Article

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3D methodology for designing Grid-Tie Photovoltaic Systems

Metodología de diseño tridimensional para Sistemas Fotovoltaicos Interconectados

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Abstract

This article presents a methodology for the design of Grid-tie photovoltaic systems using computational tools for 3D modeling, in order to have a clearer vision of installation and with the purpose of acquiring the detailed material of what is required to have a more successful initial investment for a project. As a methodological test, a solar power plant is designed on the buildings of the Faculty of Electromechanical Engineering in Manzanillo Colima. For this purpose, the Sketchup and Helioscope softwares are used to obtain the installed capacity of the buildings, selecting the solar modules, inverters and the quantity in meters of accessories such as cable, pipe, etc. SolidWorks is used to design the assembly system and obtain the amount of material with screws included and thus make a much more accurate calculation of the initial investment required.

Interconnected Photovoltaic systems, Sketchup-photovoltaic, Solar systems

Resumen

En este artículo se presenta una metodología de diseño de sistemas fotovoltaicos interconectados la red con herramientas computacionales para su modelado en tercera dimensión con la finalidad de tener una visión más clara de una instalación y con el propósito de adquirir el material detallado de lo que se requiere para tener de forma más acertada la inversión inicial de un proyecto. Como prueba metodológica se diseña una planta solar en los edificios de la Facultad de Ingeniería electromecánica en Manzanillo Colima, para esto se utilizan los softwares Sketchup y Helioscope para obtener la capacidad instalada de los edificios, seleccionar los módulos solares, inversores y la cantidad en metros de accesorios como cable, tubería, etc. SolidWorks es utilizado para diseñar el sistema de montaje y obtener la cantidad de material de forma óptima con tornillería incluida y así realizar un cálculo mucho más acertado de la inversión inicial requerida.

Sistemas Fotovoltaicos interconectados, Sketchup-fotovoltaico, Sistemas solares

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Introduction

Solar energy is one of the most attractive types of energy, especially with the constant fluctuation in the supply of the electricity grid. Modern solar cell technologies are increasing their viability due to cost reduction and greater energy production efficiency. This trend in the price of solar cells will increase the applications of solar panels in buildings, houses, commerce and industry.

Solar panels could be integrated into the facades and/or roofs of buildings. There are several geometric considerations for the installation of photovoltaic systems, regarding the installation and the azimuth angle taking into account the influence of shading caused by the environment. (Yoon, Song, & Lee, 2011).

Avoiding shading is useful not only for power generation, but also to reduce the working temperature in cells. A good design and planning can provide savings in the integration of photovoltaic energy in buildings, even in the mounting structures of photovoltaic modules. On the other hand, mounting systems are easier to install and operate the maintenance service once installed.

In the literature we can find a series of articles that use tools to analyze already installed systems or perform some planning-design of photovoltaic systems. (Mondol, Yohanis, & Smyth, 2005) present an electrical and thermal modeling for a system mounted on a sloping roof in Ballymena, Northern Ireland using TRNSYS, similar to that of (Fara, Moraru, Sterian, & Bobei, 2013). (Mohammad I., 2017) proposes to design a photovoltaic solar power plant connected to the 56.7 kW network to meet the demand for electricity at the Faculty of Engineering of the University of Mu'tah. On the other hand, (Peng, Wu, & Huang, 2012) analyze the problems related to photovoltaic energy integrated in the architectural design in China.

Simulation models to analyze the performance of photovoltaic devices are also available in some existing programs, such as PVsyst, (PVsyst, 2019), PVWATTS (Marion, Anderberg, & George, 2001), among others.

There are also a series of articles focused on obtaining the typical PV and VI curves of the photovoltaic modules as presented by (Brano, 2012). These tools provide a good prediction regarding power generation with a small margin of error; however, they do not calculate the installed capacity of a building or system.

For this reason, three-dimensional (3D) planning has also been considered recently, (Malak Yaghi, 2017) discusses the potential of solar panel implementation at the International University of Lebanon using the HelioScope simulation tool, since this tool was validated by (Guittet & Freeman, 2018). Similarly, Google SketchUp is a popular 3D drawing tool that is capable of designing complex 3D models which allows third-party add-ons to add functionality. For example, National Renewable Energy Labs is a SketchUp add-on (Stephen, Kambadkone, & Quanhui, 2009) which is primarily designed to be a geometry editor with geolocation and to work with the EnergyPlus tool to incorporate the 3D design of 3D photovoltaic systems using SketchUp, while using EnergyPlus as a building simulation engine, incorporating photovoltaic modules as in the case of (Hongxin, Guo, Gang, & Wang, 2018) and (Li, Si, & Liu, 2018).

This type of dimensioning gives a clear idea of how a photovoltaic system will be installed, since we can select the capacity of a module and size the installed capacity in the selected place, giving orientation and inclination; however clarity is lacking in the mounting systems. For this reason, this paper aims to present a design methodology that involves several tools in order to obtain in detail all the technical aspects. In this way, we can acquire a detailed list of all the material required to perform an installation and obtain the initial cost with precision to avoid losses and perform an optimized installation.

Section two illustrates the methodological proposal for the design of three-dimensional solar plants; section four shows the obtainment of the required initial investment and finally the conclusions.

Methodological design proposal

The proposed methodology is illustrated in the following flowchart showing the sequential work (Fig. 1).

First, the surface areas of buildings, trees, and any possible shade are modeled. For this the modeling technique the Sketchup and Helioscope tools are used. These allow us to properly select each of the elements that make up the system since they have incorporated a database of solar panels and inverters that exist in the market. The modeling technique enables shadow analysis to reach an estimate of photovoltaic production considering geolocation; thus, using a quantitative methodology to analyze the energy savings that can be obtained.

The mounting system is also carried out with the simulation technique using the Solidworks tool to obtain the amount of material required such as aluminum rails, screws, wiring etc. With this information, we can obtain the required initial investment and have an estimated return of investment.

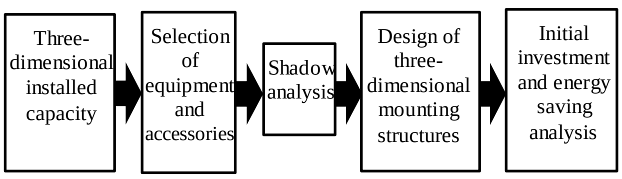

Figure 1 Flow chart of the proposed methodology

1. Dimensioning by building

In order to make the most of the area of the buildings located in the Faculty of Electromechanical Engineering, the largest possible number of panels will be placed on the surface of each building, so that they take advantage of the greatest amount of solar radiation and thus obtain a considerable energy production to create a greater impact in reducing the consumption energy to the grid.

For the dimensioning of the photovoltaic system, the Helioscope and Sketchup tools were used, both in conjunction with the use of Google Maps as shown in Figure 2, which illustrates the dimensioning in each of the faculty buildings. For this study, the use of the manufactured panel of 320 was established with technical specifications described in Table I.

This dimensioning allows taking advantage of as much space as possible for the placement of the photovoltaic modules, considering the losses due to shadows.

Figure 3 illustrates one of the buildings dimensioned with 320W photovoltaic modules oriented from north to south with an azimuth angle of 180º. In this case, aisles are left for maintenance when required. For this building, 160 panels with two 27.6kW inverters are considered, the inverter data is illustrated in Table II.

Figure 2 Dimensioning in Sketchup

Figure 3 Laboratory in Sketchup

The analysis of shadows illustrated in Figure 4 shows that there is only a loss of between 2% and 3% mainly by trees, in the months with less radiation and only a few hours after sunrise and sunset.

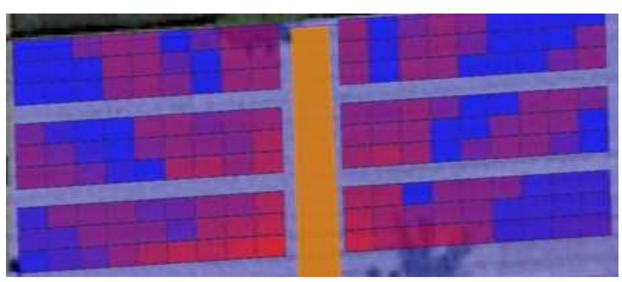

Figure 4 Laboratory shadow analysis

Model: JC320M-24/Abs	
Rated power [W]: 320	**Ground connection:** N/D
Tensión a circuito abierto: Voc[V]:45.60	**Short circuit current Isc [A]:** 9.0
Max Voltage Vmp Power: 37.40	**Max Power Current Imp [A]:** 8.56
Coef Voc temperature [V/oC] -0.137 **[%/oC]** -0.300	**Coef Isc temperature [mA/oC]** -3.6 **[%/oC]** 0.04
Max Tens Syst (IEC) [V]: 1000	**Coef Pmax temperature [%/oK]:** -0.4

Table 1 Technical specifications of the selected panel

The electrical connections are illustrated in Figure 5. It shows two parallel chains of 20 panels connected in series that will be connected to a 30A fuse which go to the input of a Maximum Power Point Tracking (MPPT) of the inverter. Connected to this are 80 panels. With this connection the inverter works correctly, since the input voltage is 920V open circuit and 18A short circuit, input values that can be seen in Table II.

2. Mounting system design using 3D SolidWorks

The purpose in this section is to acquire the necessary material for the installation considering the type of aluminum mounting rails, in addition to the necessary hardware and accessories.

It is worth mentioning that mounting systems can be designed in any other CAD tool such as Solidworks or AutoCAD; the objective is to minimize the costs in the installation of the mounting systems, as well as the accessories.

Figure 6 illustrates the assembly of all parts for the analysis of material required for the structures. Due to the size of the selected modules and looking for an optimization in the use of aluminum angle, the figure shows a structure for 9 solar panels.

Each structure is made up of 14 sections of 6m of 1.5-inch aluminum angle, these components will be fastened by 16 3/8" stainless steel screws due to the humidity and salinity of the environment.

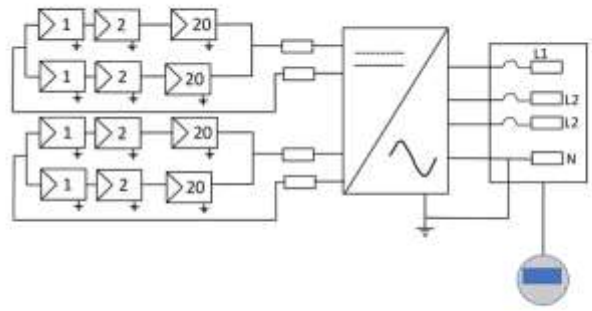

Figure 5 Single line connection diagram

3. Estimation of photovoltaic production

Once the analysis has been carried out for each of the buildings, in terms of their dimensioning, shadow analysis and disengagement of assembly structures, an analysis of energy production versus current campus consumption is performed.

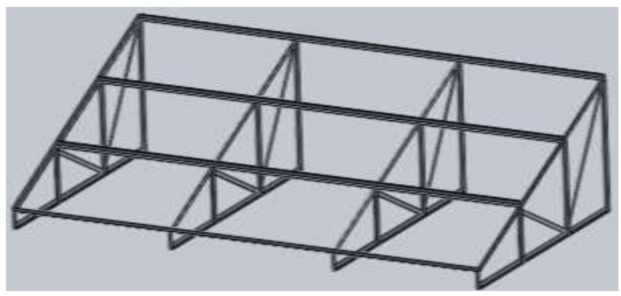

Figure 6 SolidWorks assembly system design

The monthly average of solar radiation in the inclined photovoltaic assembly indicates that the minimum generation during December is (20.9MWh/month) and maximum in March (35.07MWh/month), this is because of the variation in temperature of the location. The photovoltaic power generated for each month is illustrated in Figure 7.

These generations represent an average saving of 31.9% of total consumption. Figure 8 illustrates the generation of energy per day throughout the year; these data are obtained with the PVsys and Helioscope software and show an average daily production of around 1000kWh/day.

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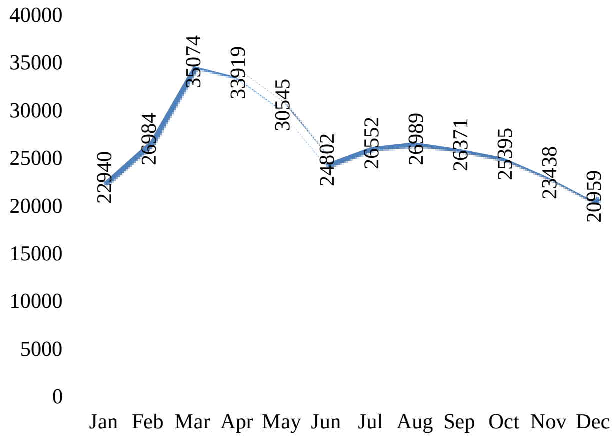

Figure 7 Monthly energy generation

Figure 9 shows the analysis of current energy consumption on campus along with the generation per month.

Investor Data	
INPUT	**OUTPUT**
Rated input power (Pdc,r) **[W]: 28600**	**Nominal Active Power** (Pac) **[W]:** 27600
Maximum input power (Pdc,max) **[W]:** 31100	**Max Active Power** (Pac fp=1) **[W]:** 30000
MPPT maximum power (Pmppt,max) **[W]:** 16000	**Max Apparent Power.** (Smax) **[VA]:** 30000
Maximum input voltage (Vin,max_abs) **[V]:** 1000	**Nominal voltage** (Vac) **[V]:** 400
Min. op tension of MPPT (Vin,min_mppt) **[V]:** 70%Vstart	**Nominal frecuency** (fr) **[Hz]:** 60
Max. op tension of MPPT (Vin,max_mppt) **[V]:** 950	**Number of phases: 3**
Maximum input voltage (Vin,max_abs) **[V]:** 1000	**Rated power factor Fp = 1**
Tens. Default activation (Vstar_ref) **[V]:** 430	
Tens. Range activation (Vstar_rag) **[V]:** 250-500	
MPPT number: 2	
Max. MPPT current (Imppt_max) **[A]:** 32	
MPPT short circuit current (Iscmax) **[A]:**40	

Table 2 Technical specifications of the selected inverter

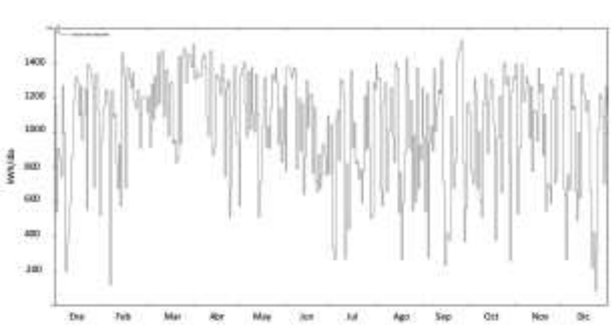

Figure 8 Energy production per day

Initial investment analysis

Table III illustrates in detail each of the materials required to perform the installation in the building illustrated. The initial cost for this building is 30,000US; it is worth mentioning that the costs were obtained with local suppliers and in some cases with manufacturers, so the initial cost depends on these and therefore may vary.

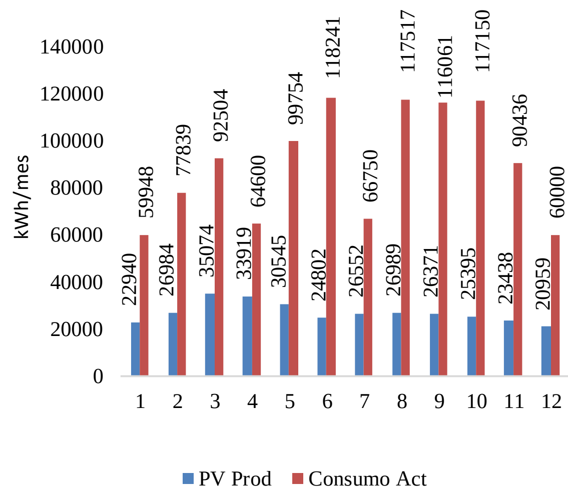

Figure 9 Energy production per day vs consumption

After performing this procedure for each of the buildings, the initial investment required ranges between 450,600US with a return of investment of 4.3 years, with the conditions under which the analysis was performed, that is, with the rates, costs and consumptions.

Conclusions

We carried out the analysis of the energy behavior of a photovoltaic system integrated in the buildings of the Faculty of Electromechanical Engineering of the University of Colima. The use of several tools such as Helioscope, PVsyst, Sketchup, Solidworks allowed us to know in detail the energy performance of the power produced and the technical needs of the project.

The roof segments chosen for the installation are suitable, since they do not offer significant losses due to shading and have enough free space. The results obtained regarding the solar resource and the technology performance are perfectly adjusted to previous studies.

Material	Quantity
320W solar panel	162
INVESTOR 27.6-TL	2
MC4 (pair)	24
MC4 3 way (pair)	2
Connection cabinet	2
30A fuse	2
50A 3Ø thermomagnetic protection	2
Anodized 6m aluminum angle	252
THW cable 10 AWG at 1000V (m)	176
Isolator switch	4
Peak Suppressor	4
T and LB Condulet	6
1 * 1/4 stainless steel screws with double washer and lock nut	500
4 * 1/4 stainless steel screws with double washer and locknut	700
1/8 * 3/4 stainless steel screw	200
Harpoon wall plug 3/8 "	144
High temperature silicon	2
3/4 "thin wall galvanized steel pipe	20
Fuse holder	4
Grounded windmill	2
Bare cable cal 8 (m)	100
THW cable cal 8 AWG (m)	12
Data Logger monitoring system.	1

Table 3 Initial investment of building

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