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Article

Grid-interconnected photovoltaic system as an alternative to achieve climate neutrality through the energy transition

Sistema Fotovoltaico Interconectado a la red, como alternativa para lograr la neutralidad climática a través de la transición energética

Marroquín de Jesús Ángel [a], Castillo-Martínez, Luz Carmen [b], Soto-Álvarez, Sandra [c] and Olivares-Ramírez, Juan Manuel [d]

[a] ROR Universidad Tecnológica de San Juan del Río• 0000-0001-7425-0625 • 81204
[b] ROR Universidad Tecnológica de San Juan del Río• 0000-0001-7953-0431
[c] ROR Universidad Tecnológica de San Juan del Río
[d] ROR Universidad Tecnológica de San Juan del Río • 0000-0003-2427-6936

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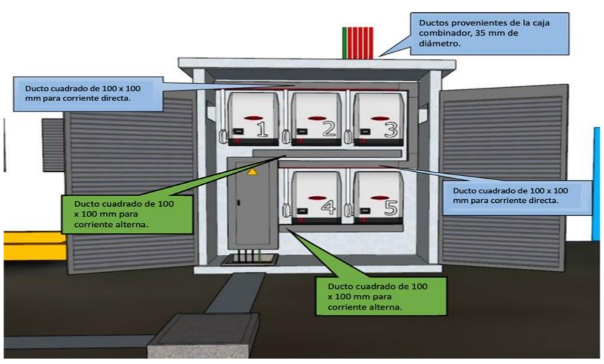
* ✉ [example@example.org]

Abstract

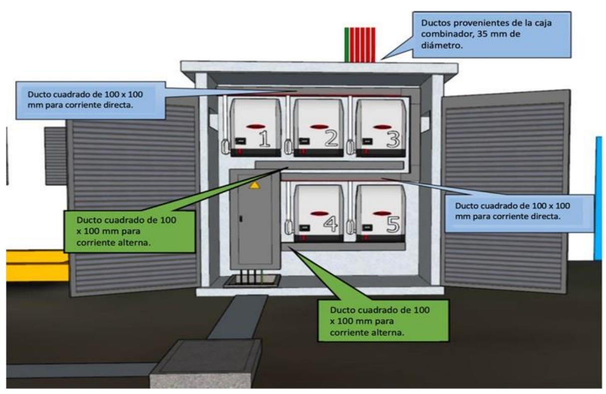
This work is based on the methodology proposed by the International Renewable Energy Agency (IRENA) as the methodology to be followed by a certified designer of photovoltaic systems. It shows the calculations to select the electrical protections, the calibers of the phase and ground conductors, channeling and distribution board, the photovoltaic system has been in operation for about four years, using the inverter manufacturer's platform, it is possible to obtain information related to the number of tons of CO2 that has been stopped emitting to the atmosphere as well as the total energy generated.



Renewable energies, Solar energy, Photovoltaic systems, Photovoltaic power plants, Distributed generation

Resumen

El presente trabajo está basado en la metodología propuesta por la Agencia Internacional de Energías Renovables (IRENA) como metodología a seguir por un diseñador certificado de sistemas fotovoltaicos. Muestra los cálculos para seleccionar las protecciones eléctricas, los calibres de los conductores de fase y de tierra, canalizaciones y tablero de distribución, el sistema fotovoltaico ha estado en operación por alrededor de cuatro años, utilizando la plataforma del fabricante de los inversores, es posible obtener información relacionada con el número de toneladas de CO2 que se ha dejado de emitir a la atmósfera de igual manera el total de energía generada..



Energías renovables, Energía solar, Sistemas fotovoltaicos, Plantas fotovoltaicas, Generación distribuida

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Introduction

The main components of a photovoltaic system connected to the grid are: the photovoltaic array, which is the element in charge of transforming the sun's radiation into electricity; and a power conditioning element, a direct current to alternating current inverter, whose function is to adapt the energy generated by the array to the electrical characteristics of the grid to which it will be connected.

A PV array is made up of a number of arrays or PV power sources. The number of units will depend on the nominal power required in the array and the peak power of the selected modules. The output voltage of the array, which corresponds to the operating voltage of the inverter, is obtained by connecting a number of arrays or PV power sources in series, and the power is obtained by connecting them in parallel. Currently, the nominal power of solar photovoltaic modules or panels is 570 Wp. The typical efficiency of these modules under standard irradiance and temperature conditions (i.e., 1,000W/m2) is between 14 and 22% for monocrystalline polycrystalline silicon (25°C, AM 1.5) and between 5 and 7% for amorphous silicon.

The most important potential benefits are:

- Modulation of peak demand when there is some degree of coincidence between the PV generation profile and the consumption profile of the building or feeder.
- Thermal relief to distribution equipment, which also implies the possibility of postponing capital investments to increase capacity or replacement.
- Reduction of transmission and distribution losses.
- Voltage support in distribution feeders.
- Reactive power compensation on the feeder.

In relation to the safety and quality aspects of the energy produced, the electricity service supply companies require manufacturers and users of this equipment to comply with article 690 of NOM 001 SEDE 2012 and applicable provisions that guarantee that the installation and operation of the inverter, as well as the photovoltaic system as a whole, is safe and does not adversely affect the quality of the energy.

Theoretical Framework

Climate change is the greatest environmental challenge facing humanity.

The 2015 Paris Agreement was decisive for action, with 195 countries agreeing to limit the global temperature increase of planet Earth to 2 °C by the end of the century compared to the pre-industrial era and to continue efforts to reduce it to 1.5 °C.

Decarbonisation is the process of reducing carbon emissions, especially carbon dioxide (CO2), into the atmosphere.

The overarching goal is to achieve a low carbon global economy that achieves climate neutrality through the energy transition.

To achieve decarbonisation, it is necessary to decarbonise energy production. By taking advantage of alternative energies it will be possible to supply electricity and mitigate the generation of polluting gases.

At the Universidad Tecnológica de San Juan del Río it is very clear that the use of renewable energies is very profitable to reduce electricity costs and contribute to the care of the environment. Renewable energies have been promoted at the university for several years.

The annual energy consumption is 422.5 MWh, the 79.2 kWp photovoltaic system installed on the roof of the ‘K’ building provides 30 percent of the energy demanded by the loads installed in the university's teaching and laboratory buildings, and produces an economic saving of 20 percent on the electricity bill paid monthly to the Federal Electricity Commission (Comisión Federal de Electricidad).

The photovoltaic plant interconnected to the grid at the Universidad Tecnológica de San Juan del Río is a clear example of how it is possible to gradually move towards the use of renewable energies, which strengthens the renewable energy career currently offered and places our university in the select group of higher education institutions that implement concrete actions for the care of the environment.

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Research question

In higher education institutions in the state of Querétaro, does the cogeneration of electrical energy by means of a photovoltaic system interconnected to the grid allow for the saving of electrical energy, contribute to a reduction in the payment of the electricity bill, and avoid the emission of tons of CO2 into the atmosphere in comparison with higher education institutions without interconnected photovoltaic systems?

Overall objective

To dimension and install a photovoltaic system interconnected to the grid, using the rooftop area of building 'K', which produces 30% of the electrical energy consumed by the electrical equipment installed in the Technological University of San Juan del Río, and which also generates an estimated saving of 20% in the payment of the current bill, based on the current regulations.

Specific objectives

1. To dimension a photovoltaic system interconnected to the grid, which produces 30% of the energy consumed by the electrical equipment installed in the teaching buildings and laboratories of the Universidad Tecnológica de San Juan del Río.

2. To install the photovoltaic panels on the roof of building 'k'.

3. Install the photovoltaic inverters

4. Interconnect the energy produced to the main low voltage board of the 225 kVA, 13.2 kV- 220 V/127 V transformer.

5. Evaluate the energy production using the on-line monitoring system of the photovoltaic system.

Hypothesis

Electrical energy will be generated with a photovoltaic system interconnected to the national electrical system with resources coming from the federation, considering the local solar radiation levels with the objective of being able to increase the operative capacity represented by the electrical energy consumption registered during the year 2017.

In 30% of the energy consumed in the facilities of the university impacting on the costs of electrical energy maintaining at most a monthly payment equivalent to the records of billable demand of the electrical equipment used in the charging period by the ComisiónFederal de Electrticidad (Federal Commission of Electricity).

Methodology

Evaluation of the installation site

The high insolation values present in most of the territory of our country are the basis for the generation of solar photovoltaic and thermal energy. Some factors such as altitude, slope and orientation of the terrain, as well as the shadows produced by the surrounding topography, influence the radiation received (Sánchez, 2023).

In addition to the above, it must also be taken into account that it also depends on the time of day and the time of year. (Edding, 2023).

Box 1

Table 1

Summary of geographical, climatic and meteorological conditions for the project design and implementation site study.

Geographical data (Vdocumento, 2023)	
Location of the installation site	Vista Hermosa, Municipality of San Juan del Río. Querétaro.
Latitude	20.369°
Longitude	-100.010°
Altitude	1978 metres above sea level
Climate and weather data	
Peak solar hours time (in hours) of a hypothetical constant solar irradiance of 1000 W/m² (Widiatmika, 2023)	6.19 kWh/m²/día
Irradiancia	5.6 kW/m²
Warmest month average temperature (Vdocument, 2023)	25.6°C
Average temperature of the coldest month	7.45°C
Average annual temperature	19°C (10 m from the surface) (Rodriguez, 2023)
Annual precipitation regime	586 mm

There are three types of solar radiation, diffuse, direct and reflected, global radiation is the sum of all three. At the earth's surface it is at best 1000 W/m2. In sizing calculations of solar photovoltaic systems, it is often appropriate to consider the amount of solar radiation reflected by the surfaces adjacent to the PV modules.

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The position of the sun varies during the day and over the seasons, so the angle at which the sun's rays strike a surface also varies. Energy generation depends on the orientation and inclination of the PV modules.

Development of the calculation

The solar radiation values at the site are obtained from National Aeronautics and Space Administration (NASA) data for latitude and longitude at a specific tilt, the recommended optimum tilt will be the latitude of the site with a tolerance of +/- 5°; at a tilt of 20°, the available annual irradiation is 6.19 HSP, but the roof of building 'K' was used, which has a tilt of 15°, a reduction factor of 2.5° annual average needs to be applied, leaving 6.04 HSP.

The photovoltaic power source used is of the Jinko solar brand, model JKM330PP-72 4BB, polycrystalline type, with a linear performance guarantee of 12 years at 90% and 25 years at 80.7% 0 to +3%. Assuming a nominal power tolerance of 0 %, on a 330 W module the power reduction due to dust is considered to be 5 %, so 330 W x 0.95; the output power of the PV power source is reduced above 25°C or increased below 25°C assuming an ambient temperature of 30°C, the effective cell temperature is 30°C + 25°C = 55°C, 30°C above the standard temperature a 313.5 W polycrystalline module with a coefficient of -0.3% per °C, temperature loss = 30°C x 0.3% x °C = 9% the 313.5 W module would lose 9% per temperature to 313.5 x 0.91 = 285.28 W. The system consists of 240 photovoltaic power sources, placed on the roof of the building 'K'.

Calculation report

Characteristics of the photovoltaic energy source:

Box 2
Table 2
Technical data of the photovoltaic module

Rated power STC	330W
Voltage at maximum peak power Vmp	37.80 V
Current at maximum peak power Imp	8.74 A
Open circuit voltage VOC	46.90 V
Short circuit current Isc	9.14 A
Temperature coefficient for open circuit voltage TCvoc	-0.30 %/°C
Total number of modules:	240 pcs. ; 79,200 W

Photovoltaic power source parameters adjusted for temperature.

For the temperature coefficient of the module, we have that:

$$\boldsymbol{Vt} = \boldsymbol{Voc} + (\text{TC} \cdot \Delta \boldsymbol{Temp} \cdot \boldsymbol{Voc}). \quad (1)$$

Where:
$\boldsymbol{Vt}$ = Output voltage at temperature different from 25°C.
$\boldsymbol{TC}$ = Temperature coefficient $\Delta \boldsymbol{Temp}$ = Temperature differential

$\boldsymbol{Vt}$=46.90$\boldsymbol{V}$+(-0.0030/°$\boldsymbol{C}$·(0-25°$\boldsymbol{C}$) ·46.9$\boldsymbol{V}$ (2)
$\boldsymbol{Vt}$ = 46.90$\boldsymbol{V}$ + 3.5175$\boldsymbol{V}$ (3)
$\boldsymbol{Vt}$ =50.4175 ~ 50$\boldsymbol{V}$

Minimum temperature recorded at the site = 0°C (Col. Vista Hermosa, Municipality of San Juan del Río, Qro.) Inverter: Brand: Fronius, Series: Symo 15.0-3 208/220, inverter power: 15.000 W. (Fronius, 2023)

Box 3
Table 3
Summary of modules and strings by inverter

Maximum MPPT voltage	850 V; 850 V / 50 V= 17 modules
Number of modules per selected chain	= 16
Number of chains	15,000W/330W = 45.45/16 = 2.84 ~ 3 chains

It was decided to place 3 strings of 16 PV power sources each: Open circuit voltage (Voc) of the string adjusted by temperature = 50 V x 16 = 800V (Vdocument, 2023), short-circuit current of each string: 9.14 Amperes. In the photovoltaic source and output circuits the ampacity or conduction capacity of the conductors must be selected with a value of 1.56 times the short-circuit current of the photovoltaic energy source (NOM-001 SEDE 2012, Art.690-8) (Government, 2023) (Idoc, 2023).

Box 4
Table 4
Calculation of conductors and protections according to the short-circuit current of the photovoltaic module

Calculation of conductors (Isc x 1.56)	(NOM-001-SEDE- 2012, 690-8 (a)(1), (b) (1))
Calculation of protections (Isc x 1.25)	(NOM-001-SEDE- 2012, 690-8 (b) (1))

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Correction factors for ambient temperature (Idoc, 2023)

In accordance with Table No. 310-15(b)(2)(a) of NOM-001-SEDE 2012, for ambient temperatures above 30°C, the current rating shall be corrected by reducing its value, ambient temperatures different from those shown in the ampacity tables shall be corrected following table 310-15(b)(2)(a) or Table 310-15(b)(2)(b) of NOM-001-SEDE-2012. Conductor calculation (Short circuit current x 1.56) = 14.26 A, in accordance with NOM-001-SEDE-2012, 690-8(a)(1), (b)(1)).

Cable temperature range = 75°C. Maximum ambient temperature: 25.6°C + 22°C = 47.6°C (22°C are added from table 310-15(b)(3)(c) of NOM- 001-SEDE-2012 for conductors exposed to sunlight). (Vdocumento, 2023).

Temperature adjustments for sun-exposed ducts on rooftops

Ducts housing conductors are exposed to direct sunlight on rooftops, the values provided in Table 310-15(b)(3)(c) should be added to the outdoor temperature to determine the corresponding ambient temperature for the application of the correction factors in Tables 310-15(b)(2)(a) or 310-15(b)(2)(b). Correction factor: Ampacity /0.75 (for adjusted ambient temperature of 47.6°C) Table No. 310-15(b)(2)(a) of (NOM-001-SEDE 2012). 14.26A / 0.75 = 19.01 A. A total ampacity to be considered for D.C. conductor calculation.

Adjustment of ampacity by number of conductors in a duct

When the number of current-carrying conductors in a duct exceeds three. Where individual conductors or multicore cables are installed without maintaining their spacing over a continuous length in excess of 0.6 m and are not installed in raceways, the allowable ampacity of each conductor shall be reduced as illustrated in Table 310-15(b)(3)(a).

Each current-carrying conductor in a group of conductors in parallel shall be counted as one current-carrying conductor.

This configuration does not apply since there are a maximum of three current-carrying conductors in the same conduit. Ampacity of conductors adjusted to temperature by a) to d) = 19 A.

Summary for conductor selection

Conductor ampacity = 156% of the maximum circuit current, calculated according to NOM-001-SEDE-2012, article 690-8. Conductor ampacity = 9.14 Amperes x 1.56 = 14.26 Amperes. Conductor ampacity adjusted for temperature = 14.26 Amperes/0.75 = 19.01 Amperes (Table No. 310-15(b)(2)(b) of NOM-001-SEDE 2012); therefore, the number of strings per inverter = 3.

Current conductor ampacity in parallel current amperes of 1 string set = 19.01 Amperes; ~ 19 Amperes. Conductor voltage = Temperature adjusted VT module voltage = 50 VDC Temperature adjusted 16-module string voltage = 800 VDC.

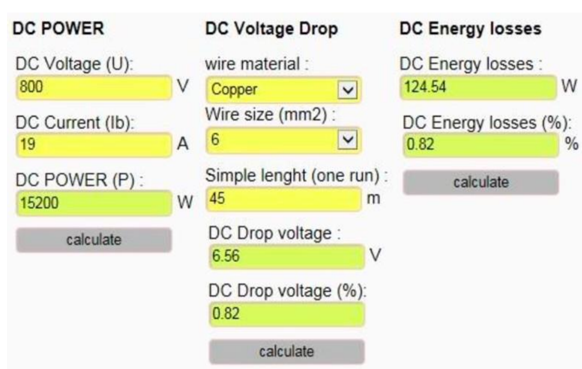
Calculation of conductors and protections for direct current

For the calculation of the PV power supply junction box conductor and protections on the DC side. Length of the string conductor furthest from the junction boxes and fuse boxes = 45 metres.

Box 5

Table 5

Voltage drop and DC power loss calculator



Conductor size: 10 AWG (6 mm2) shall be used; the conductors of the three strings to junction boxes and shields on the DC side from 1 to 5 are 10 AWG wire, 10 AWG solar cable in thick-walled metal conduit.

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In all branches or strings to the junction box and protections on the direct current side, the conductor size of the circuit from the photovoltaic source to the junction box must be selected to avoid a voltage drop of no more than 1% (Vdocument, 2023), as indicated in ANCE-ESP-02.

The maximum current to be conducted is within the permissible range according to table 310- 15(b)(16) of NOM-001-SEDE-2012 (Bedolla, 2023).

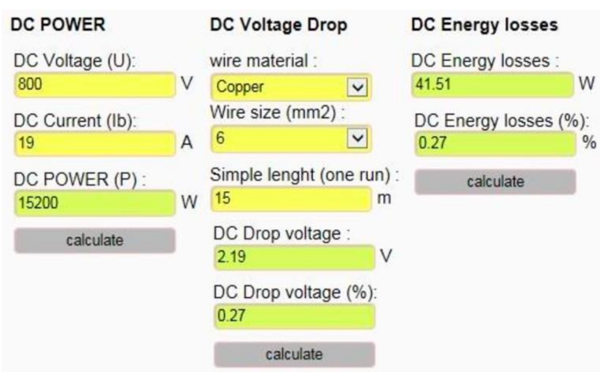
Calculation of conductors of junction boxes and protections in direct current to inverters.

Length of conductors from junction box to inverters 1 to 5 = 15 meters (Vdocumento, 2023).

Box 6

Table 6

Voltage drop and DC power loss calculator



10 AWG wire (6 mm2), 10 AWG solar wire in thick-walled metal conduit . Source: http://photovoltaicsoftware.com/DC_AC_drop_voltage_energy_losses_calculator.php

Selection of the junction boxes at the output of the PV generator

To connect the photovoltaic power sources to the junction boxes, the largest gauge conductor compatible with MC4 type connectors that come from the factory in the photovoltaic power sources was considered; 10 AWG gauge and due to the fact that the selection of conductors between the junction boxes and the inverter yields 10 AWG gauge, fuse holders will be used to protect the positive pole as a means of protection and for the negative conductor the direct passage of the photovoltaic power sources to the input to the inverters.

The IP 65 metal box or enclosure will be used with 15 single-pole fuse holders with sufficient space to house the positive, negative and earthing conductors, as well as the incoming and outgoing conduits.

Conduits and protections at the direct current input to inverters

A 4-inch x 4-inch square metal conduit is used to house the direct current wiring before entering each inverter without mixing with the alternating current wiring as specified in 310-3(c)(2). The disconnect devices included with each inverter and the fuse holders built into the inverter body itself are used for protection.

Alternating current

Calculation of the cable cross-section between the inverter output and the load centre concentrator. For the calculation of the cable cross-section between the inverter output and the load concentrator, a maximum conductor length from the inverters to the AC load centre of 3 metres is considered.

The total number of conductors in the ducting to the AC load centre or AC inverter output concentration point, upper level in the inverter room (inverter numbers 1 to 3); 3+3+3, a total of 9 current-carrying conductors, consider a factor of 80 % (Table 310-15(b)(3)(a), when selecting the conductor ampacity because the conductors of inverter number 1 do not exceed 0.60 m of travel next to the following two inverters: 50 Amperes/0.8 = 62.5 Amperes, by reference to table 310-15(b)(16), the 4 AWG gauge covers the maximum ampacity to be used; calculation result: 4 AWG gauge (21.2 mm2) covers the setting range for ambient temperature.

Lower level in inverter room (inverter numbers 4 and 5); 3+3, a total of 6 current-carrying conductors, a factor of 80 % is considered (Table 310-15(b)(3)(a), when selecting the ampacity of the conductor: 50 Amperes/0.8 = 62.5 A, from Table 310-15(b)(16), 4 AWG gauge covers the maximum amperage to be used, considering a consumption of less than 100 A, the column corresponding to the temperature of 60°C is used for the calculation. 110-14(c)(1)(a). Resulting in the calculation: 4 AWG gauge wire (13.3 mm2) (Ecorfan, 2023) .

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Box 7

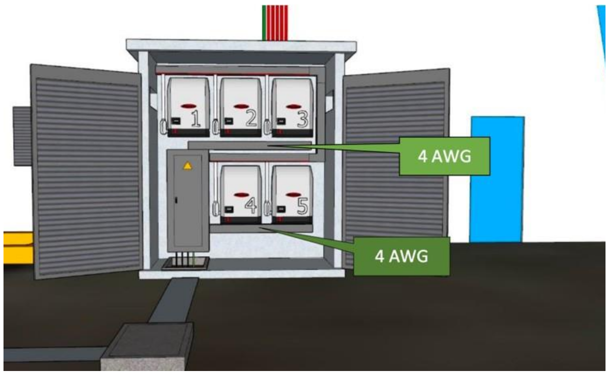

Figure 1
Inverter room

Calculation of cable cross-section from concentrator load centre to output thermal magnetic breaker (TMCB)

It is considered that the length of the conductor from the AC load centre to the output of the main inverter (Bedolla, 2023) TMCB is equal to 1 meter, the maximum ampacity when connecting the five three-phase inverters = 50 Amperes x 5 = 250 Amperes, a maximum current of 250 Amperes will circulate through the bus bars of the connection board, so the board was selected for 400 A, being below the capacity when generating the maximum amperage at maximum irradiation of the PV system. (Vdocument, 2023)

Calculation of the cable cross-section at the output of the inverter and the point of interconnection to the national electricity system, common coupling point.

In the output circuit of the inverter, the conductors must be selected to have a conductive capacity of 1.25 times the current at the rated power of the inverter, the maximum current must be the permanent output current of the inverter 690-8 (a)(3). (Vdocumento, 2023)

Box 8

Table 7
Maximum continuous current output of the inverters

Alternating current voltage	220 Volts
Phases	3; L1, L2, L3, no neutral required for the selected inverter model and configuration.
Maximum continuous current output for each inverter	39. 4 A
Driver ampacity adjusted	39.4 x 1.25=49.25 A ~ 50 A
Number of investors	5
Maximum AC current output of the PV system	250 A

Taking as a reference table 310-15(b)(16) for the type of cable used THHW 90°C, considering consumption greater than 100 A, a column corresponding to a temperature of 75°C is used for the calculation, as indicated in Art. 110-14 (1)(a)(1). The classification according to table 310-15(b)(16) results in the conductor 250 kcmil, applying the temperature correction factor of table 310-15(b)(2)(a) for an ambient temperature of 21-25°C = Amperes x 1.05= 250 A x 1.05 = 262.5 A, so finally the classification of 300 kcmil is selected for this circuit. Review the maximum admissible voltage drop criteria for photovoltaic systems in the AC circuit that does not exceed 2% and considering the distance from the inverter output panel to the switch at the common coupling point = 45 metres.

Selection of the grounding conductor

According to ANCE-ESP-02 ‘In direct current circuits, the size of the grounding conductor must not be smaller than the size of the conductor with the greatest conduction capacity (thickest wire) as established in Art. 250-93 of NOM 001 SEDE 2012. In no case less than 8.37 mm2 cross section (8 AWG gauge) for copper conductors.

In the case of equipment, the nominal size of copper or aluminium equipment grounding conductors shall not be less than that specified in the following Table (Table 250- 95 of NOM 001 SEDE 2012)’. Since the calculation based on Table 250-122 (NOM-001-SEDE-2012) results in a 14 AWG gauge, the 8 AWG gauge conductor was selected for the entire PV array installed up to the inverter input and from these to the AC concentrator board.

Calculation of protections (Short circuit current Isc x 1.25) 9.14 Amperes x 1.25= 11.43 A (NOM-001-SEDE-2012, 690-8(b) (1)). Direct current protection fuse rating = 15 A, 1000 volts.

From table 250-122 results in 14 AWG gauge and considering that in no case less than 8 AWG gauge; size selected: 8 AWG (16 mm2) green coated copper 7 wires from the PV generator chassis to the paralleling grounding bus at the inverter and from these to the paralleling bus on the AC circuit breaker concentrator plate.

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For the grounding conductor on the AC circuit from the AC circuit breaker panel to the common coupling point (250 A AC) and following the indications in table 250-122, the result is a size smaller than 4 AWG and larger than 6 AWG, therefore: the size selected for the grounding conductor in this arrangement will be 2 AWG from the AC load centre to the common coupling point to have the best possible grounding protection.

Protective devices on the DC side.

PV Generator Switching Point: As DC side protection devices were selected for each of the three strings of each of the 5 PV circuits. In accordance with 690-8 (b)(1) where necessary, overcurrent devices shall be selected as required in (a) through (d) below: a. Conduct not less than 125 percent of the maximum current calculated in 690-8 (a) . Short-circuit current Isc of 9.14 A x 1.25 = 11.43 A. Closest upper commercial fuse = 15 A. String voltage set = 800 volts direct current; fuse to be selected for 1000 volts direct current.

Surge protection in sub-array: Fuse holder with safe disconnection plus integrated disconnector at DC inverter input.

Surge or lightning protection (surge suppressor). As DC surge protection device already included in the Fronius Symo 15.0-3 208/220 inverter.

Protective devices on the AC side

The selected inverter complies with NOM-001-SEDE-2012, article 690-61 and 705-14.

AC disconnection point at the output of the inverters in parallel; for each of the 5 inverters, the 3-pole x 50 A Square DÒ thermomagnetic circuit breaker was selected, and these are contained in a three-phase Square DÒ panel for 400 A and 30 poles. Since this is a three-phase electrical system, load balancing is not necessary.

At the outlet of the load centre which has the individual output circuit breakers for each inverter, a Square DÒ 3 x 250A LAL type thermomagnetic circuit breaker will be placed to lead to another at the point of interconnection to the local electrical system, an existing I-Line type panel at the outlet of the 300 kVA substation, installed in front of building 'K'.

A Square DÒ Model SDSA50 three-pole, 240 VAC 50 kA, also called secondary lightning arrester, will be connected to the AC main circuit breaker input of the AC voltage concentrator.

In accordance with the CFE-G0100-04 specification, the location of the protections that a photovoltaic generator interconnected to the CFE must have must be described. (Vdocumento, 2023)

Box 9

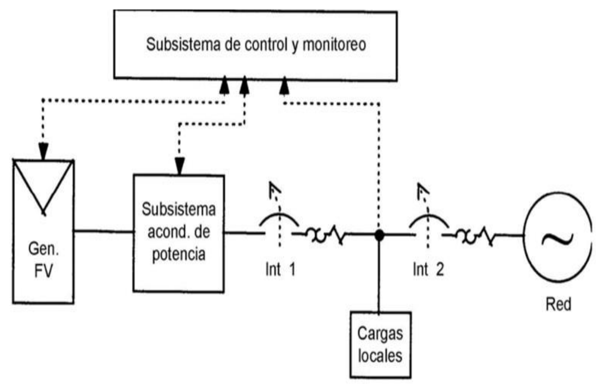

Figure 2

Location of mains disconnect switches, user responsibility

Schematic switch 1; Calculation: Maximum inverter output current x 1.25 x 39.4 A x 1.25 = 49.25 Amps x 4 = 246.25 Amps. Number of phases at the output of the inverter load centre = 3. Selected thermal magnetic circuit breaker = 250 A (Square D, type LAL 3 x 250 Amperes).

Circuit breaker 2 in the diagram refers to the main circuit breaker in the room before the point of common coupling, type I-Line 250 Amps.

Selection of the piping

For the channelling of the DC wiring from the PV source to the inverters, thick-walled metal conduit with the following dimensions was selected: (The conductors in 10 AWG solar cable have a nominal outer sheath diameter of 6.93 mm2, which is their equivalent in THW nominal outer diameter is 8 AWG cable, so this diameter is considered for the conduit calculation).

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Photovoltaic output circuit

From the photovoltaic array, strings 1 to 2, there are conductors in positive and negative 10 AWG solar cable plus the 8 AWG earth conductor, giving a total of three conductors (equivalent to 8 AWG); table C-8 of NOM-001-SEDE-2012 gives a diameter of 3/4‘ (21mm), the following diameter is selected, 1’ (27mm) to reduce the effect of temperature due to conduits exposed to sunlight.

From string 2 to string 3, there are two conductors from string 1 plus two conductors from string 2 in a 10 AWG positive and negative solar cable plus the 8 AWG earth ground conductor, a total of five conductors (8 AWG equivalent); from table C-8 results in 1’ (27mm) diameter.

From string 3 to the junction box; 3 strings, three positive conductors, three negative conductors plus the grounding wire, a total of 7 conductors 8 AWG in the same conduit. From table C-8 results in a diameter of 1 1⁄4’ (35 mm). The same for the five three-string circuits to the protective enclosure. (Vdocumento, 2023)

Box 10

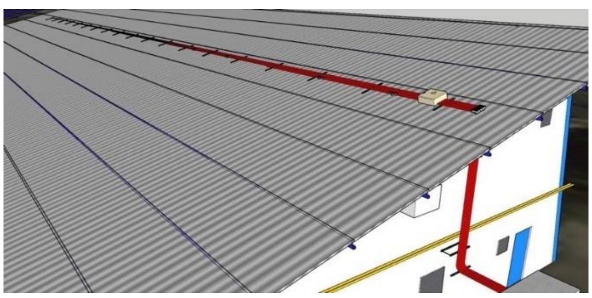

Figure 3

Piping on the roof of the building k

Incoming circuit to inverter

From protection box to collector duct before inverters; 3 strings, positive/negative plus grounding wire, 7 conductors total; 8 AWG (equivalent), for each of the five PV circuits: The same separate conduit layout continues for each PV circuit which has 1 1⁄4’ (35 mm) of metal.

Inside the inverter room a 100 mm x 100 mm square duct is used to receive the conductors of the 5 PV circuits, in total 15 solar positive conductors, 15 solar negative conductors and five grounding conductors in 8 AWG wire, giving a total of 35 8 AWG (equivalent) conductors, from this duct is sent to each inverter as shown in the following figure.

Box 11

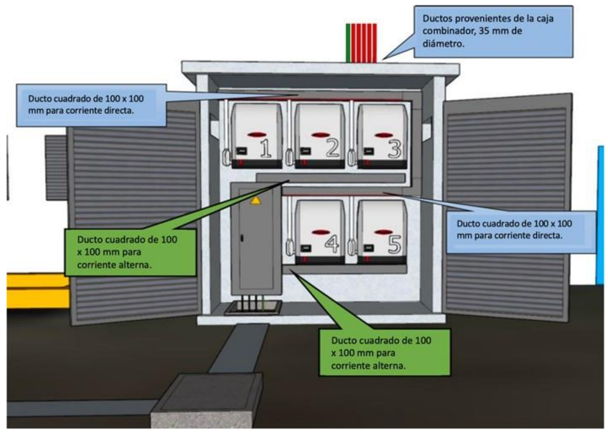

Figure 4

Inverter hut, showing the square duct that houses the DC and AC cables

Inverter output circuit to the AC concentrator panel

From the inverter output to the concentrator panel, a 100 x 100 mm square conduit is used for the 4 AWG AC conductors from inverters 1 to 5. This conduit is independent of the DC circuits.

From the concentrator panel to the interconnection point measuring point

From the concentrator panel to the interconnection point panel, prefabricated and interconnected manholes with 103 mm polyethylene conduit are used to house the three 300 kcmil gauge conductors plus the 2 AWG gauge grounding conductor resulting from the calculation of recommended conductors in table C-8 with a diameter of 2.5‘ (63mm), a 4’ (103mm) conduit will be placed for possible expansion of the photovoltaic system.

Operation of the PV system

The installation of the photovoltaic system was completed in November 2017, at the time of writing this document 354.5 tonnes of CO_2 have been saved from being emitted into the atmosphere, which is equivalent to the amount of CO_2 emitted by a vehicle, travelling a distance of 1,422,557 km, considering that the perimeter of the planet Earth is 40. In economic terms, the savings have been $1,364,495.43, the system provides 30% of the energy consumed by the equipment installed in the university's buildings and laboratories; the economic saving is 20% in the payment of the electricity bill paid to the basic services provider.

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Marroquín de Jesús Ángel, Castillo-Martínez, Luz Carmen, Soto-Álvarez, Sandra and Olivares-Ramírez, Juan Manuel. [2024]. Grid-interconnected photovoltaic system as an alternative to achieve climate neutrality through the energy transition. Journal of Technological Operations. 8[21]1-12: e5821112.
https://doi.org/10.35429/JTO.2024.8.21.1.12

The photovoltaic system interconnected to the grid has produced a total of 860.45 MWh, in the year 2018 the energy production was 104.34 MWh, this is because the system was interconnected to the grid since March 2018, from 2019 to 2020 the energy production is very similar being approximately 125 MWh, the energy production in the year 2021, decreased by 4.92% compared to 2020. For the years 2022 and 2023 the system produced 131.50, so far in the year 2024, the system has produced 98.84 MWh see figure 5.

Box 12

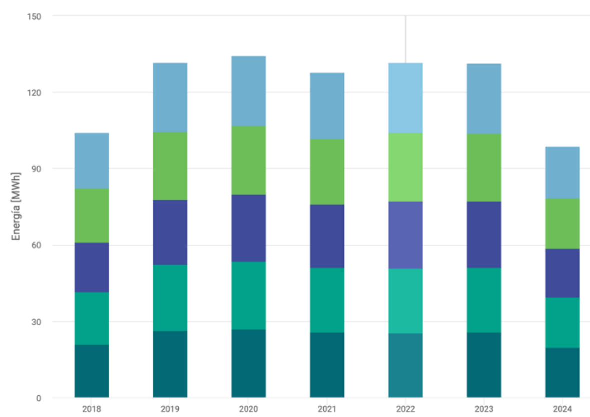

Figure 5

Energy production of the grid-connected PV system

Figure 6 shows the screenshot of the online monitoring system of the electricity production of the 79.2 kWp photovoltaic plant installed on the rooftop of the "K" building of the Technological University of San Juan del Río.. (Vdocumento, 2023)

Box 13

Figure 6

Overview of online monitoring of electricity production for Wednesday 18 September 2024 at 11:56 a.m. CET

Source: https://www.solarweb.com/PvSystems/ PvSystem?pvSystemId=4ba513d4-5bf0- 40c9-beed-2c46583274ae

The grid-connected photovoltaic system (Sánchez Tello, 2023), places the university in the select group of higher education institutions (Valparaiso, 2023) that produce a percentage of the energy that is consumed, which generates awareness among students, society in general, and takes advantage of renewable energies, which brings environmental benefits.

The Universidad Tecnológica de San Juan del Río is an evaluating and certifying entity (Consejo Nacional de Normalización y Certificación de Competencias Laborales) (CONOCER) and offers training and certification courses in standard EC0586.01 (UTSJR, 2023), entitled installation of photovoltaic systems in residence, commerce and industry. This system has been used as part of the training services currently being offered by the technological services area of the university's department of linkage and complements the training of future engineers in renewable energies at our university.

Box 14

Figure 7

Maintenance activities on the roof of photovoltaic power sources system

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Conclusions

The methodology for the design criteria and performance calculation of the PV system is based on what is proposed by the International Renewable Energy Agency (IRENA) (Irena, 2023), which a certified designer must put into practice. The system complies with the regulations in force in our country, to date it has produced 668.87 MWh of energy, which is equivalent to the average consumption of 458 homes of 4 members during a year; it produces 30% of the energy consumed in the laboratories and teaching buildings; there is a saving of 20% in the payment of the bill to the utility company.

According to a quote provided by a company, the maintenance (Rodriguez, 2023) of the 240 photovoltaic power sources costs $2,045.96, and it was suggested to the management that this activity be carried out by students of the renewable energy programme.

The system has been operating without problems; maintenance activities have been carried out on the panels' cover by the students of the ES01SM-20 group, practices that are developed in the renewable energy and photovoltaic systems subjects of the renewable energy engineering curriculum, which contributes to their training.

The use of personal protective equipment for working at heights allows the knowledge acquired (Ortiz, 2023) in the industrial safety subject, which is also part of the renewable energy engineering curriculum, to be put into practice.

The useful life of the equipment is approximately 25 years; it is important to perform maintenance activities on the system, checking all components. This system places the university among the select group of universities that generate a percentage of their energy and contribute to the care of the environment.

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