Project Description

Lone Tree PV Plant

Prepared for: PCR

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1. INTRODUCTION

The objective of this report is to describe the specifications and design of the solar photovoltaic plant Lone Tree. The current description of the project could be subject to changes in the next stages of the project development.

The rated power of the PV Plant is 10.00 MWac and the peak power is 11.81 MWdc resulting in a DC/AC ratio of 1.18. The main characteristics of the project are shown in Table 1.

Table 1. Project Characteristics

Lone Tree Solar Project	
Main characteristics	
Location	Johnson County, Iowa
Rated power (AC)	10.00 MWac
Peak power (DC)	11.81 MWdc
Ratio DC/AC	1.18
Civil characteristics	
Suitable plot area	50 acre
Ground coverage ratio (GCR)	30.71 %
Structure type	One-axis tracker
Pitch distance	21 ft
Electrical characteristics	
PV Modules (550.0 Wp)	21465
Power station (up to 2500 kW)	4
Number of inverters (up to 125 kVA)	84

The general layout of the PV plant is shown in Figure 1.

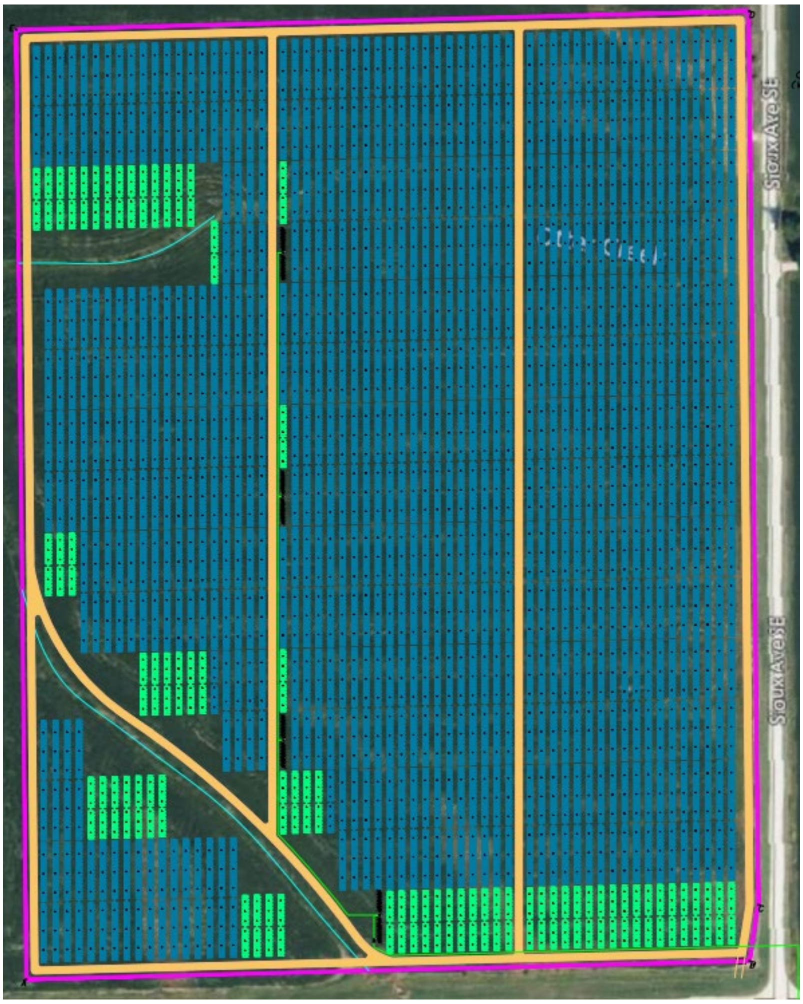

Figure 1. General layout

2. SITE

2.1. Location

The PV Plant location has the characteristics shown in Table 2

Table 2. Location characteristics

PV Plant location characteristics	
City / Town	Lone Tree
Region	Iowa
Country	United States
Latitude	+41.5° N
Longitude	-91.48° W
Altitude	197 m
Timezone	UTC -6

The project location is shown in Figure 2. A closer view of the region is shown in Figure 3.

Figure 2. Location of PV Plant in the region of Iowa, in United States

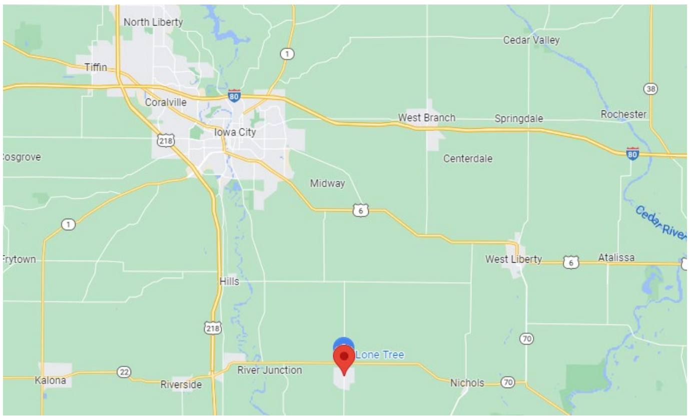

Figure 3. Closer view of the PV plant in the region of Iowa

2.2. Plot Areas

The area where the PV plant is to be built consists of 1 available area, with a total surface area of 40 acres. A total of 1 restricted area is not suitable for the installation of PV modules. The final available area covers a surface of 39.84 acre.

The size of each area and the total suitable area for installation purposes is shown in Table 3.

Table 3. Size of plot areas of the project.

Area name	Surface
Available areas	
Area 1	41.54 acre
Area 2	3.32 acre
Restricted areas	
Area 1	0.2 acre
Area 2	0.1 acre
Total available area	**44.86 acre**

The substation (blue), the plot area(s) (magenta) and, if any, the restricted area(s) (cyan) are shown in Figure 4.

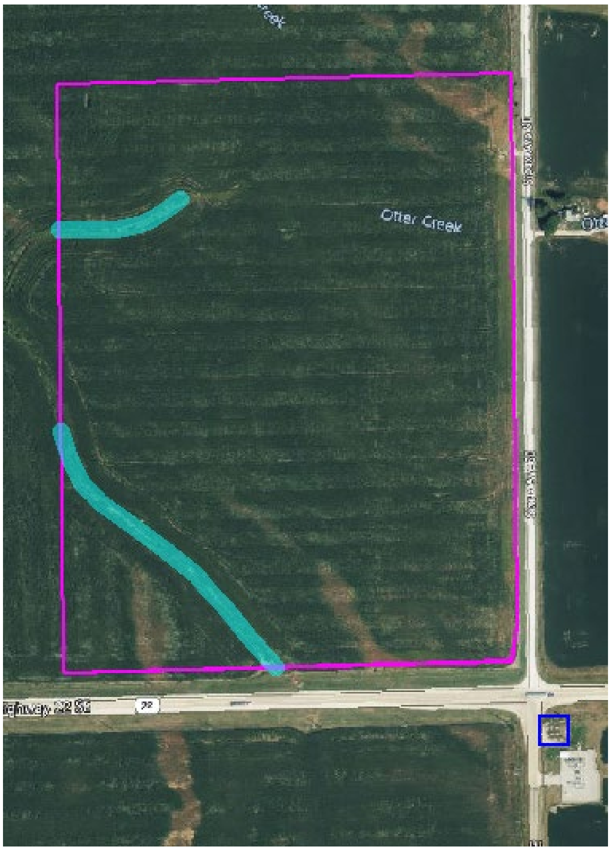

Figure 4. Plot Areas of the Lone Tree PV Plant

2.3. Horizon profile

The solar irradiance reaching the photovoltaic modules will change if there are hills or mountains on the horizon. These physical obstructions will block the beam component of the irradiance during some periods of the day and will have an impact on the diffuse component as well. Therefore, the horizon profile directly impacts the energy yield of the photovoltaic plant.

The horizon line has an average elevation of 0.5° and a maximum elevation of 1.5°. Throughout the year, the Sun will be blocked by the horizon line for a total of 57 hours. The data source for the horizon line was the PVGIS 5 database.

The blocked elevations over the complete azimuth range are shown in Figure 5.

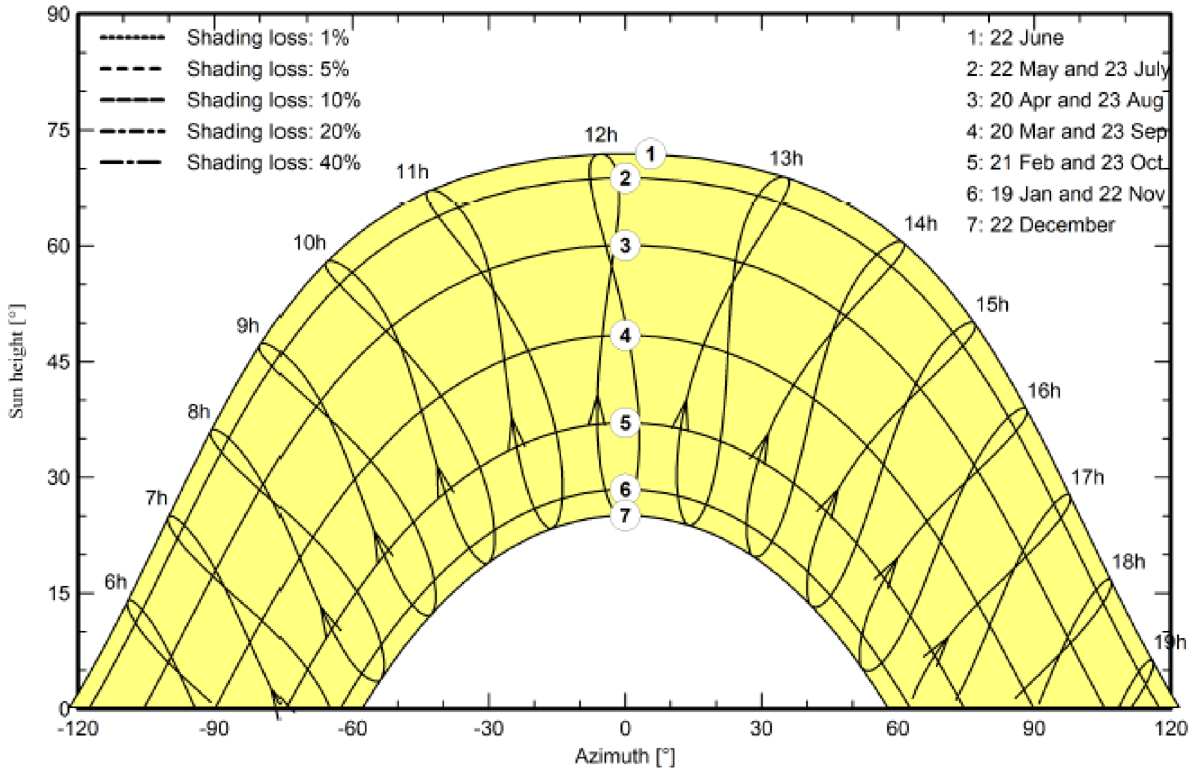

Figure 5. Horizon profile (data source: PVGIS 5)

3. SOLAR RESOURCE

The aim of the solar resource analysis is to provide an estimation of the solar energy the photovoltaic plant would receive throughout a typical year.

The solar resource is usually given as a series of hourly values for the irradiance and temperature, for a period of one year. This series is called the Typical Meteorological Year (TMY).

The source used to generate the TMY was the PVGIS database. It includes meteorological data ranging from 2005 to the present (the actual period used may vary depending on the location) and has a spatial resolution of 4 km by 4km. The uncertainty of the PVGIS data varies between ±3% to ±10%, depending on the location.

The hourly temperature values found in the TMY yield the following aggregates:

- Minimum temperature: -4.74 °C.
- Maximum temperature: 23.78 °C.
- Average temperature: 10.45°C.

The results of the solar resource analysis are shown in Table 4.

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	58.6	25.76	-4.74	82.9	76.3	0.962	0.926	0.946
February	81.0	29.78	-3.26	113.7	106.9	1.331	1.286	0.958
March	121.8	46.35	4.20	164.0	158.1	1.863	1.801	0.930
April	144.2	79.40	10.85	180.0	173.5	2.023	1.866	0.878
May	175.9	84.69	17.16	223.9	215.1	2.402	2.326	0.880
June	187.6	75.63	21.70	240.2	230.5	2.528	2.448	0.863
July	192.4	84.49	23.78	249.5	242.9	2.659	2.461	0.836
August	170.3	73.44	22.47	222.3	211.5	2.341	2.268	0.864
September	131.7	52.26	18.32	178.2	172.9	1.932	1.870	0.889
October	96.0	44.21	11.55	127.2	122.3	1.427	1.380	0.919
November	60.6	26.60	4.66	82.6	77.1	0.921	0.886	0.909
December	49.4	26.72	-2.20	64.8	59.2	0.752	0.691	0.904
Year	1469.7	649.33	10.45	1929.3	1846.2	21.139	20.209	0.887

Table 4. Solar resource monthly values

4. MAIN EQUIPMENT

The main equipment used to convert the solar energy to electricity is:

- Photovoltaic modules, which convert the solar radiation into direct current.
- The single-axis tracker, which supports and orients the PV modules to minimize the angle of incidence between the incoming sun rays and the PV modules surface during the day.
- The string combiner boxes, which consolidate the output of the strings of photovoltaic modules before reaching the inverter.
- Central inverters, which convert DC from solar field to AC.
- Power Transformers, which raise the voltage level from low to medium.
- Power Stations, which hold the necessary equipment to convert the DC power to AC.

The electrical configuration of the PV plant can be seen in Figure 7.

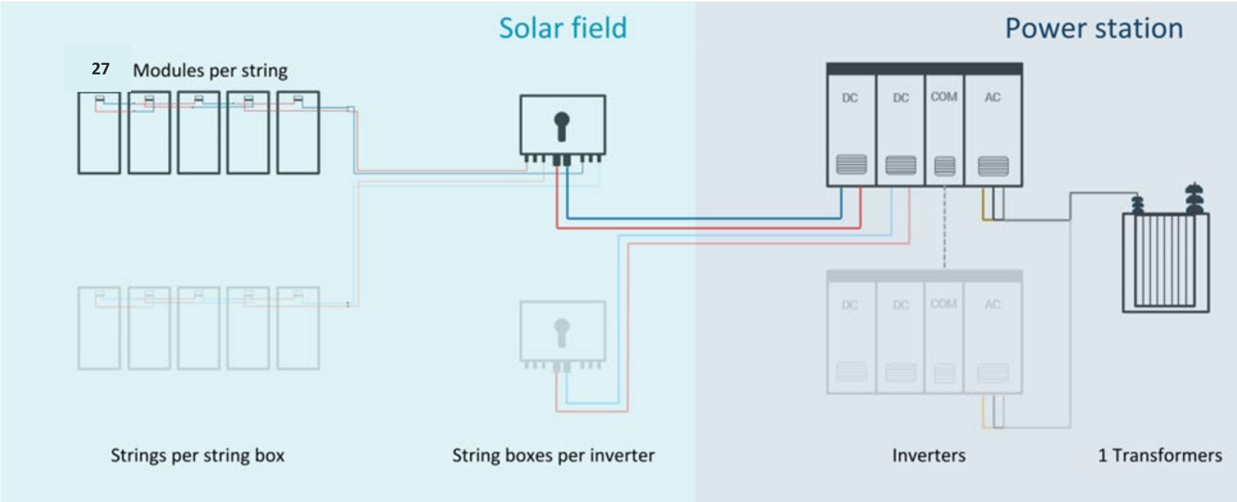

Figure 7. Simplified electrical configuration diagram

4.1. Photovoltaic module

The selected photovoltaic module is the SPR-P6-555-UPP-V2 Bifacial model, manufactured by SunPower. It has a peak power of 555.0 W, and the technology of the cells is Si-mono.

The features of the photovoltaic module are shown in Table 5.

The module has a bifaciality factor of 65.00 %.

Table 5. Photovoltaic module characteristics

Photovoltaic module characteristics	
Main characteristics	
Module model	ZXM7-SHLDD-144-550
Manufacturer	ZNshine Solar
Technology	Si-mono
Type of module	Bifacial
Maximum voltage	1500 V
Standard test conditions (STC)	
Peak power	550.0 W
Efficiency	21.28 %
MPP voltage	41.90 V
MPP current	13.13 A
Open circuit voltage	50.20 V
Short circuit current	13.89 A
Temperature coefficients	
Power coefficient	-0.35 %/°C
Voltage coefficient	-0.29 %/°C
Current coefficient	0.050 %/°C
Mechanical characteristics	
Length	2279mm
Width	1134mm
Thickness	35mm
Weight	33.5 kg

An example picture of a Bifacial Si-mono module is shown in Figure 8.

Figure 8. Example of a Bifacial Si-mono photovoltaic module

4.2. Single axis N-S tracker

The PV solar modules will be mounted on North-South oriented one-axis solar trackers, integrated on metallic structures combining galvanized steel and aluminum parts, forming a structure fixed to the ground. An example of a single-axis tracker is shown in Figure 9.

Figure 9. Example of single-axis tracker

Single-axis trackers are designed to minimize the angle of incidence between the incoming sun rays and the photovoltaic panel plane of array. The tracking system consists of an electronic device capable of following the sun through the day. The main features of the tracking system are summarized in Table 6.

Table 6. Main characteristics of the single-axis trackers

Single-axis tracker characteristics	
Model	Sky Line
Manufacturer	Arctech
Technology	Single-row
Configuration	1V
Tracking angle limits	+52 / -52 °
Number of modules per row	54 modules (maximum 60 modules)
Pitch distance	6.40m
Minimum ground clearance	0.60m

4.3. String combiner box

The string boxes collect the power generated by the DC array, connect the strings in parallel to the inverter, and provide electrical protection to the PV field. To match the number of inputs of the inverters, several parallel strings will be concentrated to function as a single circuit. Junction boxes shall be installed with a fuse per string to protect each array. Overvoltage DC dischargers will be installed, and one DC switch will be situated in the output line. Additionally, a communication system may be installed to monitor the string current and voltage.

An example of a string box is shown in Figure 10.

Figure 10. Example string box

The string boxes will be installed in a shaded area and shall be easily accessible to facilitate maintenance. They will be placed behind the PV modules and use existing structure poles if possible so that they remain shaded and prevent damage caused by rainwater or other meteorological phenomena.

4.4 String inverter

The inverter converts the direct current produced by the photovoltaic modules to alternating current. It is composed of the following elements:

- One or several DC-to-AC power conversion stages, each equipped with a maximum power point tracking system (MPPT). The MPPT will vary the voltage of the DC array to maximize the production depending on the operating conditions.
- Protection components against high working temperatures, over or under voltage, over or under-frequencies, minimum operating current, mains failure of the transformer, anti-islanding protection, protection against voltage gaps, etc. In addition to the protections for the safety of the staff personnel.
- A monitoring system, which has the function of relaying data regarding the inverter operation to the owner (current, voltage, power, etc.) and external data from monitoring of the strings in the DC array (if a string monitoring system is present).

In Figure 11 a commonly used photovoltaic inverter for utility-scale PV plants is shown.

Figure 11. Example of central photovoltaic inverter

The main characteristics of the selected inverter are shown in Table 7.

Table 7. Inverter characteristics

Inverter characteristics	
Main characteristics	
Inverter model	Sunny Highpower Peak3 125-US
Inverter type	String
Manufacturer	SMA
Maximum DC to AC conversion efficiency	98.5 %
Input side (DC)	
MPPT search range	705 - 1450 V
Maximum input voltage	1500 V
Output side (AC)	
Rated power	125 kVA
Power at 30 C (datasheet)	125 kVA
Power at 50 C (datasheet)	125 kVA
Output voltage	480 V
Output frequency	60 Hz

4.5. Power transformer

The power transformer raises the voltage of the inverter AC output to achieve a higher efficiency transmission in the power lines of the photovoltaic plant. An example of a power transformer is shown in Figure 12.

Figure 12. Example of power transformer

The main features of the power transformer are shown in Table 8.

Table 8. Power transformer characteristics

Power transformer characteristics	
Rated power	2750 kVA
Voltage ratio	0.48/12.47kV
Cooling system	ONAN
Tap changer	2.5%, 5%, 7.5%, 10%
Short circuit (Xcc)	0.08

4.5. Power Station

The power stations or transformer stations are indoor buildings or containers. The voltage of the energy collected from the solar field is increased to a higher level to facilitate the evacuation of the generated energy.

An example of an Indoors power station is shown in Figure 13.

Figure 13. Example of an Indoors power station

The power station shall be supplied with medium voltage switchgears that include one transformer protection unit, one direct incoming feeder unit, one direct outcoming feeder unit and electrical boards. Particularly, for the first power station of each MV line, a direct incoming unit will not be installed.

The main features of the default power station are shown in Table 10.

Table 10. Power station characteristics

Power station characteristics	
Voltage ratio	12.47 V
Service	Indoors

5. PV PLANT SIZING

5.1. Electrical configuration

The photovoltaic generator array consists of photovoltaic modules connected in serial and parallel associations. This configuration is defined by the module and inverter technical features, the power system requirements, and the meteorological conditions of the specific location in United States.

The methodology used to define the electrical configuration consists of sizing the strings of modules, electrical junction boxes (if present), wiring and inverters to find an electrical configuration that satisfies the DC/AC ratio goal. Some of the design criteria considered were:

- Reaching the maximum DC voltage possible, staying below the maximum rated voltage of the photovoltaic modules, 1500 V. This is done to minimize the DC power transmission losses.
- The photovoltaic generator array (DC field) is oversized with respect to the rated power of the AC system, to maximize the energy yield.

The AC system was designed to meet a power factor requirement at the substation input. The required power factor at the substation input is 0.950. To meet this requirement, it was determined that the power factor at the inverter output will be 0.932.

The main features of the electrical configuration are shown in Table 11.

Table 11. Electrical configuration characteristics

Electrical configuration characteristics	
Plant rated power	10.00 MWac
Plant peak power	11.81 MWdc
DC/AC Ratio	1.18
Modules per string	27

The medium voltage network connecting the power stations to the substation operates at 12.47 kV. It is composed of 1 medium voltage branches.

5.2. Electrical Cabling Design

The goal when calculating the characteristics of the electrical wiring is to minimize the cable lengths and sections. The sections are selected according to the NFPA 70 National Electrical Code.

When selecting a cable cross section, the current carrying capacity, the voltage drop, and the short circuit current were considered. The maximum allowed voltage drop was 1.5% for the DC side, and 0.5% for the AC cables of the MV network.

A 1 AWG earthing cable is used for the low voltage and medium voltage trenches, while a 1/0 AWG earthing cable is used in the case of the power stations.

A summary of the selected cable sections and their installation method is shown in Table 12.

Table 12. Summary of the selected cable sections

Section	Conducting material	Insulating material	Installation type
Strings to Inverter			
10 AWG	Cu	XHHN	Fastened to structure
12 AWG	Cu	XHHN	Fastened to structure
Inverter to PS			
350 kcmil	Al	XHHN	Buried in trench
PS to MV switchgears			
500 kcmil	Al	XHHN	Buried in trench
350 kcmil	Al	XHHN	Buried in trench

5.3. Civil works

Some of the parameters considered for the civil works required to build the photovoltaic plant are shown in Table 13.

Table 13. Civil works

Civil works	
Pitch distance	21 ft
Distance between consecutive rows	5 ft
Road width	12 ft
LV trench maximum section	4.31 ft2
MV trench maximum section	12.92 ft2

For the design of the PV plant under study, roads of 12 ft have been used. These roads run a total area of 2.7 acres.

Road ditches used for drainage and for channeling water are placed on one side of the roads.

A total perimeter of 5939.22 ft of woven wire fence will surround the different areas of the PV plant. The fence has at least 8 ft of height and 10 ft between posts. For every 164.04 ft of fence, a light post of 13.12 ft of height and a microwave barrier system are installed. For every 328.08 ft of fence, a video camera post of 19.69 ft of height is installed.

Low voltage cables from string inverters to the Power Stations have been directly buried in trenches. Various rows of cables may be included inside the same trench. Low voltage and medium voltage trenches are separated.

The minimum depth at which the low voltage cables are placed is 23.62 in. These cables are horizontally in touch. The vertical separation between the low voltage cables is 1.97 in.

A simplified trench cross section of the LV trenches is shown in Figure 14.

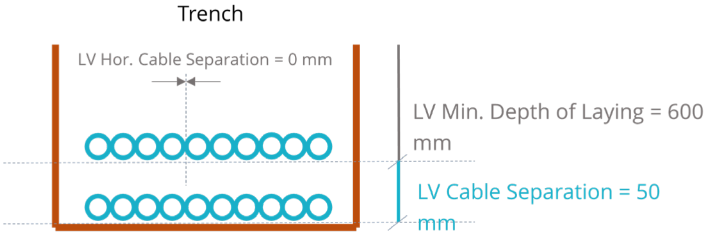

Figure 14. Simplified LV trench cross section

The minimum depth at which medium voltage cables are placed is 27.56 in. These cables are separated horizontally by 7.87 in. The vertical separation between them is 7.87 in.

A simplified trench cross section of the MV trenches is shown in Figure 15.

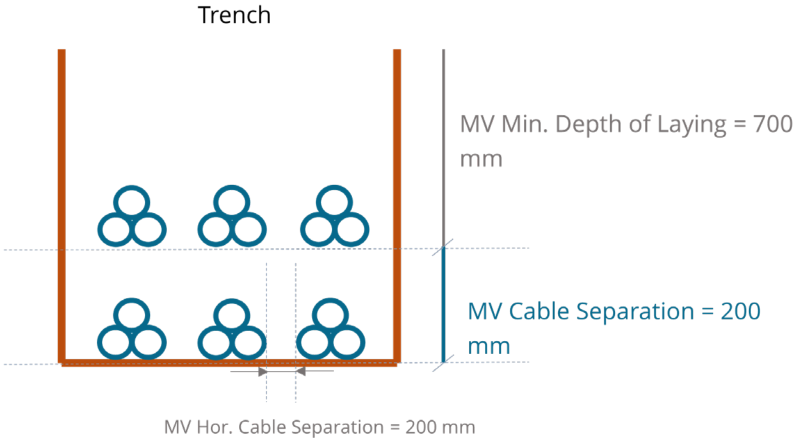

Figure 15. Simplified MV trench cross section

The offset horizontal space between the cable rows and the trench boundaries is 1.97 in.