Escuela Técnica de Ingeniería

PUESTA A TIERRA DE PLANTAS FOTOVOLTAICAS DE GRADO UTILITY

EXPOSITOR

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Especialista en Ingeniería y Diseño Electromecánico de Líneas de Transmisión y subestaciones

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EDUCACIÓN

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EXPERIENCIA

PDVSA

inel Passion for Engineering

Constructora CONKOR

ElectroEnergy

CONTENIDO

CONTENIDO

Disposición Física

1.1 Disposición física

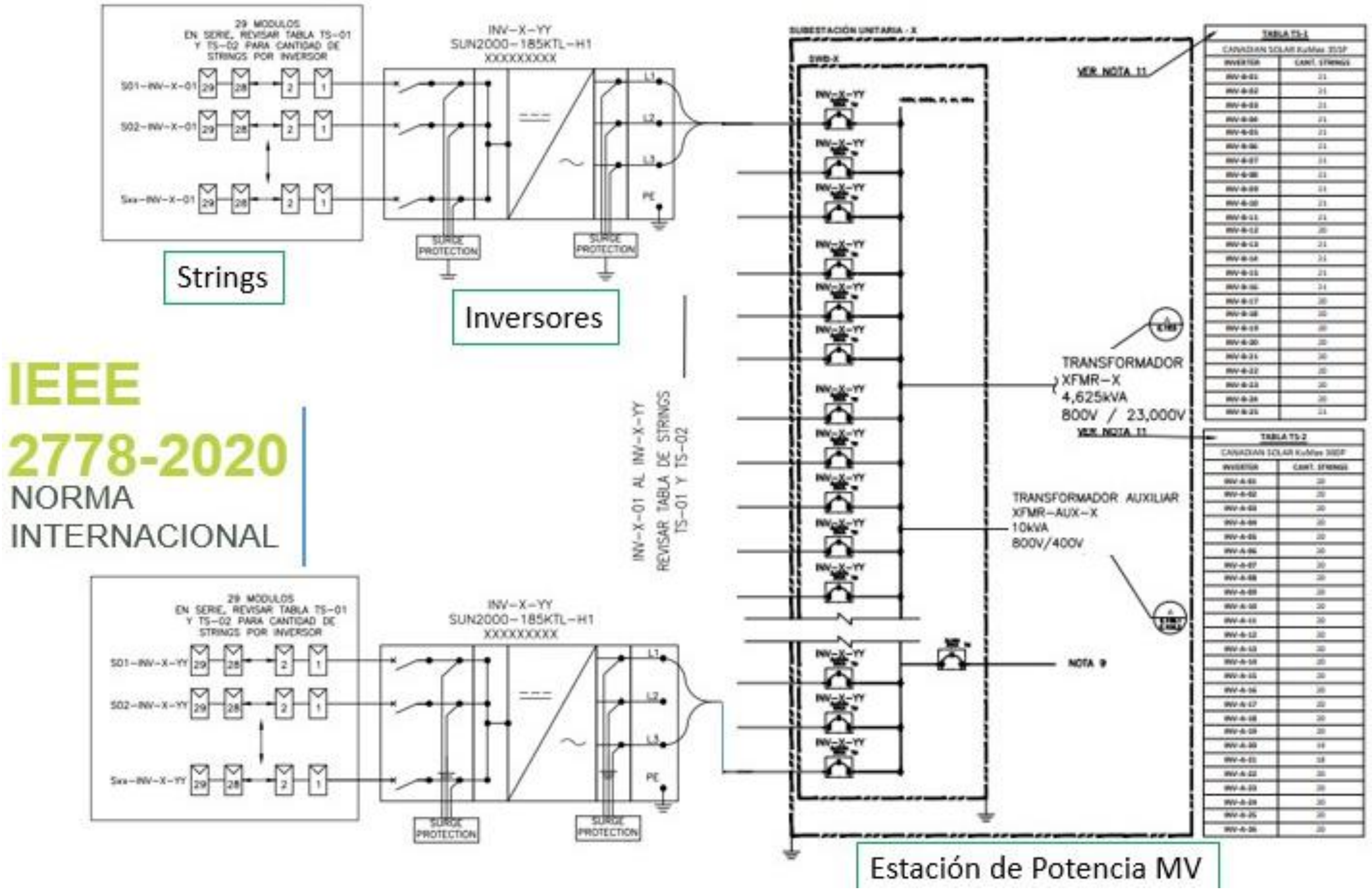
Stateline solar farm, Ver en Google Earth
https://n9.cl/oijzc

(8) Solar Photovoltaic (PV) Power Plant - YouTube

Energía solar | PHOENIX CONTACT

Diagrama de Conexiones

2.1 Conexiones Eléctricas SPP



https://en.sungrowpower.com/productDetail/745

Diagrama de Conexiones

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2.2 Esquema General

60364-7-712 © IEC:2002 – 21 –

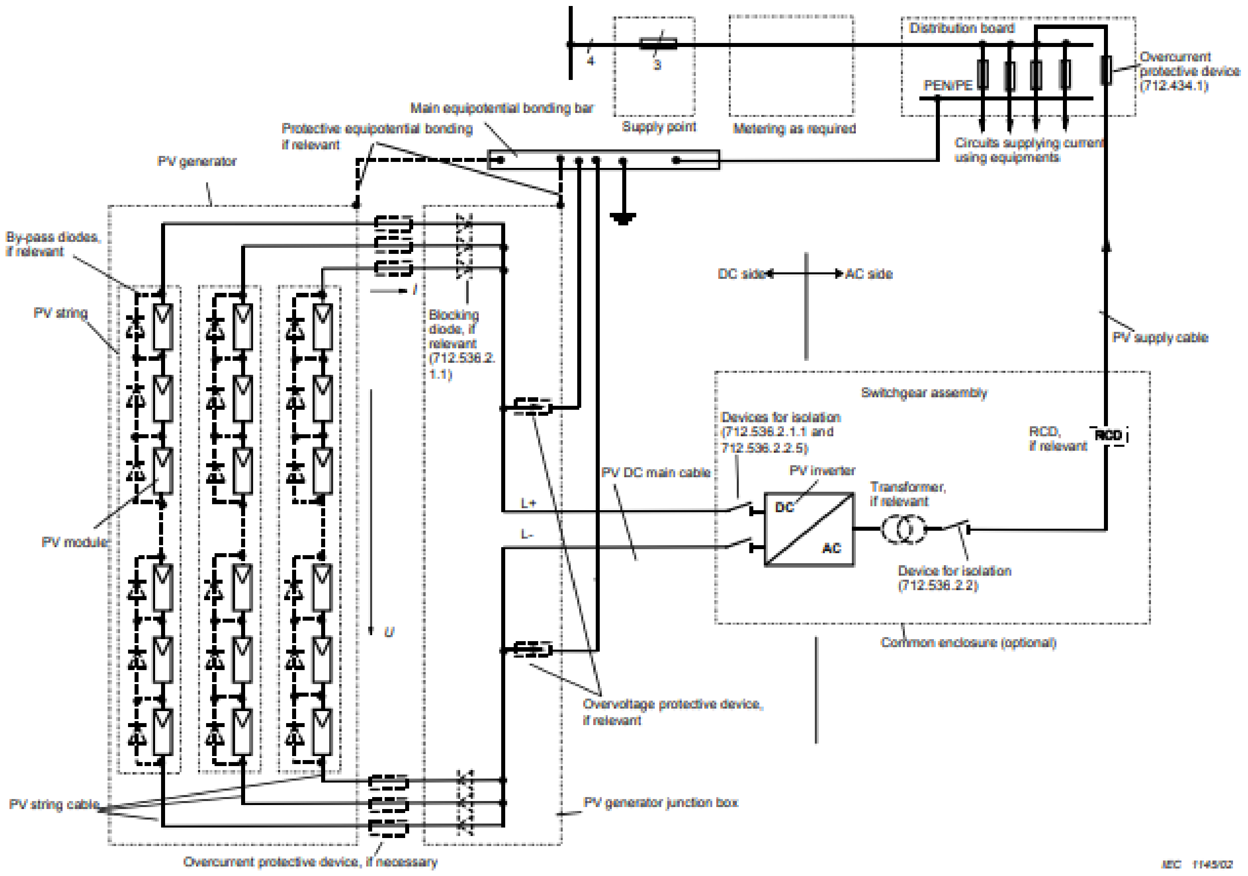
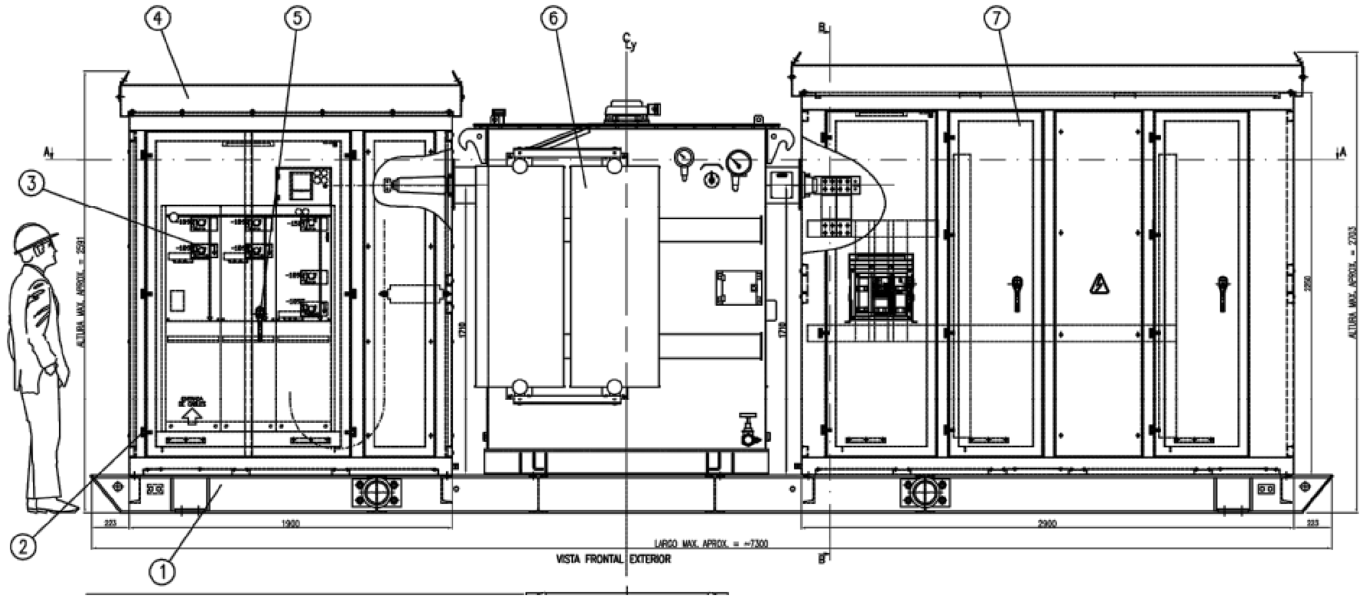


Figure 712.1 – PV installation – General schema – One array

Diagrama de Conexiones

2.3 Vistas de las Power Stations



https://en.sungrowpower.com/productDetail/745

Subestación Unitaria

Normativa

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3.1 Normatividad y criterios

- NFPA 70 National electrical code.
- UL 2703 Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels.
- UL 3703 Estándar for solar trackers
- IEEE 80-2013 GUIDE FOR SAFETY IN AC SUBSTATION GRUNDING
- IEEE 81-2012 Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Grounding System.
- IEEE 2778-2020 IEEE Guide for Solar Power Plant Grounding for Personnel Protection.
- IEC 60364-7-712: 2017 Requisitos para instalaciones o ubicaciones especiales - Sistemas de suministro de energía solar fotovoltaica (PV).

Metodología

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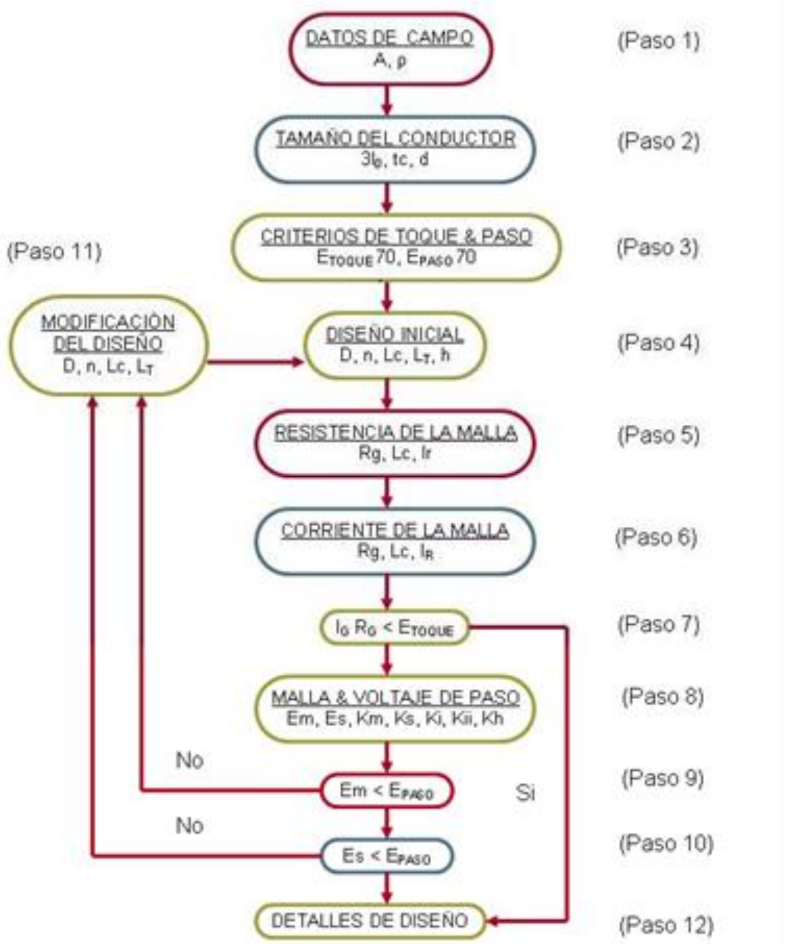
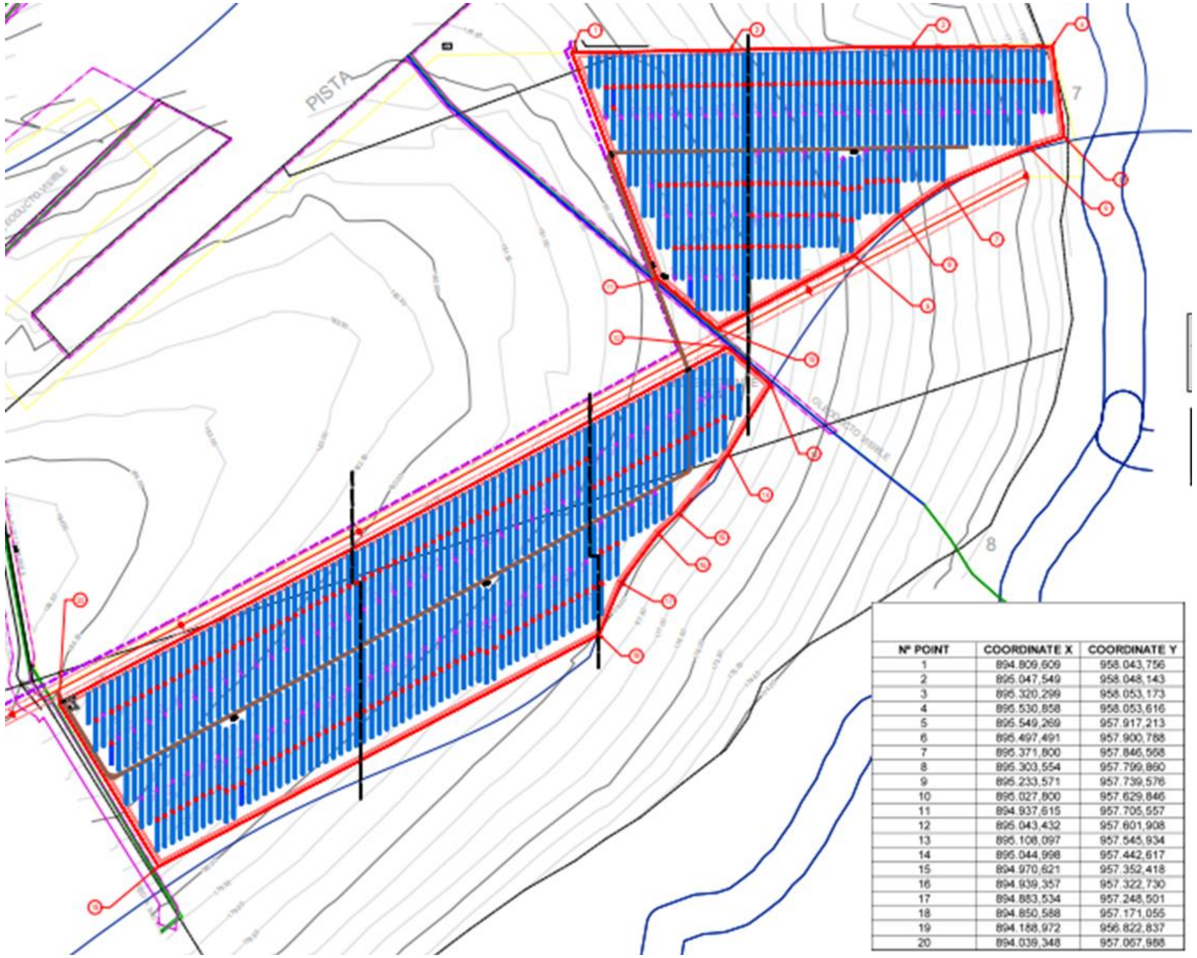
4.1 Metodología de diseño





Nº POINT	COORDINATE X	COORDINATE Y
1	894.809,609	958.043,756
2	896.047,549	958.048,143
3	896.320,299	958.053,173
4	896.530,858	958.053,616
5	896.549,269	957.917,213
6	896.497,491	957.900,788
7	896.371,800	957.846,568
8	896.303,554	957.799,860
9	896.233,571	957.739,576
10	896.027,800	957.629,846
11	894.937,615	957.705,557
12	896.043,432	957.601,908
13	896.108,097	957.545,934
14	896.044,998	957.442,617
15	894.970,621	957.352,418
16	894.939,357	957.322,730
17	894.883,534	957.248,501
18	894.850,588	957.171,056
19	894.188,972	956.822,837
20	894.039,348	957.067,988

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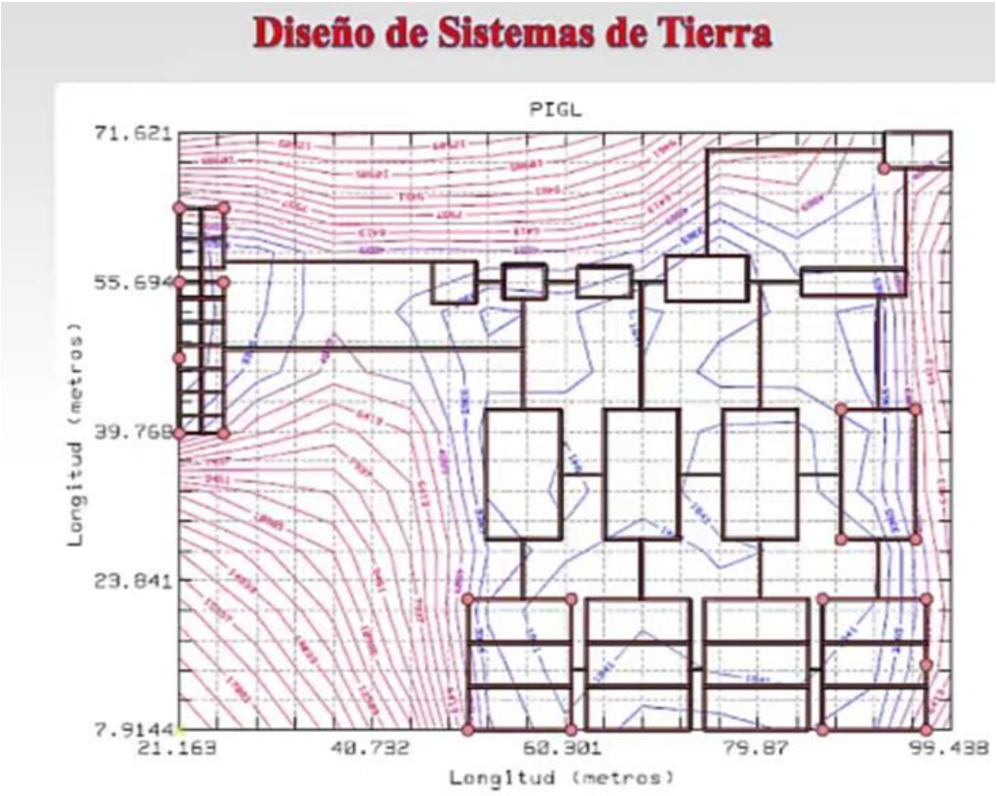
IEEE 2778-2020, IEEE 80-2013

Metodología

4.2 Métodos de diseño

1. Método de Elementos Finitos FEM.
2. Método IEEE 80.



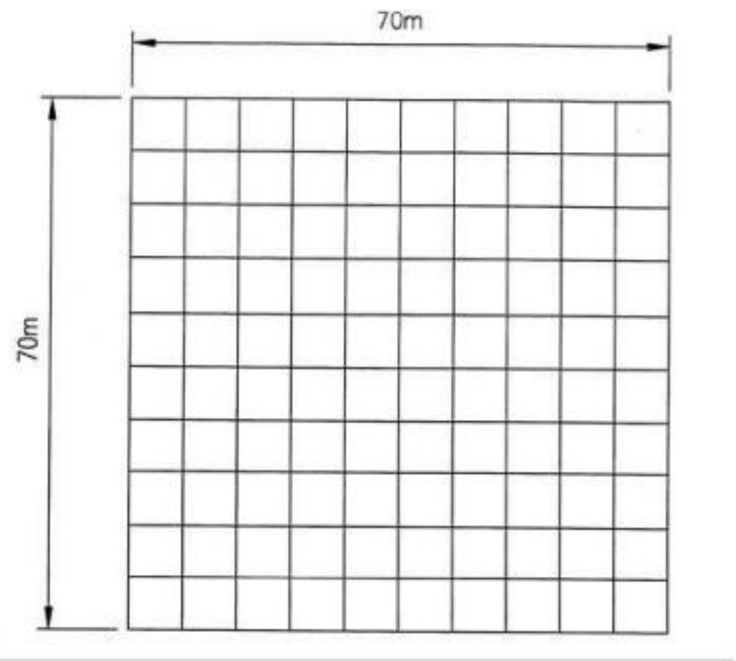


Figure B.1—Square grid without ground rods

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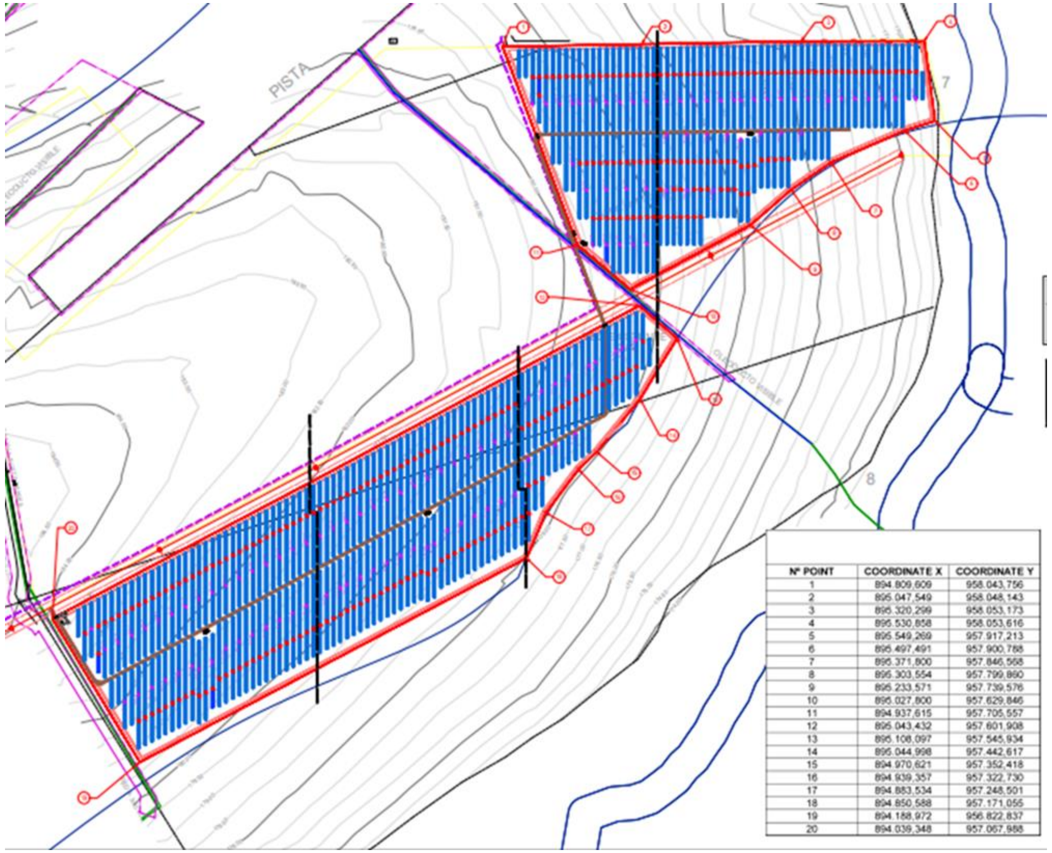
IEEE 2778-2020, IEEE 80-2013

Metodología

4.3 Diseño inicial



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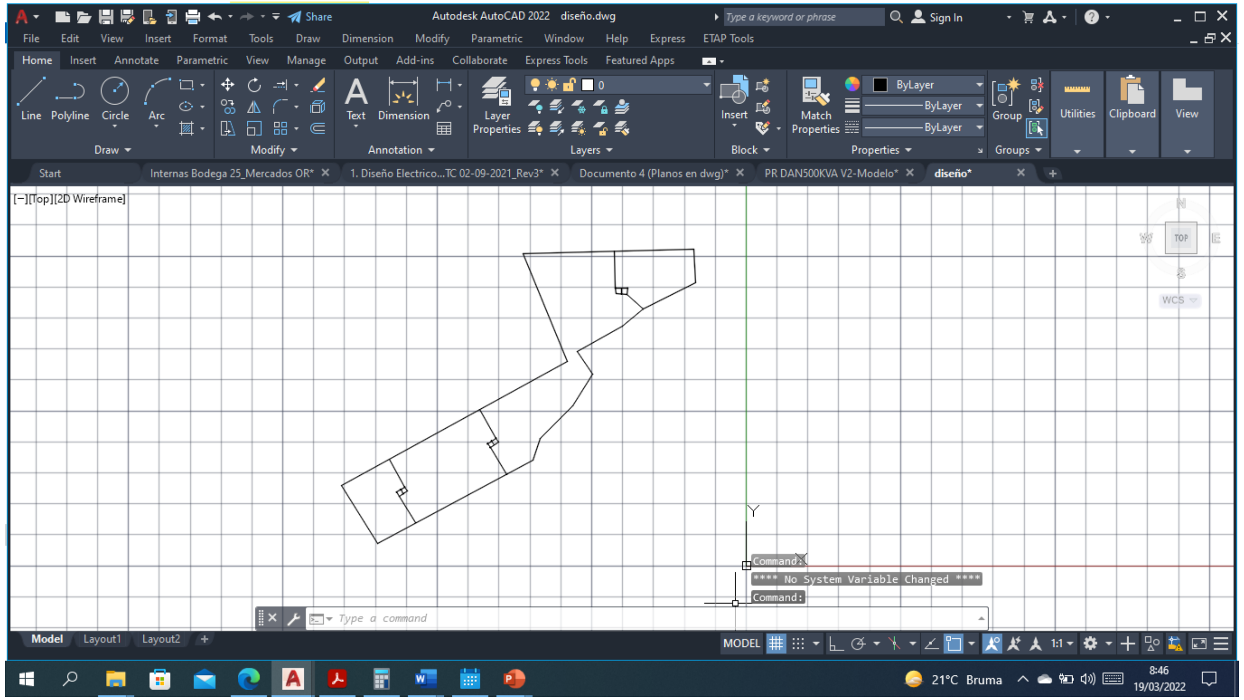

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IEEE 2778-2020, IEEE 80-2013

Conductor de tierra

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5.1 Selección del conductor

$$A_{mm^2} = I \frac{1}{\sqrt{\left(\frac{TCAP \times 10^{-4}}{t_c \alpha_r \rho_r}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)}}$$

$$A_{kcmil} = I \frac{197.4}{\sqrt{\left(\frac{TCAP}{t_c \alpha_r \rho_r}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)}}$$

Table 1—Material constant

Description	Material[a] conductivity (% IACS)	α_r factor[a] at 20 °C (1/°C)	K_O at 0 °C (0°C)	Fusing[a] temperature T_m (°C)	Resistivity[a] at 20 °C ρ_r (μΩ-cm)	Thermal[a] capacity $TCAP$ [J/(cm^3 · °C)]
Copper, annealed soft-drawn	100.0	0.003 93	234	1083	1.72	3.4
Copper, commercial hard-drawn	97.0	0.003 81	242	1084	1.78	3.4
Copper-clad steel wire	40.0	0.003 78	245	1084[c]	4.40	3.8
Copper-clad steel wire	30.0	0.003 78	245	1084[c]	5.86	3.8
Copper-clad steel rod	17.0	0.003 78	245	1084[c]	10.1	3.8
Aluminum-clad steel wire	20.3	0.00360	258	657	8.48	3.561
Steel, 1020	10.8[b]	0.003 77	245	1510	15.90	3.8
Stainless-clad steel rod[c]	9.8	0.003 77	245	1400[c]	17.50	4.4
Zinc-coated steel rod	8.6	0.003 20	293	419[c]	20.10	3.9
Stainless steel, 304	2.4	0.001 30	749	1400	72.00	4.0

- ✓ La sección del conductor se calcula de acuerdo a lo establecido en la parte 11.3 de la IEEE 80.
- ✓ Los software comerciales lo calculan automáticamente, también puede usar esta pagina Web: Earth Grid Conductor Sizing Calculator - ELEK Software

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IEEE 2778-2020, IEEE 80-2013

Bibliotecas de ingeniería

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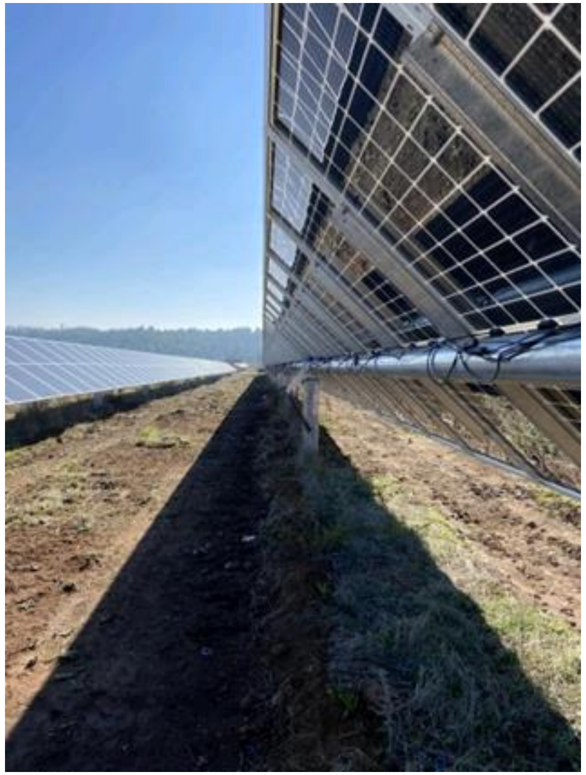
5.2 Electrodos y conductores Auxiliares



Equipotencializacion

6.1 Recomendación de conexión a tierra

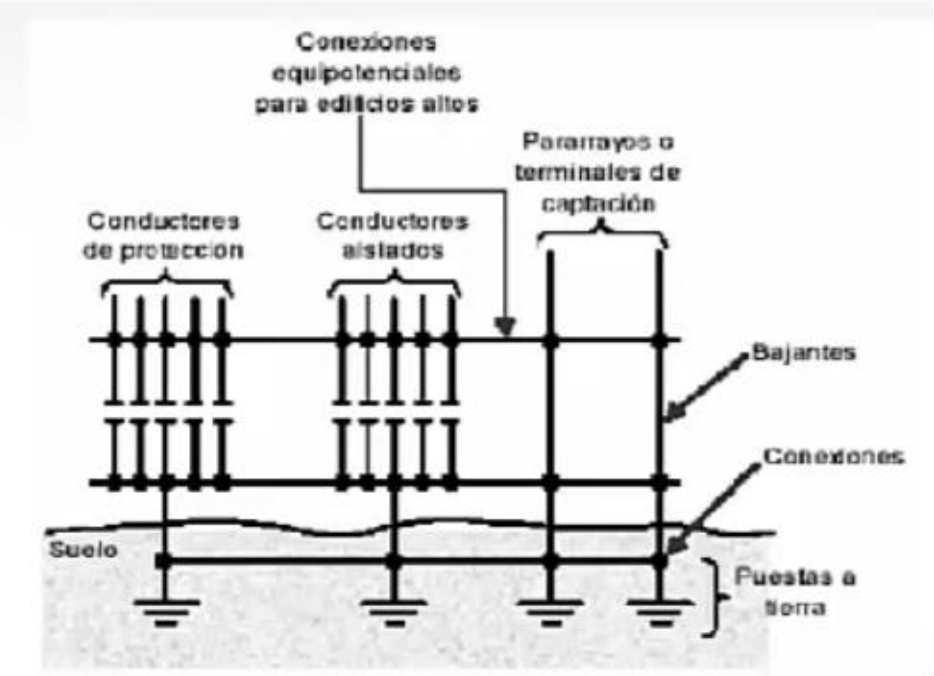


Figura 10. Conexiones potenciales sugeridas para edificios altos

4.4 Fence grounding

Where the National Electrical Safety Code® (NESC®) (Accredited Standards Committee C2) is applicable, metal fences surrounding a SPP may require grounding as of the publication of this document [B1]. From a technical standpoint, additional fence grounding may not be necessary if the fence posts are metallic and bonded to any fence mesh material. However, analysis of touch voltages on the fence is required to confirm compliance with the practices of IEEE Std 80.

It is not uncommon to have fence-plant separation of 6 m (20 ft) or more if there is a perimeter road, which significantly decreases the conductive coupling between the fence and faulted equipment. Bonding the fence causes the fault voltages to be transferred onto the fence, which in many cases would require a significant amount of additional grounding and/or surfacing along the site fence.

A more practical option is to analyze the site's metal fence(s) with faults at various locations near the perimeter of the SPP grounding system. If the analysis indicates that touch or step voltage limits are exceeded along portions of the site fence, additional localized fence grounding and/or crushed rock surfacing may be placed in those specific areas.

When fences are parallel to or crossing under transmission lines, magnetic and capacitive induction can also pose a concern, although this effect may be substantially smaller than the conductive component from a fault scenario. These aspects can be considered on a case-by-case basis.

NEC 70, IEEE 1100, IEC 61000-5-2

Resistividad

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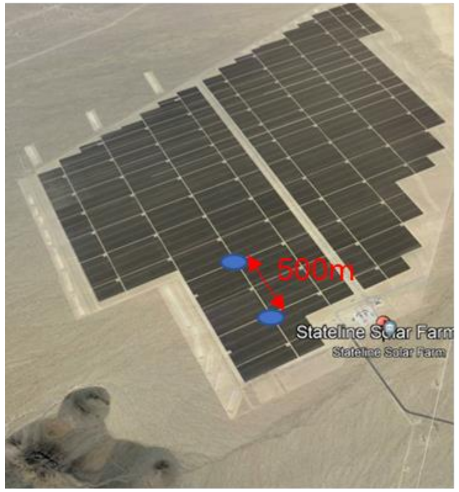
7.1 Medición de resistividad



5.1.1 Soil resistivity testing

To get sufficient information to perform the analyses of the grounding system, it is necessary to collect a significant amount of soil resistivity data throughout the SPP prior to construction. Ideally this includes a combination of a large number of shorter traverses and a few very long traverses of soil resistivity. The long traverses of soil resistivity are used to characterize the lower layer(s) of soil. Generally, the bottom layer remains constant across the entire site and can significantly influence the overall grounding system impedance.

Short traverses should consist of measurements from small spacings (around 0.5 m or less) up to maximum spacings of at least 30 m (100 ft). For some SPP sites where significant variation of resistivity with depth is expected, these tests may need to be extended to a maximum spacing upwards of 75 m (250 ft). Typically these shorter traverses should be made in a grid across the site with separations between center points on the order of 500 m (1650 ft) [B3]. Short traverses can be used to develop upper-layer soil models for each location where the data was gathered.

Longer traverses are critical for the accurate characterization and analysis of any large grounding system [B4]. Ideally, the maximum spacing of the soil resistivity test would equal the largest SPP diagonal dimension; however, this is not practical for larger SPP sites. For larger plants, the largest spacings for the longer traverses may need to be around 300 m (1000 ft) in order to get a few probe spacings measuring this deepest layer [B3]. If measured apparent resistivities have not stabilized with little change over increasing probe spacings, the traverses should be extended until the resistivities do level out. In large plants it is advisable for multiple long traverses to be performed in varying areas within the plant to improve accuracy of the SPP soil model.

7.2 Modelo del suelo

5.1.2 Soil model development

Each traverse of soil resistivity data measured should be analyzed separately. The shorter traverses in a given area are used to represent the upper layers of local soil. The nearest longer traverse(s) of soil resistivity data provides data on the deeper layers of soil. For smaller plants, the bottom layer of soil often is the same for the entire SPP. Some very large SPPs may require the use of different values for the lower layer(s) of soil resistivity.

Utilizing the data from the short and long traverse models for a given site, an overall soil model for a given area of analysis can be developed. Table 1 shows an example of combining a short traverse (with two layers of soil detected) and a long traverse (three layers of soil detected due to the larger probe spacings). The resistivity of the upper and middle layers is based on the short traverse, and the resistivity of the bottom layer uses the long traverse. For depths, the top layer(s) utilize the depths known from the short traverse. Selecting the depth of the next to bottom layer is the most difficult aspect if there is not a direct correlation between the middle layer resistivities. One approach is to place the bottom layer at the same total depth as measured in the long traverse (35 m in this example).

Table 1—Sample soil model development

	Soil resistivity and thickness		
	Short taverse (local) (tested to 30 m)	Long traverse (nearby)	Combined local model
Top layer	50 Ω·m for 2 m	30 Ω·m for 4 m	50 Ω·m for 2 m
Second (middle) layer	120 Ω·m (bottom measured with shorter traverse)	100 Ω·m for 31 m (cumulative depth 35 m)	120 Ω·m for 33 m (cumulative depth 35 m)
Third (bottom) layer		65 Ω·m	65 Ω·m

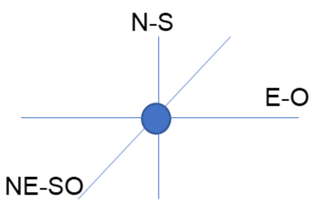
Utilizing this methodology, a soil model can be developed for each region where a short traverse of soil resistivity was measured. These various models then can be considered for analysis as discussed in 5.4.

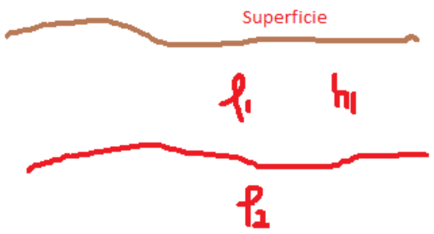
The following tabulation from Kinyon [B96] offers some idea of how the calculated and actual measured resistance for five different substations compare. Equation (56) was used to compute the grid resistance. See Table 9.

Table 9—Typical grid resistances

Parameter soil texture	Sub 1 sand and gravel	Sub 2 sandy loam	Sub 3 sand and clay	Sub 4 sand and gravel	Sub 5 soil and clay
Resistivity (Ω-m)	2000	800	200	1300	28.0
Grid area (ft^2)	15 159	60 939	18 849	15 759	61 479
Buried length (ft)	3120	9500	1775	3820	3000
R_g (calculated Ω)	25.7	4.97	2.55	16.15	0.19
R_g (measured Ω)	39.0	4.10	3.65	18.20	0.21

An average value of all measured resistivity values is frequently substituted for the uniform soil resistivity in Equation (55). If this average resistivity is used, Equation (56) usually produces a resistance that is higher than the value that would result from a direct resistance measurement. The calculated and measured resistance values shown in Table 9 do not reflect this trend, because Kinyon [B96] based his calculations on the "... lowest average value of resistivity measured on the site." Readers are referred to Kinyon [B96] for further discussion on his choice of resistivity values used in Table 9.





Cortocircuito

8.1 Corriente de cortocircuito

5.2.4 Fault locations to use for analysis

Analysis should be performed at a reasonable sampling of line-to-ground fault locations throughout the SPP and at the interconnect substation if the grounding system is attached. The specific number of sites depends on the size of the plant and the variation of fault currents through the site. Typically, a short-circuit model is developed for the site, often modeling to each GSU location. This allows for realistic fault values to be used for each location analyzed, accounting for the fact that values are often significantly lower far away from the main collector substation. A subset of locations may be used as discussed in 5.4.

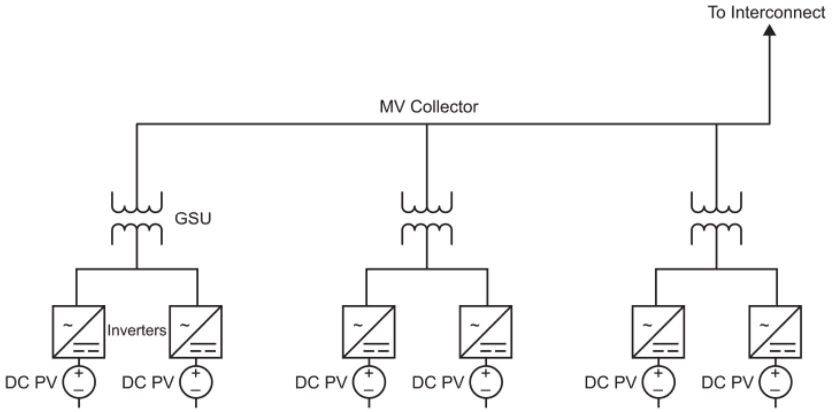


Figure 1—Sample SPP partial single line diagram

- ✓ Según la IEEE 367 la falla que se debe considerar en el diseño es la mayor entre la Monofásica a tierra y la Bifásica a tierra, sin embargo se puede escoger la corriente monofásica a tierra por la baja probabilidad de ocurrencia que tiene la falla bifásica a tierra.
- ✓ Según IEEE 80 La duración de la falla la dicta el tiempo de despeje en segunda zona de los reles de respaldo (Normalmente en un sistema Sólidamente puesto a tierra es 0,5segundos).
- ✓ La corriente de falla y El factor X/R se obtiene del estudio de cortocircuito.

IEEE 2778-2020, IEEE 367-2012

9.1 Consideraciones especiales

5.3 SPP grounding design

SPPs are large systems that require an optimized design to reduce costs while providing a grounding system that is sufficient. The use of software is often a requirement to validate the performance of a grounding system for a large SPP. Even using software, complete modeling of the entire system can be difficult. The following sections discuss an approach to design a grounding system and perform this analysis.

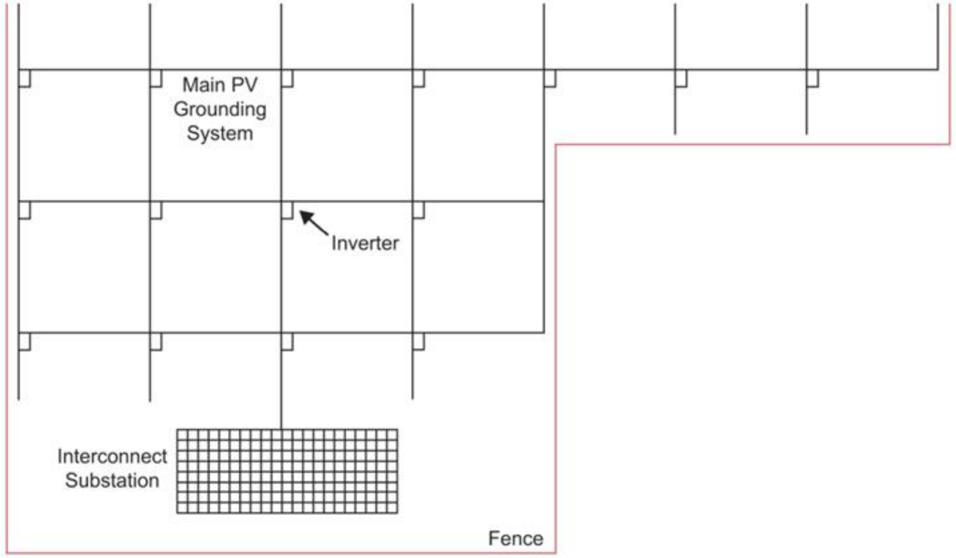


Figure 2—Sample primary grounding grid layout

Diseño

9.2 Uso de electrodos verticales

5.3.3 Use of ground rods

The use of ground rods generally provides little benefit in an extremely large grounding system except to provide some local reduction of touch voltages (including locations such as fence corners or gates), or where a shallow high resistivity layer exists such that the main grounding system is not in lower resistivity soil, but ground rods could reach into the lower layer. The steel support posts also provide a similar benefit if deep enough and bonded into the grounding system. By examining the soil structure, hundreds or thousands of unnecessary ground rods may be avoided. In some cases, using a large number of ground rods in certain areas may increase fault current flow to that area, raising voltages nearby.

Diseño

9.3 Uso de material de superficie

5.3.4 Application of insulating surfacing material

Crushed rock insulating surfacing is often not required as part of an SPP design. If some areas (such as portions of the site fence or gates) do require surfacing, it should be placed in the minimally required areas. Additionally, the cost of additional copper for small areas may be balanced against the cost of installation and maintenance of rock.

Referencias Bibliográficas

Escuela Técnica de Ingeniería

Referencias Bibliografías

[1] NFPA 70 National electrical code.

[2] UL 2703 Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels.

[3] UL 3703 Estándar for solar trackers

[4] IEEE 80-2013 GUIDE FOR SAFETY IN AC SUBSTATION GRUNDING

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[7] IEC 60364-7-712: 2017 Requisitos para instalaciones o ubicaciones especiales - Sistemas de suministro de energía solar fotovoltaica (PV).


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