (2020). Optical and electrical performance investigation of truncated 3X non-imaging low concentrating photovoltaic-thermal systems. ***Energy Conversion and Management***, 220, 113056. https://doi.org/10.1016/j.enconman.2020.113056

Chaware, A. V., Dambhare, S. S., Pathan, V., & Mistry, G. (2021). Design and Optimization of Mini-grid PV System for Developing Country. 2021 9th IEEE International Conference on Power Systems (ICPS), 1-6. https://doi.org/10.1109/ICPS52420.2021.9670199

Gassar, A. A. A., & Cha, S. H. (2022). Feasibility assessment of adopting distributed solar photovoltaics and phase change materials in multifamily residential buildings. ***Sustainable Production and Consumption, 29***, 507-528. https://doi.org/10.1016/j.spc.2021.11.001

Haggag, A., Aboshosha, A., & Azouz, M. (2021). Computer-Aided Design and Simulation-Based Efficiency Improvement of the First Egyptian Solar City. 2021 22nd International Middle East Power Systems Conference (MEPCON), 491-496. https://doi.org/10.1109/MEPCON50283.2021.9686277

Kanniappen, S. M., Sewsunker, R., & Lazarus, I. J. (2022). Design Scheme for Ring-Based Extra Low Voltage Off-Grid Photovoltaic Direct Current Microgrids for Rural Electrification. 2022 30th Southern African Universities Power Engineering Conference (SAUPEC), 1-6. https://doi.org/10.1109/SAUPEC55179.2022.9730642

Khezri, R., Mahmoudi, A., & Aki, H. (2022). Optimal planning of solar photovoltaic and battery storage systems for grid-connected residential sector: Review, challenges and new perspectives. ***Renewable and Sustainable Energy Reviews***, 153, 111763. https://doi.org/10.1016/j.rser.2021.111763

Manoj, N., Chakraborty, S., Kumar Yadav, S., Singh, J., & Chopra, S. S. (2022). Advancing simulation tools specific to floating solar photovoltaic systems – Comparative analysis of field-measured and simulated energy performance. ***Sustainable Energy Technologies and Assessments***, 52, 102168. https://doi.org/10.1016/j.seta.2022.102168

Marín, D. S., Zalamea, E. F., Barragán, E. A., Zalamea, E. F., & Barragán, E. A. (2018). POTENCIAL FOTOVOLTAICO EN TECHUMBRE DE EDIFICIOS INDUSTRIALES DE ALTA DEMANDA ENERGÉTICA, EN ZONAS ECUATORIALES. ***Revista hábitat sustentable***, *8*(1), 28-41. https://doi.org/10.22320/07190700.2018.08.01.03

Monteagudo, J. P., & Crespo, G. (2021). Evaluación Económica de Proyectos de Ahorro de Energía.

Othman, R., & Hatem, T. M. (2022). Assessment of PV technologies outdoor performance and commercial software estimation in hot and dry climates. ***Journal of Cleaner Production***, 340, 130819. https://doi.org/10.1016/j.jclepro.2022.130819

Santos, R. D., Fuentefría, A. S., Fernández, M. C., & Llanes, M. V. (2018). Análisis de la influencia del ángulo de inclinación en la generación de una central fotovoltaica. ***Revista de Ingeniería Energética***, ***39***(3), 11. http://scielo.sld.cu/scielo.php?pid=S1815-59012018000300002&script=sci_arttext&tlng=en

Saymbetov, A., Mekhilef, S., Kuttybay, N., Nurgaliyev, M., Tukymbekov, D., Meiirkhanov, A., Dosymbetova, G., & Svanbayev, Y. (2021). Dual-axis schedule tracker with an adaptive algorithm for a strong scattering of sunbeam. ***Solar Energy***, 224, 285-297. https://doi.org/10.1016/j.solener.2021.06.024

Setiawan, R. J., Fauzi, I., & Enja, M. (2018). Smofim: smoke fish machine based on solar photovoltaic integrated android mobile iot (internet of things) with exhaust filter reducing co, co2 and hc pollutants as an effort to improve the economy of the fishermen community at trisik beach. ***Jurnal Ilmiah Penalaran dan Penelitian Mahasiswa 2***, 42-51.

Stolik, D. (2014). La energía FV: oportunidad y necesidad para Cuba. http://scielo.sld.cu/scielo.php?pid=S0252-85842014000200005&script=sci_arttext&tlng=pt