People's Democratic Republic of Algeria Ministry of Higher Education and Scientific Research

**University M'Hamed BOUGARA – Boumerdes**

**Institute of Electrical and Electronic Engineering**

**Department of Power and Control Engineering**

Final Year Project Report Presented in Partial Fulfilment of the Requirements for the Degree of

# MASTER

**In Electrical and Electronic Engineering**

Option: **Power Engineering**

# Electrical Installation Design and Study of an Industrial Oil and Gas Project: Application on EGPDF Pipeline

**Presented by: OULDAMMAR Bilal**

**Supervisor: Dr. BOUCHAHDANE Mohammed**

**Co-supervisor: Mr Taibi Zakaria**

# Abstract

The main purpose of this thesis is to introduce methods and standards of design, calculation and selection of electrical equipment and protection systems in an industrial oil and gas plant, application on EGPDF Pipeline. These calculations and selections are based on common international standards (IEC, BS, NF, AS, NZS…), also performed with the convenient computer software (AutoCAD, PVsyst, e-Design, CYMGrd, Pulsar designer)

The project will constitute a high qualified training for real electrical engineering project in order to blend in a professional environment.

## ***Dedication***

*Dedicated to thee who hast supported me the most and given me strength when most needed, dearest father.*

*Beloved and affectionate mother, thou hast given me the love and passion without which I would be lost.*

*Can't thank you enough...*

# Acknowledgement

In the name of Allah, the Most Gracious and the Most Merciful Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this project.

I would like to express my deepest and sincere gratitude to my project Supervisor Dr. BOUCHAHDANE.M, it was great a privilege and honor working and studying under your supervision. And many thanks to my co-supervisor Mr TAIBI.Z whom I can't thank enough, without you this work wouldn't have come to light. I would like also to thank other teachers for their precious help during our work. Thanks ever so much!!

## Abbreviation and Acronyms:

IEC: International Electrotechnical Commission.

BS: British Standard

NF: French Standard (Norme Française)

AS: Australien Standard

NZS: New Zealand Standard

IEEE Std:  Institute of Electrical and Electronics Engineers Standards Association

EGPDF: Extension Gazoduc Pedro Duran Farell [1]

SCADA: Supervisory Control And Data Acquisition

XLPE: Cross Linked Polyethylene

PVC:  Polyvinyl Chloride

PV: Photovoltaic

HVAC: High Voltage Alternative Current

MV: Medium Voltage

UPS Uninterruptible Power Supply

SLD: Single Line Diagram

EPR: Ethylene Propylene Rubber

ESEAT: Early Streamer Emission Air Terminal

# Contents

## List of tables:

## List of figures :

## General Introduction:

Power engineers are concerned with the application of proven techniques and procedures to the solution of practical engineering problems. They exercise Technical Responsibility and are competent to exercise creative abilities and skills in areas technology. Professional Engineering Technicians contribute to the design, development, manufacture, commissioning, decommissioning, operation or maintenance of products, equipment, processes or services.

In order to acquire and assert these qualities, we opted in this project in electrical engineering to be indulged in the professional environment of the engineer which is the design and study office, by obtaining a design project of electrical installations for an oil and gas site.

In this context, the Algerian engineering firm Pegaz Engineering carried out studies of the Gas Pipeline project from El Aricha – Beni Saf. This project will be dealing with one part of the project which the cutoff station is covering the development of electrical design studies for the cutoff station located in Sebdou.

The main purpose of this project is to introduce methods and standards of design, calculation and selection of electrical equipment and protection systems according to common international standards (IEC, BS, IEEE Std, NF, AS, NZS…). These calculations and selections are also performed with the convenient computer software.

This very project is fundamentally organized in four chapters; the first chapter will present generalities about the project in hand with input data and introduces the general electrical philosophy of the project, it will allow us to better understand the specifications, and therefore have more details on the installation. The second chapter will be devoted to the methods of calculation and sizing of energy sources; that is to say the PV module, the battery bank and the battery charger, whereas the third chapter deals with cables (sizing and selection) and protection devices, while the fourth chapter presents the grounding and lightning protection systems.

# THEORETICAL BACKGROUND

## Theoretical Background:

## Photovoltaic Panels:

Principle of Operation Of A Silicon Photovoltaic Cell:

As soon as it is lit, a photovoltaic cell, also called photocell, generates a direct electric current at its terminals, under a voltage. Its operating principle (illustrated below) is simple: it consists of converting the kinetic energy of photons (particles of light, for example component of solar radiation) into electrical energy. [2]

The manufacturer accompanies his module with a sheet indicating the characteristics of the module in particular: [3]

- The characteristics of the module (weight, dimensions, surface and fixing points ...),

- Characteristic curves current = f (voltages) under standard operating conditions

- The open circuit voltage measured across the PV cell under standard operating conditions, VCO (V) Volt,

- The short-circuit current measured at the terminals of the PV cell under standard operating conditions, ICC (A) Ampere,

- The nominal power, the maximum power measured at the terminals of the PV cell under standard operating conditions (STC) Nominal Pmax (W) Watt,

- The rated power voltage, maximum power across the PV cell under standard operating conditions, V Pmax rated CO (V) Volt,

By extension and for ease, professionals characterize a PV module simply by:

- Rated power at standard operating conditions (STC); Pnominale = Pmax (W) Watt,

- The nominal voltage of the PV module (usually 12, 24, 48 VDC, Vnominale (V) Volt).

## Dc Uninterruptible Power Supplies:

Battery charger technology for AC and DC UPSs can be simple as in the case of a domestic car battery charger, or complex as in instrumentation or fire and gas battery chargers. Complex battery chargers are designed to have:[4]

- Predetermined current and voltage versus time charging characteristics.
- Electronic protection against overloads and short circuits.
- Minimum supervision and maintenance.
- Occasionally a form of automatic duty-standby change over facility is required.

Modern chargers use fast acting and accurate electronic devices to control the desired output characteristics. The rectifying device can be diodes or thyristors.

The rectifying device is usually in the form of a single phase for units up to about 25 kVA, or a three-phase bridge-connected device for larger units. The rectifying device is fed by a single phase or three-phase transformer. The output from the rectifier is passed through a current detection circuit (a resistance shunt or special magnetic device) and a smoothing reactor (or choke). Signals are taken from the current detector and from the output terminals, are fed back to a control circuit which produces the desired current and voltage characteristics. The control circuit also incorporates overcurrent and overvoltage protection so that the battery and its load are not damaged during abnormal conditions. Some loads cannot tolerate overvoltages, not even for a short time.

## Cables and Protection :

Cables provide a highly reliable and compact method of transmitting power from its source to its consumer. Cables are installed in open air on racks or ladders, in the ground, or underwater as in the case of submarine cables. Power at all the voltages normally encountered in the oil industry i.e., less than 100 V and up to 33 kV, can be transmitted efficiently by single and multi-core cables. [4]

Over the last 30 years there has been a progressive improvement in the materials used in the construction of cables, especially in the non-metallic materials. This has been due to several necessary requirements e.g., [4]

a) To maximize the conductor temperature and hence the power transmitted.

b) To provide high resistance to mechanical wear and tear, both during the laying of the cables, and in their on-going use when they may be disturbed in the future.

c) To withstand the effects of chemical attack from their environment e.g., when laid in polluted ground.

d) To withstand the damaging effects of steady state and transient overvoltages.

e) To withstand the impact of heat from the environment when exposed to fire and high radiant temperatures.

f) To withstand freezing temperatures and embrittlement.

g) To be resistant to ultraviolet light when exposed to bright sunlight.

## Grounding:

### Purpose of Grounding:

There are three main reasons why it is necessary to earth, or to ground, electrical equipment: [4]

- To prevent electric shock to human operators, maintenance personnel and persons in the vicinity of electrical equipment.

- To minimize damage to equipment when excessive current passes between the conductors and the casing or frame during an internal fault condition.
- To provide a point of zero reference potential in the power system for the conductors.

**Electric Shock:**

Electric shock occurs when two factors exist: [4]

- Two points in an electrical circuit that have unequal potentials are in contact with the human body.
- The difference in these two potentials exceeds a lower threshold value.

At the threshold limit slight perception of pain or 'tingling' near to the points of contact will occur. A continuous alternating current at a power system frequency, e.g. 50 or 60 Hz, of approximately 1 mA will cause this slight reaction. Increasing the current causes a greater intensity of reaction. At approximately 12 mA the muscles become very difficult to control, i.e. almost unable to 'let go' of the contact. Between approximately 20 mA and 50 mA the current tends to cause difficulty in breathing, but not to an irreversible extent. A continuous current above 50 mA and up to 100 mA will tend to cause ventricular fibrillation and may lead to heart failure and death.

## Lightning:

In order to be able to plan a lightning protection system it is first necessary to deter- mine the protection class for the building in planning. Lightning protection classes I to IV are assigned according to different values of the efficiency of the lightning protection system, the mesh size and the lightning sphere size. For each protection class, we can determine the shielding angle of a building according to the height of the air terminal above the ground.[5]

The air terminal serves as the striking point for lightning. The mesh size of the air terminals is 10 m X 20 m maximum for normal buildings, and 10 m X 10 m for hospitals. The mesh must be installed so that no point on the surface of the roof is more than five meters from an air terminal conductor. The height of the lightning rod may not be more than 20 m, and the distance from the building must be at least 2 m. The building is regarded as protected when the angle is 45°. The roof superstructures, of electrically non-conductive material, may not be longer than 0.3 m. A roof ventilation system may not be attached without being first included in the lightning protection concept. If the roof ventilation system is protected by a lightning rod, then the distance between the ventilation system and the lightning rod must be determined. [5]

The down conductor (Table 16.2) connects the air terminal to the grounding system. For every 20 m, measured along the edges of the roof, a down conductor must be installed, outwards from the corners of the building. Through the air terminal, a zone of protection with a shielding angle of 45° is then formed. [5]

# CHAPTER I:
# PROJECT ORGANIZATION

# I. Project Organization

## I.1. Introduction:

This chapter we will present the project in hand and give an overview of the work that is going to be done. First we will describe the project which consists of the development of the fields of EGPDF 48 " El Aricha – Beni Saf by Sonatrach. We will also see the general philosophy of electricity, it will allow us to better understand the specifications, and therefore have more details on the design of the installation, subject of this thesis.

## I.2. Project description:

EGPDF 48 " El Aricha - Beni Saf is located between El Aricha Arrival Terminal of the GPDF Pipeline of Willaya of Naâma and the Arrival Terminal Beni Saf, it consists mainly of a pipeline Ø48 " with a length of 200 Km. The cutoff station essentially consists of:

- The 48V PV module, which will be installed on a 12 meters high structure which is the battery chamber.
- The battery chamber shall have enough space to shelter the battery bank and the distribution panels.
- The cathodic protection panel is separately installed.
- 13 electro valves (20W each) will control the flow of gas in the pipelines and fed from the SCADA/TELECOM panel.

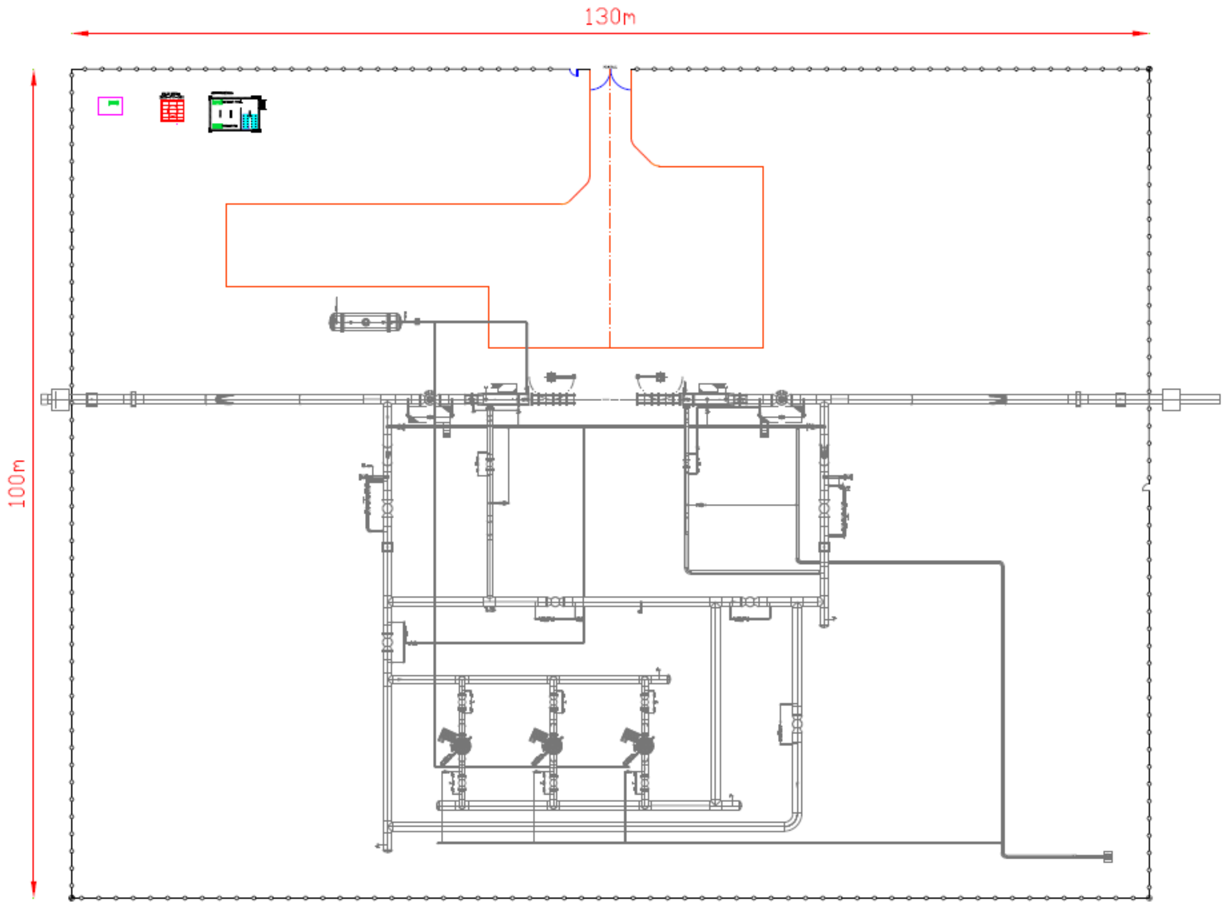



Figure I. 1: cutoff station layout

## I.3. Project Design Electrical Philosophy:

This part describes the general requirements for the design, engineering and of electrical installations to be provided for the 48 " EGPDF Gas Pipeline project.

### I.3.1. Power Source:

**Main Feed**: The source of energy of the remote station of the present project is the solar system with an output voltage of 48Vcc with accumulators in autonomy of 05 days and permissible voltage fluctuation of ± 10%

### I.3.2. Eligible Voltage Drop:

The maximum allowable voltage drop on the cables, expressed in percent (%) of the rated line voltage at full load will be as follows:

- Main electrical distribution 2%
- Secondary Electrical Distribution 3%

### I.3.3. Protective Devices

All protective equipment in the system will be designed to allow fault detection and selective tripping of faulty equipment isolation systems to reduce the negative effects on the power supply.

### I.3.4. Electrical Equipment

#### I.3.4.1. Low Voltage Equipment

The low-voltage switchgear shall be of the indoor type with self-supporting metal casing, with molded case circuit breakers for supply circuits.

Low voltage switchgear will be designed, selected and manufactured in accordance with applicable IEC standards.

#### I.3.4.2. Cables Installation

##### I.3.4.2.1. Installing Cables Above the Ground

The cables will be installed mainly on hot dip galvanized steel ladder type trays.

Cable trays will be installed without a detachable cover for proper ventilation, except when:

- Mechanical damage to the cables may occur during plant maintenance.
- A spill of oil or chemicals may occur.

The cable trays will be designed to withstand the effects of wind on paths loaded with cables.

The cables used for control over cable trays can be laid in bundles over several layers as long as the thermal factor does not affect the capacity of the cables.

Cables should not be installed in parallel with hot lines or high temperature surfaces. If possible, a clearance of 300 mm will be provided.

### I.3.4.3. Types of Cables

Unless exceptionally specified, the power and control cables will have the following specifications:

- Conductor: copper core, rigid and wired (Class 2).
- Isolation: Crosslinked Polyethylene (XLPE)
- Armor: The armor of the cables will be galvanized steel for multi-conductor cables, and non-ferrous materials, such as stainless steel or aluminum for single conductor cables.

### I.3.4.4. Dimensions of Cables

Very low voltage installations are considered non-sensitive for safety. Their voltage levels are indeed less than 50V.

On the entire site, power and control cables are armed.

Intensity:

The permissible current values will be derated according to the following parameters:

- Ambient temperature of the soil,
- Exposure to sunlight,
- Thermal resistivity of the soil,
- Grouping and spacing,
- Installation method including the installation of the cables under sleeves or gutters.

The cable usage factors for thermal limits and installation conditions are in accordance with the dimensioning criteria given in IEC60-287.

**Allowable voltage drops:**

The maximum voltage drops allowed is 5%

The dimensions of the cables shall be determined in accordance with the requirements specified in paragraph 7.1 and the conditions below:

The current carrying capacity of the cables will be based on the following conditions:

- Ambient temperature: 55 ° C
- Soil temperature: 30 ° C
- The minimum section of the drivers will be as follows:
- LV power cable: 2.5 mm2
- Control and signal cable: 1.5 mm2

- Cable for socket: 2.5 mm2
- Lighting cable: 2.5 mm2

## I.3.5. Grounding And Protection Against Lightning

The following requirements apply to all units:

### I.3.5.1. General

The grounding system must meet the basic requirements for the protection of persons, the selectivity of the earth fault protection systems and to ensure protection by the efficient flow of earth lightning and static charges.

- The grounding system is provided for:
- Facilitate rapid detection and isolation of electrical faults.
- Minimize equipment damage due to electrical faults
- Protect against lightning and electrostatic charges
- Minimize the inverse effects of electromagnetic interference on instrumentation and telecom.

The grounding system will consist of:

- Grounding the electrical system (TNS system)
- Grounding the masses
- Protection against lightning
- Grounding for electrostatic discharge
- Grounding instrumentation and telecom

As a general rule, the grounding network will be installed around substations, process units, structures, equipment and other electrical installations. The grounding network will consist of a main ground wire, main cable lead wires to individual connections, and grounding electrodes.

The conductors for the grounding network will be sheathed copper cables. The sheath is green / yellow PVC.

The conductor diameter for the main cable will be at least 95 mm2. The branch cable will have a diameter sufficient to carry the short circuit current.

Underground grounding conductors will be laid directly into the ground at a depth of 1m.

The resistance value of the grounding system must not exceed 1Ω.

**Note:** The grounding system must be isolated from the lightning protection system.

### I.3.5.2. Protection Against Lightning

The lightning protection will be carried out by means of lightning rod placed out of danger zones with a protection radius sufficiently protecting. It will be used to protect against lightning strikes of all equipment and structures installed.

The lightning rod batch will consist chiefly of:

- **Protection System**

  The lightning rod will be of the type of ignition device with a large radius of action to largely cover the site in question and their streets according to the plans, installed on the mat of the solar panel.

- **Earthling Descents**

  A descent will be executed from the lightning rod. The descent will be from the inside of the mat with braided copper cable braid of a suitable section. The bypass radius shall not be less than 20 cm. The acroterial crossing will be done by means of reservation of 50 mm of diameter.

- **Control Bar**

  The descent will be stopped on a control bar so as to measure the resistance of the earth connections and the electrical continuity of the descent.

  The control joints, placed under removable covers, will be located two meters above the ground to be accessible only for checks. Between the floor and the control joints, the cable will be protected by PVC pipe, fixed to the frame by collars.

- **Lightning Torque Counter**

  The lightning counter makes it possible to count the lightning strikes on an external protection installation. Its digital display allows a direct and comfortable reading of the number of recorded impacts. The recording of the lightning strikes and their memorization does not require any external power supply and is thus not dependent on the life of the battery.

## I.4. Engineering Job Overview:

In general, the electrical engineer is a person who participates in progress. It's him (or her) that is required when it comes to solving technological problems but also to innovate. They occupy multiple functions there. An engineer in electrical engineering can interfere in research and development, in the design and manufacture of products, in consulting and expertise, in the exploitation and implementation of production, in commercial activities.

### I.4.1. Tasks of an Electrical Engineer in a Project:

- All fields of activity are concerned with development and modernization, so engineers work in all fields:
  - Industry, Energy.
  - Security, Agriculture.
  - Research, finance.
  - The environment, IT, Construction.

- During his training, the engineer acquires other skills that he will use throughout his professional life:
    - Problem Analysis: Ability to use the appropriate knowledge and principles to identify, formulate, analyze and solve complex engineering problems and arrive at supported conclusions.
    - Investigation: Ability to study complex problems using methods involving the conduct of experiments, analysis and interpretation of data, and synthesis of information to formulate valid conclusions.
    - Individual and team work: ability to function effectively as a member or team leader, preferably in a multidisciplinary work context.
    - Professionalism: Understanding the roles and responsibilities of the engineer in society, including the critical role of protecting the public and the public interest.
    - Economics and Project Management: ability to appropriately integrate business and economic practices, such as project management, risk and change,
    - Continuous Learning: The ability to identify and meet one's own training needs in a changing world in order to maintain competence and contribute to the advancement of knowledge.

Being an engineer is a really versatile job where you learn every day.

### I.4.2. Deliverables Electrical Engineering

The engineering prepares drawings, diagrams, calculation notes, specifications, applications and any other document that may be necessary to cover the detailed design of the installation and the acquisition of all necessary materials.

# CHAPTER II:

# Electrical Source Study

# II. Electrical Source Study

## II.1. Introduction:

This chapter will deal with the steps that must be followed to establish a load list and size the electrical energy sources (photovoltaic panel and battery) based on international standards.
This system consists of solar panels that feed the loads with a direct current and at the same time charge the batteries to ensure the supply of the load when the PV panels does not provide the sufficient voltage to feed the load.

## II.2. Load list :

### II.2.1. Definition:

Load List (also known as Load Schedule) is an important document – the **backbone** or **base** of any Electrical System Design (ESD). It is considered to be a **live document** that can be updated even after the concerned plant starts operating. It's normally drafted at the beginning of any project. [6]

### II.2.2. Calculation Methodology:

There are no standards governing load schedules and therefore this calculation is based on generally accepted industry practice. The loads classification is mainly based on three parameters, the first criterion is the voltage, and the second parameter is based on the load duty such that there three types of loads; continuous, intermittent and standby loads applying duty factors of 1, 0.5 (or any predefined factor according the runtime of the equipment) , 0.1 respectively.

And finally depending on the criticality of the load, depending on whether it is a normal load, an essential load or a critical load. The collected information is then used to calculate the individual and global operating power, design, and peak power in continuous, intermittent, and standby service.

### II.2.3. Calculation Steps:

The basic steps for creating a load schedule are: [7]

**Step 1: Collect list of loads:**

The first step is to gather a list of all the electrical loads that will be supplied by the power system affected by the load schedule. There are generally two types of loads that need to be collected:

- Process loads: are the loads that are directly relevant to the facility. In factories and industrial plants, process loads are the motors, heaters, compressors, conveyors, etc. that form the main business of the plant.

- Non-process loads: are the auxiliary loads that are necessary to run the facility, e.g. lighting, HVAC, utility systems (power and water), DCS/PLC control systems, fire safety systems, etc.

## Step 2: Collect electrical load parameters:

A number of electrical load parameters are necessary to construct the load schedule:

- Rated power: is the full load or nameplate rating of the load and represents the power it receives when fed with the nominal voltage.
- Efficiency: accounts for the losses incurred when converting electrical energy to mechanical energy (or whatever type of energy the load outputs). Some of the electrical power drawn by the load is lost, usually in the form of heat to the ambient environment.
- Utilization factor (ku): is a factor that takes into account or depends on the operating time of equipment connected to the network.
- Simultaneity factor (ks): since the installed equipment does not necessary run in the same time a simultaneity factor can be employed.
- Reserve factor (kr): since the installation can be modified due to an expansion in prospect we use the reserve factor in order not to change the whole installation.

## Step 3: Classify the loads:

Once the loads have been identified, it is needed to classify them accordingly:

**Voltage level:**

It's indispensable to know what voltage level and which switchboard should the load be located, Large loads may need to be on MV or HV switchboards depending on the size of the load and how many voltage levels are available.

**Load duty:**

Loads are classified according to their duty as continuous, intermittent and standby loads:

- Continuous loads: loads are those that normally operate continuously over a 24 hour period.
- Intermittent loads: loads that only operate for a fraction of a 24 hour period
- Standby loads: loads are those that are on standby or rarely operate under normal conditions.

**Load criticality:**

Loads are typically classified as either normal, essential and critical:

- Normal loads are those that run under normal operating conditions, e.g. main process loads, normal lighting and small power, ordinary office and workshop loads, etc.

- Essential loads are those necessary under emergency conditions; when the main power supply is disconnected and the system is being supported by an emergency generator.
- Critical loads are those critical for the operation of safety systems and for facilitating or assisting evacuation from the plant, and would normally be supplied from a UPS or battery system.

### Step 4: Calculate consumed load

The consumed power is the quantity of electrical power that the load is expected to consume [7]. For each load we calculate the consumed active and reactive loading, derived as follows:

$$P_a = \frac{P_n}{\eta}$$

Where:

- Pa is the consumed active power
- Pn is the absorbed active power
- Ƞ is the load efficiency in pu

### Step 5: Calculate operating, peak and design load:

The operating, peak and design load may differ from organization/ client to another, a generic method is presented as follows:

**Operating load:** is the expected load during normal operation and it is the sum of the total continuous load and the intermittent load multiplied by its duty factor [7] (in our design it is taken 30%)

$$OL = \sum L_C + 0.3 * \sum L_i$$

Where:

- OL is the operating load (in Watts)
- ∑Lc is the sum of the continuous load
- ∑Li is the sum of intermittent load

**Peak load:** The peak load is the expected maximum load during normal operation. Peak loading is typically infrequent and of short duration, occurring when standby loads (with a duty factor of 0.1) are operated. [7]

$$PL = \sum L_C + 0.3 * \sum L_i + 0.1 * \sum L_s$$

Where:

- PL is the peak load (in Watts)
- ∑Lc is the sum of the continuous load
- ∑Li is the sum of intermittent load

- ∑Ls is the sum of standby load

**Design load:** The design load is the load to be used for the design for equipment sizing, electrical studies, etc [7]. The design load is generically calculated as the larger of either:

$$DL = 1.1 * OL + 0.1 * \sum L_S$$

Where:

- DL is the design load
- OL is the operating load
- ∑Ls is the sum of standby load

In our study the load list is accordingly constructed based on the given loads as presented below:

| Equipment | Voltage (V) | Current (I) | Power (W) | Duty Factor (%) | Watts | |
|---|---|---|---|---|---|---|
| | | | | | Continuous | intermittent |
| SCADA/ TELECOM | 48 | 10.42 | 500 | 100 | 500 | |
| Charger loss | 48 | 0.78 | 180 | 100 | 180 | |
| Cathodic Protection 1 | 48 | 2.32 | 480 | 100 | 480 | |
| Battery chamber lighting | 48 | 0.17 | 36 | 30 | | 10.8 |
| Shelter Lighting | 48 | 0.17 | 36 | 30 | | 10.8 |
| Battery chamber extractor | 48 | 0.24 | 50 | 30 | | 15 |
| Total Power (W) | | | | | 1196.6 | |
| Total energy (Wh) | | | | | 28718.4 | |

Table II. 1: load list

$P_{tot} = \sum P = 1196.6\ W$

$E_{tot} = P_{tot} * 24 = 28718.4\ Wh$

## II.3. Single line diagram SLD:

### II.3.1. Definition:

The single-line diagram as: a diagram giving the configuration of the electrical networks, including those of automatisms serving the different parts of the work and showing their mutual relations and the means used for this purpose. [8]

### II.3.2. Design Bases

The design of the solar system shall be based on the loads consumption and other requirements covered by this specification. Nevertheless, the contractor must examine the solar system load consumers relative to the allowable power in addition to reserve capacity.

### II.3.3. SLD Representation of our system:

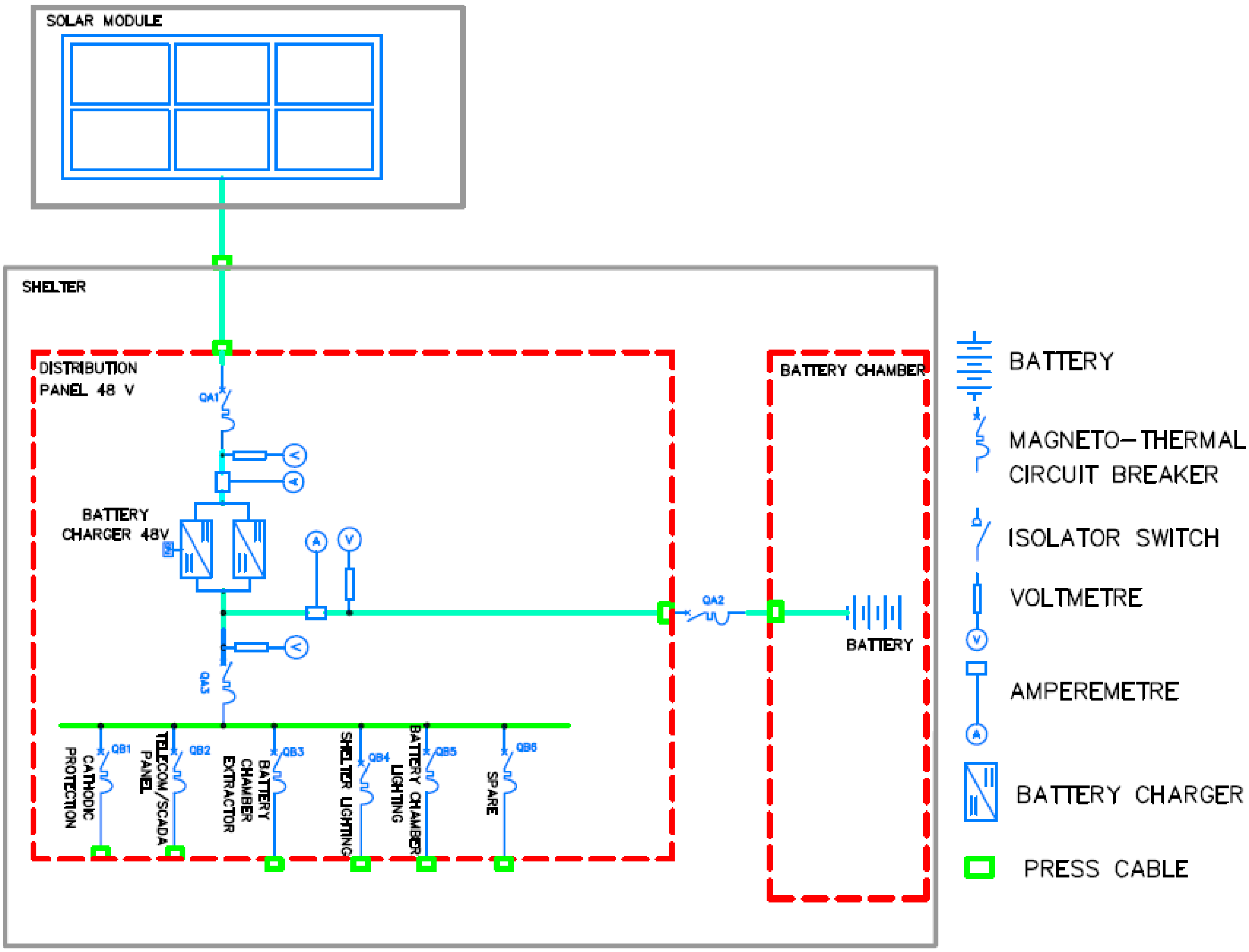



Figure II. 1: single line diagram of the system.

## II.4. Solar panels:

### II.4.1. Introduction:

This calculation outlines the sizing of a standalone solar photovoltaic (PV) power system. Standalone PV systems are commonly used to supply power to small, remote installations (e.g. telecoms) where it isn't practical or cost-efficient to run a transmission line or have alternative generation such as diesel generators.
Although this calculation is biased towards standalone solar PV systems, it can also be used for hybrid systems that draw power from mixed sources (e.g. commercial PV,

hybrid wind-PV systems, etc.) Loads must be adjusted according to the desired amount that the solar PV system will supply.
This calculation is based on crystalline silicon PV technology. The results may not hold for other types of solar PV technologies and the manufacturer's recommendations will need to be consulted.

### II.4.2. Calculation Methodology

The calculation is loosely based on AS/NZS 4509.2 (2002) "Standalone power systems - System design guidelines". The methodology has the following six steps:

- Step 1: Estimate the solar irradiation available at the site (based on GPS coordinates or measurement)
- Step 2: Collect the loads that will be supported by the system
- Step 3: Construct a load profile and calculate design load and design energy
- Step 4: Calculate the required battery capacity based on the design loads
- Step 5: Estimate the output of a single PV module at the proposed site location
- Step 6: Calculate size of the PV array

### Step 1: Estimate the Solar Irradiation:

The easiest option is to estimate the solar irradiation (or solar insolation) by inputting the GPS coordinates of the site into the NASA-SSE (Surface Meteorology and Solar Energy program) website. For any given set of GPS coordinates, the website provides first pass estimates of the monthly minimum, average and maximum solar irradiation (in kWhm2/ day) at ground level and at various tilt angles. Experiments have shown that it is sufficient to tilt the module at a 30 degree angle for a better performance. The angle of inclination corresponds to the angle formed by the solar module plane relative to the horizon. After we collect this data, we choose an appropriate tilt angle and identify the best and worst months of the year in terms of solar irradiation. The table below demonstrates the monthly average irradiation accompanied with the ambient temperature.

| Month | Global Irradiation ($kWhm^2$/ day) | Temperature |
|---|---|---|
| January | 3.08 | 12.1 |
| February | 3.78 | 13.1 |
| March | 5.33 | 15.2 |
| April | 6.41 | 16.5 |
| May | 7.12 | 19.08 |
| June | 8.09 | 23.4 |
| July | 8.04 | 26.7 |
| August | 7.37 | 26.7 |
| September | 5.78 | 23.6 |
| October | 4.61 | 20.07 |
| November | 3.45 | 15.9 |
| December | 2.81 | 13.4 |

| | | |
|---|---|---|
| Yearly | 5.50 | 18.9 |

Table II. 2**:** monthly solar irradiation and temperature of the site

## Step 2: Collect the Solar Power System Loads:

It is a question of estimating the consumption of supposedly known equipment. The goal is to get the average total consumption per day.

The average total energy required each day E (Wh / d) is the sum of the energy consumption of the various equipment constituting the system to be studied

$$E = \sum_{i} E_i$$

In our case $E_{tot} = 28718.4$ Wh

## Step 3: Calculate the Peak Power Pc of the PV Generator:

In order to calculate the peak power Pc, some factors must be taken into account:

- Efficiency of the photovoltaic generator: Losses due to dust, heating of modules, wiring, etc.
- Battery efficiency: Typically 75% to 90%, include wiring and aging losses.
- The effective PV Cell Temperature (as it will be used in the subsequent calculations).

Firstly, the average effective PV cell temperature at the installation site needs to be calculated. It can be estimated for each month using the following formula: [9]

$$T_{cell.eff} = T_{a.day} + 25$$

Where: $T_{cell.eff}$ is the average effective PV cell temperature (˚C)

$T_{a.day}$ is the average daytime ambient temperature at the site (˚C)

In our case $T_{cell.eff} = 12.9 + 25 = 37.9\ ^{\circ}\mathrm{C}$

- **MPPT Regulator:** for a solar power system using a Maximum Power Point Tracking (MPPT) charge regulator / controller, the derated power output of the PV module can be calculated using the following equation: [9]

$$P_{mod} = P_{stc} * f_{temp} * f_{man} * f_{dirt}$$

Where: $P_{mod}$ is the derated output power of the PV module using an MPPT charge controller (W)

$P_{stc}$ is the nominal module power under standard test conditions (W)

$f_{temp}$ the temperature derating factor (pu)

$f_{man}$ is the manufacturer's power output tolerance (pu)

$f_{dirt}$ is the derating factor for dirt / soiling (Clean: 1.0, Low: 0.98, Med: 0.97, High: 0.92)

The temperature derating factor is determined from equation:

$$f_{temp} = 1 - \gamma(T_{cell.eff} - T_{stc})$$

Where:

- γ is the Power Temperature Coefficient (% per deg C) (typically 0.005 for crystalline silicon)
- $T_{cell.eff}$ is the average effective PV cell temperature (°C)
- $T_{stc}$ is the temperature under standard test conditions (typically 25 °C)

In our case: $f_{temp} = 1 - \gamma(T_{cell.eff} - T_{stc}) = 1 - 0.005(37.9 - 25) = 0.9355$

Now we can estimate the derated output power of the module, the chosen module is ASE-260-DG-FT/268W with $P_{stc} = 268\text{W}$

$$P_{mod} = P_{stc} * f_{temp} * f_{man} * f_{dirt} = 268 * 0.9355 * 1 * 0.97 = 243{,}2 \text{ W}$$

### Step 4: Size the PV Array:

The number of modules required for a PV array where this is the sole energy source, can be calculated from the following equation: [9]

$$N_p = \frac{E_{tot} * f_0}{P_{mod} * H_{tilt} * \eta_{coul} * N_s}$$

Where: Np = number of parallel strings of modules in the array (rounded up to the next whole number), dimensionless

- Etot is total design daily energy demand from the d.c. bus, in watthours
- fo is oversupply co-efficient, dimensionless
- Pmod is the derated output power of the module, in watts
- Htilt is daily irradiation on the tilted plane, in peak sun hours
- Ƞcoul is coulombic efficiency of the battery, dimensionless
- Ns is number of series connected modules per string (an integer); since the module output voltage is 48V and the system voltage is also 48 then $N_s$=1.

$$N_p = \frac{28718.4 * 1.2}{243{,}2 * 5.5 * 0.9 * 1} = 29$$

## II.5. Battery sizing:

### II.5.1. Introduction:

Sizing a stationary battery is important to ensure that the loads being supplied or the power system being supported are adequately catered for by the battery for the period of time (i.e. autonomy) for which it is designed.

Improper battery sizing can lead to poor autonomy times, permanent damage to battery cells from over discharge, low load voltages, etc.

## II.5.2. Calculation methodology:

There are five main steps in this calculation:

- Collect the loads that the battery needs to support.
- Construct a load profile and calculate the design energy (VAh).
- Select the battery type and determine the characteristics of the cell.
- Select the number of battery cells to be connected in series.
- Calculate the required Ampere-hour (Ah) capacity of the battery.

The design energy was found in previous section $E_{tot}$= $28718.4\ Wh$

The selected battery is: sealed lead acid battery

### II.5.2.1. Number of battery cells to be connected in series:

The most common number of cells for a specific voltage rating is shown below:

| Rated Voltage | Lead-Acid | Ni-Cd |
|---|---|---|
| 12V | 6 | 9-10 |
| 24V | 12 | 18-20 |
| 48V | 24 | 36-40 |
| 125V | 60 | 92-100 |
| 250V | 120 | 184-200 |

Table II. 3: most common number of cells for a specific voltage ratings

### II.5.2.2. Determine battery capacity:

The minimum battery capacity required to accommodate the design load over the specified autonomy time can be calculated as follows: [10]

$$C_{min} = \frac{E_d(K_a * K_t * K_c)}{V_{dc} * K_{dod}}$$

Where:

- $E_d$ is the design energy over the autonomy time (Wh)
- $V_{dc}$ is the nominal battery voltage (Vdc)
- $K_a$ is a battery ageing factor (%)
- $K_t$ is a temperature correction factor (%)
- $K_c$ is a capacity rating factor (%)
- $K_{dod}$ is the maximum depth of discharge (%)

An explanation of the different factors:

- **Aging factor**: captures the decrease in battery performance due to age.
- **Temperature correction factor**: the capacity for battery cells are typical quoted for a standard operating temperature of 25C and where this differs with the installation temperature, a correction factor must be applied.
- **Capacity rating factor**: accounts for voltage depressions during battery discharge. Lead-acid batteries experience a voltage dip during the early stages of discharge followed by some recovery. Ni-Cds may have lower voltages on discharge due to prolonged float charging (constant voltage).

Takin the factors: $K_a = 1.1$ , $K_t = 1.1$ , $K_c = 1.1$
The selected autonomy is 5 days so the design energy to be stored is:

$$E_d = 5 * E_{tot} = 5 * 28718.4 = 143.6\ kWh$$

Thus the minimum battery capacity can be calculated:

$$C_{min} = \frac{143.6\ kWh(1.1 * 1.1 * 1)}{48 * 0.8} = 4524.8\ Ah$$

### II.5.2.3. Calculation of number of cells:

When the battery voltage is not allowed to exceed a given maximum system voltage, the number of cells will be limited by the manufacturer's recommended cell voltage required for satisfactory charging[10]. That is, as shown in Equation:

$$\frac{\text{Maximum allowable system voltage}}{\text{Cell voltage required for satisfactory charging}} = \text{Number of cells}$$

We select a battery Ah capacity that exceeds the minimum capacity calculated above.

For Instance 2420 Ah batteries are selected coupling two parallel strings yields a total capacity of 4840 Ah in order to cover the needed capacity, therefore the total number of battery cells needed is 2×24 (2 parallel strings and 24 series strings)

According to the equation the maximum series cells is: $\frac{52.8}{2} = 26$

## II.6. Charger Sizing:

Battery charging methods and voltage regulation settings should be chosen to suit the batteries and the duty cycle that they experience. The primary source of information for correct regulator settings should be the battery manufacturer. Guidelines may also be provided by the manufacturer of the regulator or other charging equipment (e.g. inverter or battery charger).
The charger should be sized to supply the inverter at full load and also charge the batteries (at the maximum charge current). The design DC load current can be calculated by: [11]

$$I_{L.dc} = \frac{P}{V_{dc}}$$

Where $I_{L.dc}$ is the design DC load current (full load) (A)
S is the selected system rating (kVA)

$V_{dc}$ is the nominal battery / DC link voltage (Vdc)

$$I_{L.dc} = \frac{P}{V_{dc}} = \frac{1196.6}{48} = 24.8A$$

The maximum battery charging current can be computed as follows:

$$I_c = \frac{CK_l}{t_c}$$

Where: $I_c$ is the maximum DC charge current (A)

C is the selected battery capacity (Ah)

$K_l$ is the battery recharge efficiency / loss factor (typically 1.1) (pu)

$t_c$ is the minimum battery recharge time (hours)

$$I_c = \frac{CK_l}{t_c} = \frac{4840 * 1.1}{30} = 177.4\ A$$

Thus the total charger current is:

$$I_{charger} = I_{L.dc} + I_c = 29.1 + 177.4 = 206.5A$$

We can consider three parallel chargers of 70A each.

## II.7. Calculation using software: PVSYST

PVsyst software is a commercial software to design and check the performance of photovoltaic solar installations. First the geographical parameters of the site need to be imported then user needs are input and the system equipment shall be specified.

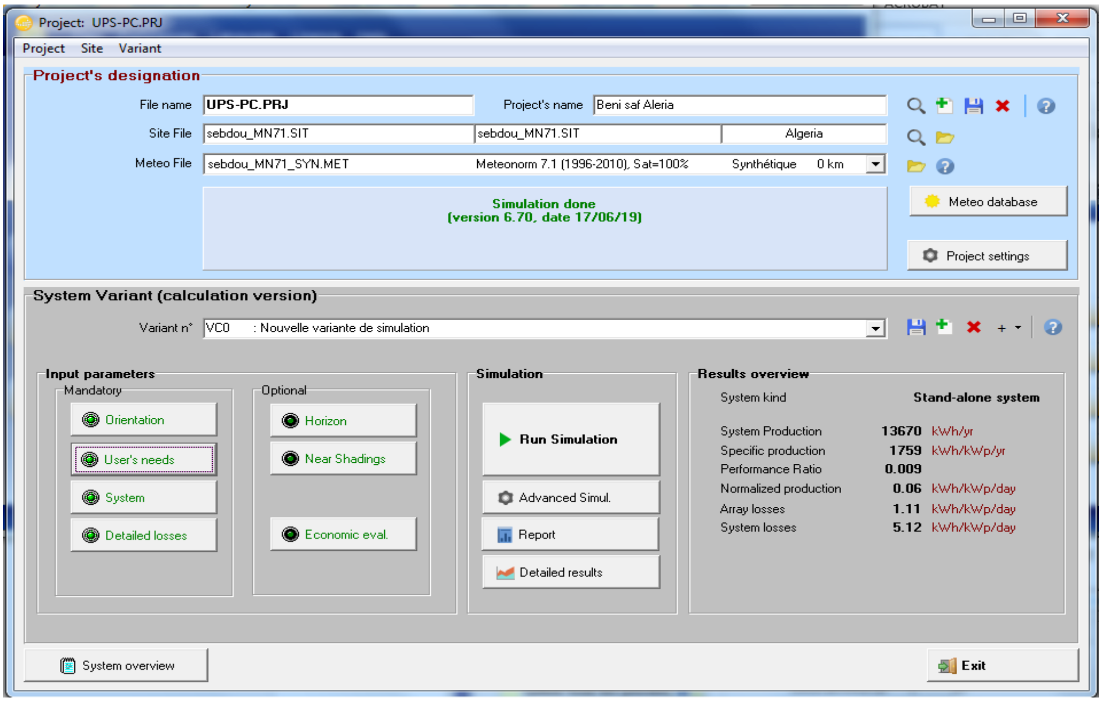



Figure II. 2: interface of PVsyst V6.70 software

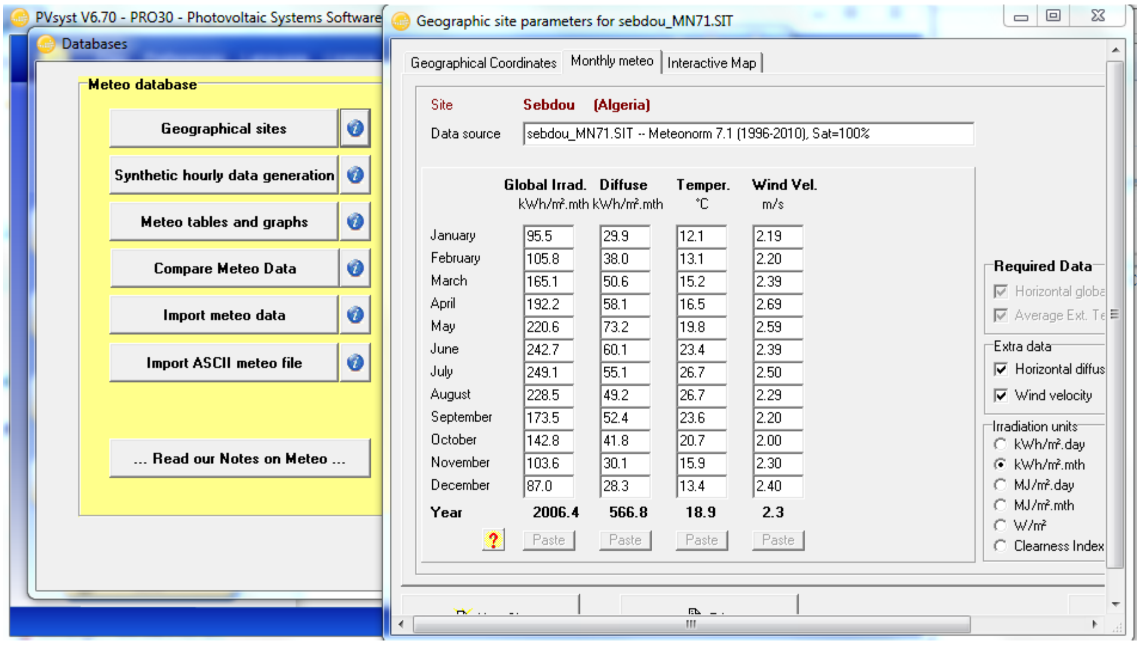



Figure II. 3: importing geographical parameters

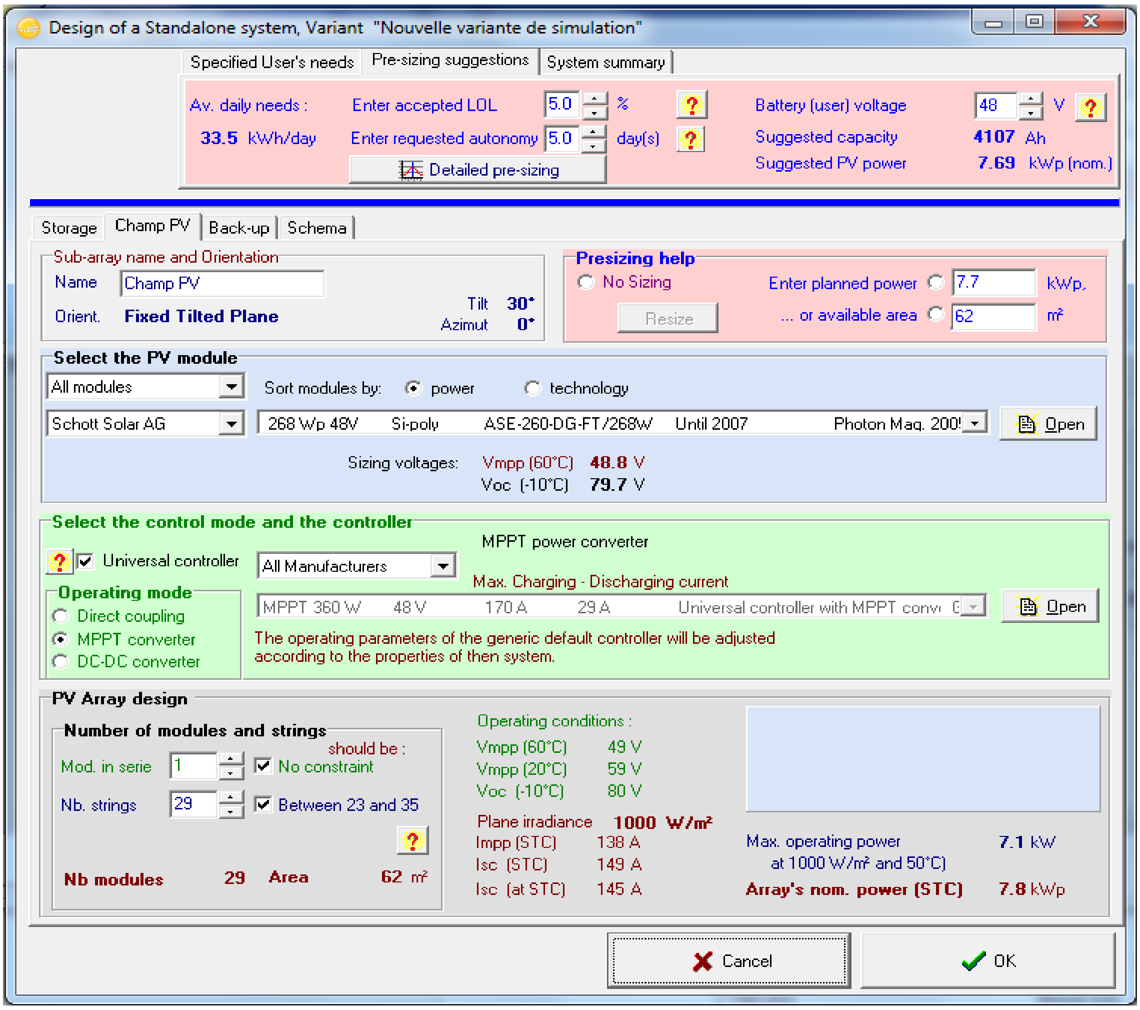



Figure II. 4: system parameters and equipment selection

After running the calculation a report that shows the details about the system is obtained (figure II.4) According to the report 29 PV panels are needed in parallel, and 48 battery cells (2 parallel strings of 24 series cells).

| PVSYST V6.70 | | 17/06/19 | Page 1/4 |
|---|---|---|---|

**Stand Alone System: Simulation parameters**

| | | | | | |
|---|---|---|---|---|---|
| **Project :** | **Beni saf Aleria** | | | | |
| **Geographical Site** | | **Sebdou** | | Country | **Algeria** |
| **Situation** | | Latitude | 34.64° N | Longitude | -1.33° W |
| Time defined as | | Legal Time | Time zone UT+1 | Altitude | 0 m |
| | | Albedo | 0.20 | | |
| **Meteo data:** | | **sebdou** | Meteonorm 7.1 (1996-2010), Sat=100% - Synthétique | | |
| **Simulation variant :** | **Nouvelle variante de simulation** | | | | |
| | | Simulation date | 17/06/19 09h45 | | |
| **Simulation parameters** | | System type | **Stand-alone system** | | |
| **Collector Plane Orientation** | | Tilt | 30° | Azimuth | 0° |
| **Models used** | | Transposition | Perez | Diffuse | Perez, Meteonorm |
| **PV Array Characteristics** | | | | | |
| **PV module** | Si-poly | Model | **ASE-260-DG-FT/268W** | | |
| Original PVsyst database | | Manufacturer | Schott Solar AG | | |
| Number of PV modules | | In series | 1 modules | In parallel | 29 strings |
| Total number of PV modules | | Nb. modules | 29 | Unit Nom. Power | 268 Wp |
| Array global power | | Nominal (STC) | **7.77 kWp** | At operating cond. | 7.06 kWp (50°C) |
| Array operating characteristics (50°C) | | U mpp | 51 V | I mpp | 138 A |
| Total area | | Module area | **62.2 m²** | | |
| **PV Array loss factors** | | | | | |
| Thermal Loss factor | | Uc (const) | 20.0 W/m²K | Uv (wind) | 0.0 W/m²K / m/s |
| Wiring Ohmic Loss | | Global array res. | 6.3 mOhm | Loss Fraction | 1.5 % at STC |
| Serie Diode Loss | | Voltage Drop | 0.7 V | Loss Fraction | 1.2 % at STC |
| Module Quality Loss | | | | Loss Fraction | 2.5 % |
| Module Mismatch Losses | | | | Loss Fraction | 1.0 % at MPP |
| Strings Mismatch loss | | | | Loss Fraction | 0.10 % |
| Incidence effect, ASHRAE parametrization | | IAM = | 1 - bo (1/cos i - 1) | bo Param. | 0.05 |
| **System Parameter** | | System type | **Stand Alone System** | | |
| **Battery** | | Model | **OPzV Solar 2740** | | |
| | | Manufacturer | Moll | | |
| Battery Pack Characteristics | | Voltage | 48 V | Nominal Capacity | 4140 Ah |
| | | Nb. of units | 24 in series x 2 in parallel | | |
| | | Temperature | Fixed (40°C) | | |
| **Controller** | | Model | Universal controller with MPPT converter | | |
| | | Technology | MPPT converter | Temp coeff. | -5.0 mV/°C/elem. |
| Converter | | Maxi and EURO efficiencies | 97.0 / 95.0 % | | |
| Battery Management control | | Threshold commands as | SOC calculation | | |
| | | Charging | SOC = 0.90 / 0.75 | i.e. approx. | 51.1 / 50.1 V |
| | | Discharging | SOC = 0.20 / 0.45 | i.e. approx. | 47.2 / 48.9 V |
| **User's needs :** | | Daily household consumers | Constant over the year | | |
| | | average | 33.5 kWh/Day | | |

Figure II. 5: calculation report obtained from PVsyst.

## II.8. Conclusion:

In this chapter we have learned to master ways of calculating and dimensioning equipment (PV panels, battery, and battery charger) starting with constructing a load list and the single line diagram, calculations were performed based on international standards and Pvsyst software was used in order to check and compare the results.

# CHAPTER III:
# CABLES AND PROTECTION

# III. Chapter III: Cables and protection:

## III.1. Cables sizing and selection:

### III.1.1. Introduction:

Cable sizing methods do differ across international standards (e.g. IEC, NEC, BS, etc) and some standards emphasize certain things over others. However the general principles underlying any cable sizing calculation do not change. In this article, a general methodology for sizing cables is first presented and then the specific international standards are introduced.

#### III.1.1.1. Description

Single core or multicore cables with copper or aluminium conductor, insulated, either armoured or none armoured and sheathed.

#### III.1.1.2. Construction:

Conductor: Plain circular, compacted or shaper, copper or aluminium conductor

Insulation: XLPE; cross linked polyethylene or PVC; Polyvinyl chloride.

Armour: aluminium or galvanized steel, wire or tape. [12]

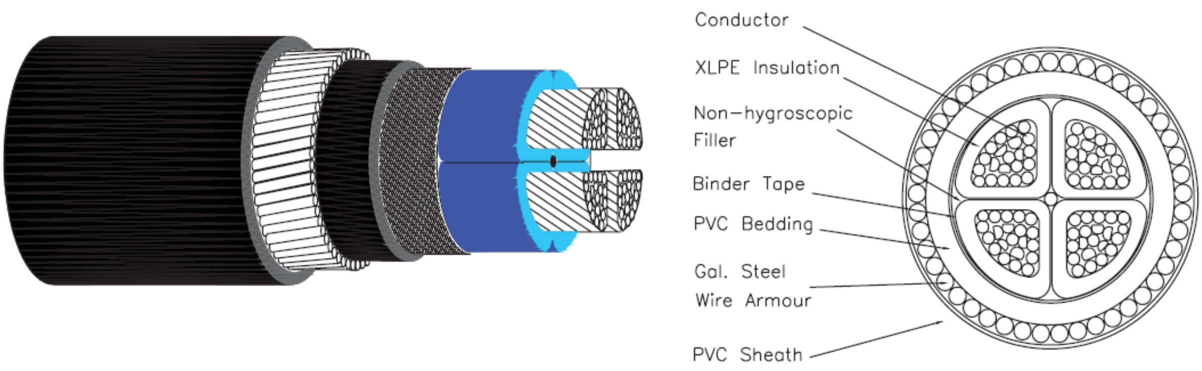



Figure III. 1: construction of an armoured power cable with XLPE isolation

### III.1.2. Why do the calculation?

The proper sizing of an electrical (load bearing) cable is important to ensure that the cable can:

- Operate continuously under full load without being damaged
- Withstand the worst short circuits currents flowing through the cable
- Provide the load with a suitable voltage (and avoid excessive voltage drops)
- (optional) Ensure operation of protective devices during an earth fault

### III.1.3. General Methodology

All cable sizing methods more or less follow the same basic five steps process:

1) Gathering data about the cable, its installation conditions, the load that it will carry, etc.
2) Determine the minimum cable size based on continuous current carrying capacity
3) Determine the minimum cable size based on voltage drop considerations
4) Determine the minimum cable size based on short circuit temperature rise
5) Select the cable based on the highest of the sizes calculated in step 2, 3, 4

### III.1.4. Cable Layout:

Cable layout plays an important role in electrical installation work as it transmits information on the connection of various appliances and equipment to the power grid. It shows how electrical cables are interconnected and can also show where devices and components can be connected to the system. The information on the drawings provides the complete design or layout of the electrical installation and also helps to assemble the various equipment.

From the site schemes and electrical power generation equipment layout cable paths are drawn using AutoCAD. AutoCAD 2014

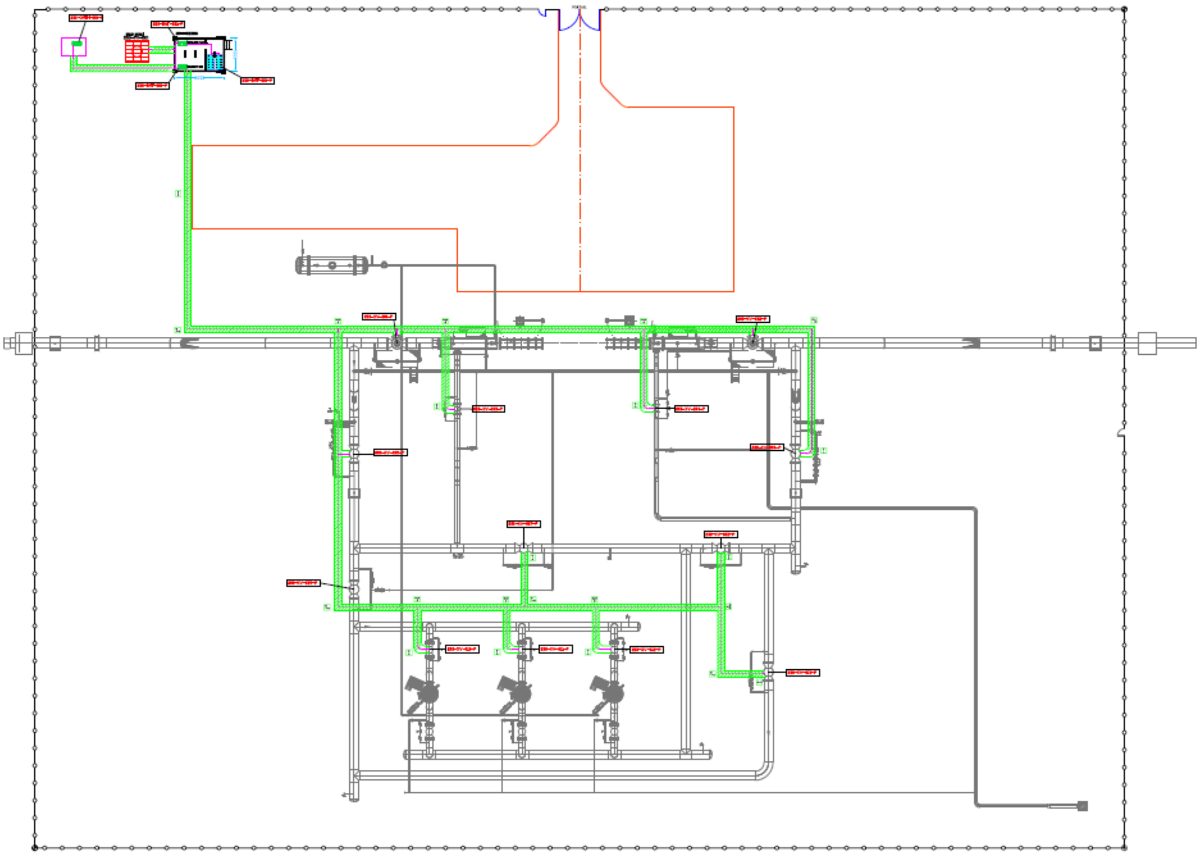


Figure III. 2: Cable layout shows in detail the cable routing and installation

### III.1.5. Data Gathering:

The first step is to collate the relevant information that is required to perform the sizing calculation. Typically, we will need to obtain the following data:

### III.1.6. Load Details:

The characteristics of the load that the cable will supply, which includes:

- Load type: motor or feeder
- Three phase, single phase or DC
- System / source voltage
- Full load current (A) - or calculate this if the load is defined in terms of power (kW)
- Full load power factor (pu)
- Locked rotor or load starting current (A)
- Starting power factor (pu)
- Distance / length of cable run from source to load - this length should be as close as possible to the actual route of the cable and include enough contingency for vertical drops / rises and termination of the cable tails

#### III.1.6.1. Cable Construction:

The basic characteristics of the cable's physical construction, which includes:

- Conductor material - normally copper or Aluminium
- Conductor shape - e.g. circular or shaped
- Conductor type - e.g. stranded or solid
- Conductor surface coating - e.g. plain (no coating), tinned, silver or nickel
- Insulation type - e.g. PVC, XLPE, EPR
- Number of cores - single core or multicore (e.g. 2C, 3C or 4C)

The cables used in this study are as follows:

Conductor: copper core, rigid and wired (Class 2).
Isolation: Crosslinked Polyethylene (XLPE)
Armor: galvanized steel for multi-conductor cables, and non-ferrous materials, such as stainless steel or aluminum for single conductor cables.

#### III.1.6.2. Installation Conditions

How the cable will be installed, which includes:

- Above ground or underground
- Installation / arrangement - e.g. for underground cables, is it directly buried or buried in conduit? For above ground cables, is it installed on cable tray / ladder, against a wall, in air, etc.
- Ambient or soil temperature of the installation site

- Cable bunching, i.e. the number of cables that are bunched together
- Cable spacing, i.e. whether cables are installed touching or spaced
- Soil thermal resistivity (for underground cables)
- Depth of laying (for underground cables)

### III.1.6.3. Correction Factors Of Cable

The ampacity of a cable quoted from the manufacturer is based on a specific set of installation conditions. When a cable is installed in a different set of conditions the cable must be derated appropriately. [13]

$$I_T \geq \frac{I_n}{C}$$

$$\mathrm{C} = \mathrm{C}_1 * \mathrm{C}_2 * \mathrm{C} * \mathrm{C}_4 * \mathrm{C}_5$$

- $I_T$ Current currying capacity
- $I_n$ Base current rating
- C1 ground Temperature factor (Direct buried cables only)
  C2 Ambient Temperature factor (Cables run on tray only)
  C3 Depth of Lay factor (Direct buried cables only)
  C4 Grouping factor
  C5 Thermal Resistivity of the ground factor (Direct buried cables only)

The values from each one of these factors, where applicable, are then multiplied together to give an overall rating factor for the cable. In our case the factors are obtained from IEC 60364-5-52 standard and the depth of lay factors are obtained from Elsewedy Cables catalogue

| Ground temperature | Insulation | |
|---|---|---|
| | PVC | XLPE / EPR |
| 10 | 1.1 | 1.07 |
| 15 | 1.05 | 1.04 |
| 20 | 1 | 1 |
| 25 | 0.95 | 0.98 |
| 30 | 0.89 | 0.93 |
| 35 | 0.84 | 0.89 |
| 40 | 0.77 | 0.85 |
| 45 | 0.71 | 0.8 |
| 50 | 0.63 | 0.76 |
| 55 | 0.55 | 0.71 |

Table III. 1**:** Correction factors for ambient ground temperatures other than 20 °C to be applied to the current-carrying capacities for cables in ducts in the ground

| Ambient Temperature °C | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
|---|---|---|---|---|---|---|---|---|
| PVC Isolation 70 °C | 1.29 | 1.22 | 1.15 | 1.08 | 1.00 | 0.95 | 0.82 | 0.71 |
| XLPE Isolation 90 °C | 1.18 | 1.14 | 1.10 | 1.05 | 1.00 | 0.90 | 0.89 | 0.84 |

Table III. 2: Correction Factors Associated To the Ambient Temperature

| Thermal resistivity, K·m/W | 0,5 | 0,7 | 1 | 1,5 | 2 | 2,5 | 3 |
|---|---|---|---|---|---|---|---|
| Correction factor for cables in buried ducts | 1,28 | 1,20 | 1,18 | 1,1 | 1,05 | 1 | 0,96 |
| Correction factor for direct buried cables | 1,88 | 1,62 | 1,5 | 1,28 | 1,12 | 1 | 0,90 |

Table III. 3**:** Correction factors for soil thermal resistivities other than 2.5 K.m/W to be applied to the current-carrying capacities

| Number of circuits | Cable to cable clearancea | | | | |
|---|---|---|---|---|---|
| | Nil (cables touching) | One cable diameter | 0,125 m | 0,25 m | 0,5 m |
| 2 | 0,75 | 0,80 | 0,85 | 0,90 | 0,90 |
| 3 | 0,65 | 0,70 | 0,75 | 0,80 | 0,85 |
| 4 | 0,60 | 0,60 | 0,70 | 0,75 | 0,80 |
| 5 | 0,55 | 0,55 | 0,65 | 0,70 | 0,80 |
| 6 | 0,50 | 0,55 | 0,60 | 0,70 | 0,80 |
| 7 | 0,45 | 0,51 | 0,59 | 0,67 | 0,76 |
| 8 | 0,43 | 0,48 | 0,57 | 0,65 | 0,75 |
| 9 | 0,41 | 0,46 | 0,55 | 0,63 | 0,74 |
| 12 | 0,36 | 0,42 | 0,51 | 0,59 | 0,71 |
| 16 | 0,32 | 0,38 | 0,47 | 0,56 | 0,38 |
| 20 | 0,29 | 0,35 | 0,44 | 0,53 | 0,66 |

Table III. 4: Reduction factors for more than one circuit, cables laid directly in the ground

| Depth of Lay (m) | Up to 70 mm2 | From 95 to 240 mm2 | More than 300 mm2 |
|---|---|---|---|
| 0.50 | 1.00 | 1.00 | 1.00 |
| 0.60 | 0.99 | 0.98 | 0.97 |
| 0.80 | 0.97 | 0.96 | 0.94 |
| 1.00 | 0.95 | 0.93 | 0.92 |
| 1.25 | 0.94 | 0.92 | 0.89 |
| 1.50 | 0.93 | 0.90 | 0.87 |
| 1.75 | 0.92 | 0.89 | 0.86 |
| 2.00 | 0.91 | 0.88 | 0.85 |

Table III. 5: Correction Factors Associated to the Depth of Lay

### III.1.7. Continuous Current Carrying Capability

The continuous current is calculated based on the rating of the equipment. Once the current has been determined, a cable can be selected based on the calculated current and the rating factor on the type of installation of the cable.

The minimum current carrying capacity of the installed cable is determined by:

$$\text{Installed Current Capacity of Cable} = \text{Reduction Factor of Cable} \times \text{Nominal Current Rating of Cable}$$

### III.1.8. Voltage Drop

The equipment will generally be located in a different location from where it is supplied. Due to the resistance and reactance of the cable, this will cause a volt drop to occur in the cable.

The maximum permissible voltage drop in a power distribution feeder cable is:

| Equipment Type & Location | Permissible Volt Drop |
|---|---|
| Main distribution | 2.0% |
| Secondary distribution | 3.0% |

Table III. 6: maximum permissible voltage drop in a power distribution cables

The volt drop is calculated from the following formula: [14]

$$U = \mathrm{b}(\,\rho_1 \frac{L}{S}\, cos\phi + \lambda \frac{L}{S}\, \sin\phi)/I_B$$

where

- U is the voltage drop in volts;
- b is the coefficient equal to 1 for three-phases circuits, and equal to 2 for single-phase circuits.
- $\rho_1$ is the resistivity of conductors
- L is the straight length of the wiring systems in meters.
- S is the cross-sectional area of conductors, in mm2;
- cos $\phi$ is the power factor
- $\lambda$ is the reactance per unit length of conductors
- $I_B$ is the design current (in amps)

The voltage drop values for LV cables (unipolar & multipolar) are mentioned in Elsewedy Cables catalogue in (mV/Amp/Meter) so we can deduce the voltage drop for each cable by multiplying the given values in the length and the current, if the voltage drop is higher than the permitted values then we shall increase the cable section.[15]

| Cable section ($mm^2$) | Cu conductor voltage drop ( mV/AMP/Meter) | |
|---|---|---|
| | PVC Isolation & PVC sheath | XLPE Isolation & PVC sheath |
| 1.5 | 20.345 | 20.341 |
| 2.5 | 12.397 | 13.197 |
| 4 | 7.741 | 7.731 |
| 6 | 5.199 | 5.191 |
| 10 | 3.101 | 3.094 |
| 16 | 1.988 | 1.982 |
| 25 | 1.280 | 1.276 |
| 35 | 0.959 | 0.955 |
| 50 | 0.720 | 0.715 |
| 70 | 0.524 | 0.520 |
| 95 | 0.397 | 0.394 |

Table III. 7: voltage drop for LV cables given in (mV/AMP/Meter)

### Assumptions

The following assumptions have been made for the purposes of this calculation:

- The cables data used is taken from El-Sewedy Power Cable Datasheet– Low Voltage (600/1000V).
- The depth of lay has been assumed as 800mm.
- IEC 60364-5-52 is used to determine rating factors of the cable in air and direct buried.
- The thermal resistivity of the ground assumed as 2.5 °K.m/W.
- Ambient temperature 55°
- ground temperature 30°

### Example of Calculation:

For cathodic protection $I_n = 10A$ and C=0.902 thus $I_T = 11.08A$

From the cable catalogue a cable of 2.5 $mm^2$ is enough but a cable of this cross section has a voltage drop of 13.197 mv/amp/m which yields a total Voltage drop of 2.64V (more than 3%)

Thus we should select a cable of 6 $mm^2$ that has a total voltage drop of 1.04V (2.16%)

Calculations for the other cables are tabulated in Table III.5

## III.2. Protection:

### III.2.1. Overload Protection

The matching of overload protection equipment for cables and lines must be based on the following conditions (IEC 60 364, Part 43):

- Nominal current rule:

The overload protection equipment should be chosen so that its rated current In or current setting Ie for power circuit breakers is less than or equal to the current carrying capacity Iz of the cable or line: [16]

$$I_b \leq I_n \leq I_z$$

- Tripping rule:

The conventional tripping current I2 must not exceed 1.45 times the current carrying capacity of the cable or line: [16]

$$I_2 \leq 1.45 I_z$$

$I_b$ Operating current
$I_n$ Nominal current
$I_z$ Permissible current carrying capacity
$I_2$ Conventional tripping current

Based on this we can the protection devices:

| From | To | Load current (A) | Cable current (A) | Assigned CB current $I_n$ (A) |
|---|---|---|---|---|
| PV module | Distribution panel | 3x70 | 82 | 3x80 |
| Distribution panel | Battery | 177.4 | 268 | 200 |
| Distribution panel | SCADA/TELECOM Panel | 10.42 | 34 | 16 |
| Distribution panel | Cathodic protection | 10 | 63 | 16 |
| Distribution panel | Battery chamber lighting | 0.75 | 34 | 6 |
| Distribution panel | Battery chamber extractor | 1.04 | 34 | 6 |
| Distribution panel | Shelter lighting | 0.75 | 34 | 6 |

Table III. 8: protective devices selection for each cable

| FROM "A" | TO "B" | POWER [W] | LENTH [m] | CIRCUIT VOLTAE [V] | CURRENT [A] | CORRECTION FACTOR | MAX CABLE CURRENT | VOLTAGE DROP [V] | VOLTAGE DROP [%] | CABLE SECTION [mm^2] |
|---|---|---|---|---|---|---|---|---|---|---|
| SOLAR MODULE | DISTRIBUTION PANNEL | 9912 | 10 | 48 | 3x70 | 0.902 | 82,00 | 0,89 | 1,86 | 3X2C10 |
| DISTRIBUTION PANNEL | BATTERY | 8515 | 10 | 48 | 177,40 | 0.76 | 268,00 | 0,70 | 1,46 | 2x1C95 |
| DISTRIBUTION PANNEL | SCADA/TELECOM PANNEL | 500 | 5 | 48 | 10,42 | 0.76 | 34,00 | 0,69 | 1,43 | 2C2,5 |
| DISTRIBUTION PANNEL | CATHODIC PROTECTION PANNEL | 480 | 20 | 48 | 10,00 | 0.902 | 63,00 | 1,04 | 2,16 | 2C6 |
| DISTRIBUTION PANNEL | BATTERY CHAMBER LIGHTING | 36 | 10 | 48 | 0,75 | 0.76 | 34,00 | 0,10 | 0,21 | 2C2.5 |
| DISTRIBUTION PANNEL | BATTERY CHAMBER EXTRACTOR | 50 | 10 | 48 | 1,04 | 0.76 | 34,00 | 0,14 | 0,29 | 2C2,5 |
| DISTRIBUTION PANNEL | SHELTER LIGHTING | 36 | 10 | 48 | 0,75 | 0.76 | 34,00 | 0,10 | 0,21 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 01 | 20 | 65 | 48 | 0,42 | 0.324 | 37,00 | 0,36 | 0,74 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 02 | 20 | 120 | 48 | 0,42 | 0.324 | 37,00 | 0,66 | 1,37 | 2C2.5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 03 | 20 | 100 | 48 | 0,42 | 0.324 | 37,00 | 0,55 | 1,15 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 04 | 20 | 120 | 48 | 0,42 | 0.324 | 37,00 | 0,66 | 1,37 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 05 | 20 | 100 | 48 | 0,42 | 0.324 | 37,00 | 0,55 | 1,15 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 06 | 20 | 150 | 48 | 0,42 | 0.324 | 37,00 | 0,82 | 1,72 | 2C2.5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 07 | 20 | 130 | 48 | 0,42 | 0.324 | 37,00 | 0,71 | 1,49 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 08 | 20 | 160 | 48 | 0,42 | 0.324 | 37,00 | 0,88 | 1,83 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 09 | 20 | 100 | 48 | 0,42 | 0.324 | 37,00 | 0,55 | 1,15 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 10 | 20 | 120 | 48 | 0,42 | 0.324 | 37,00 | 0,66 | 1,37 | 2C2.5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 11 | 20 | 130 | 48 | 0,42 | 0.324 | 37,00 | 0,71 | 1,49 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 12 | 20 | 140 | 48 | 0,42 | 0.324 | 37,00 | 0,77 | 1,60 | 2C2,5 |
| DISTRIBUTION PANNEL | ELECTROVALVE 13 | 20 | 170 | 48 | 0,42 | 0.324 | 37,00 | 0,93 | 1,95 | 2C2,5 |

Table III. 9: Cable Schedule for the cutoff station equipment

## III.3. Calculation Using Software:

**e-Design** is the single point of access to ABB LP Design Software. It provides a quick and immediate interface to use Design software and support services.

The main functionalities of the program are:

- Drawing single-line electric diagrams key diagram of the auxiliary circuits.
- Calculating line current and voltage drops and short-circuit currents.
- Dimensioning low and medium voltage cables.
- Dimensioning switching and protection devices.
- Setting and coordinating protection devices.
- Verifying cable protection.
- Printing single-line diagrams and project documentation·

For the simulation, when a new project is opened the Power supply details can be entered as well as the selectin calculation methods and standards and types of cables and circuit breakers and other specifications and options can be set. Then in the drawing field the single line diagram is drawn:

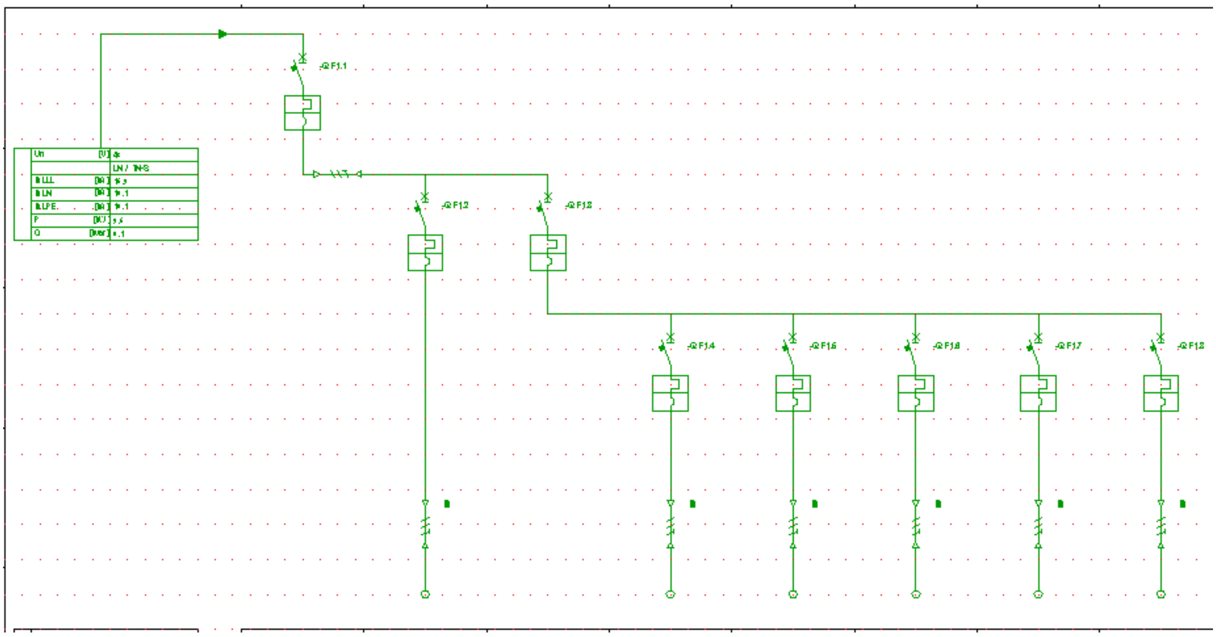


Figure III. 3: single line diagram of our system installation.

After the simulation is ran the software automatically selects the suitable equipment based on the system specifications and the software database, and a report can be obtained.

The cable and circuit breaker selection for the battery for example are depicted in figures below

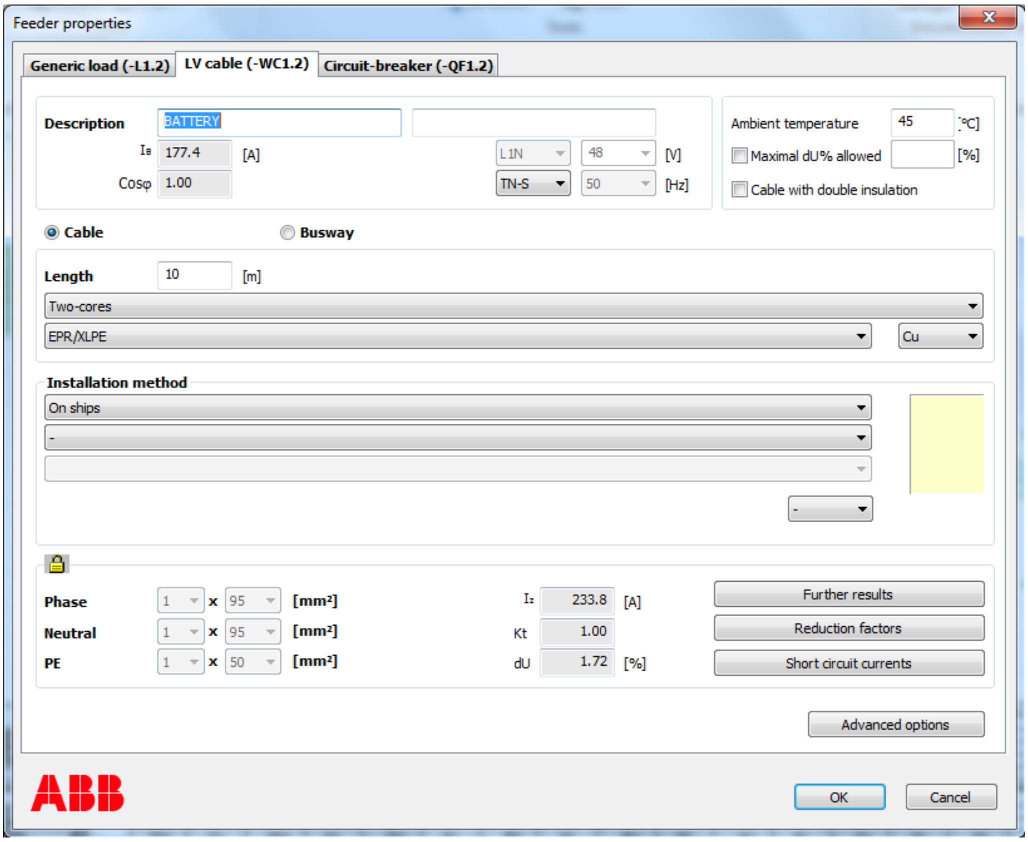


Figure III. 4: Cable properties that was assigned to the battery

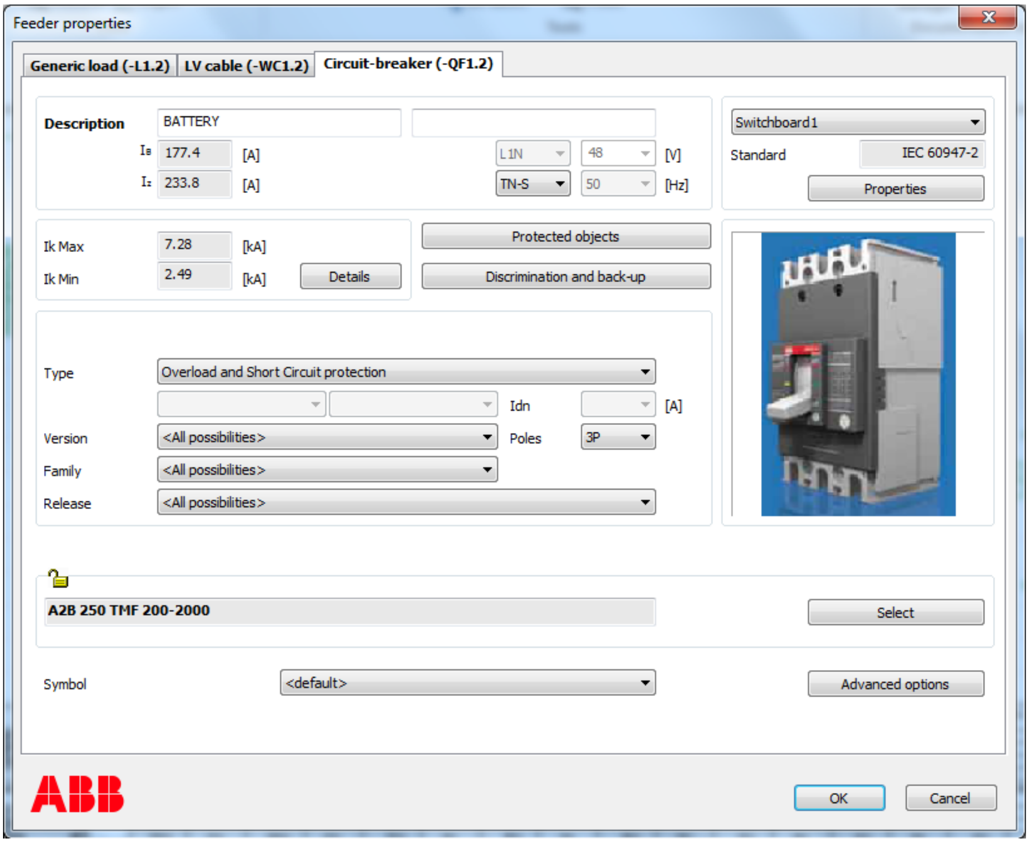


Figure III. 5: circuit breaker that was assigned to protect the battery bank

Simulation results for the other equipment are tabulated below:

| Equipment | Load current (A) | Cable section ($mm^2$) | Assigned CB | CB current $I_n$ (A) |
|---|---|---|---|---|
| Distribution panel (with main CB) | 200.4 | 240 | A2B 25O TMF 250-2500 | 250 |
| Secondary CB | | | | |
| Battery | 177.4 | 95 | A2B 25O TMF 200-2500 | 200 |
| SCADA/TELEC OM Panel | 10.42 | 2.5 | S201L-C16 NA | 16 |
| Cathodic protection | 10 | 6 | S201L-C16 NA | 16 |
| Battery chamber lighting | 0.75 | 2.5 | S201L-C6 NA | 6 |
| Battery chamber extractor | 1.04 | 2.5 | S201L-C6 NA | 6 |
| Shelter lighting | 0.75 | 2.5 | S201L-C6 NA | 6 |

Table III. 10: summary of the simulation results

## III.4. Conclusion:

In this chapter the standards were used for dimensioning the cables that feed the installation using the calculation notes with the cable layout design, then the protection for all installations was selected based on the equipment rated current and the cable current.

For further confirmation and making sure the calculations were reliable e-Design software was used, and the output results were satisfyingly close to those manually calculated using standards.

# CHAPTER IV:
# GROUNDING AND LIGHTNING PROTECTION

# IV. Chapter IV: Grounding And Lightning Protection :

## IV.1. Grounding

### IV.1.1. Introduction:

The grounding system in a plant / facility is very important for a few reasons, all of which are related to either the protection of people and equipment and/or the optimal operation of the electrical system.

This calculation is based primarily on the guidelines provided by IEEE Std 80 (2000), "Guide for safety in AC substation grounding".

### IV.1.2. Why Do The Calculation?:

The grounding calculation aids in the proper design of the grounding system. Using the results of this calculation, we can:

- Determine the minimum size of the grounding conductors required for the main earth grid
- Ensure that the grounding design is appropriate to prevent dangerous step and touch potentials (if this is necessary)

### Prerequisites

The following information is required / desirable before starting the calculation:

- A layout of the site
- Maximum earth fault current into the grounding grid
- Maximum fault clearing time

### IV.1.3. Measurement Of Soil Resistivity

The resistance to the earth of any earth electrode may be determined by the resistivity of the surrounding soil.

NOTE Resistivity depends upon the soil structure, strata, rock formation. The resistivity can change with:

- Depth.
- Temperature.
- Moisture content.
- Can vary from place to place.

The design of the grounding installation may be started with knowledge of the soil resistivity. For example, for a simple installation the type and number of earth electrodes may be estimated and the separation needed of HV and LV earths may be determined. For grid substations sample measurements should be taken at many locations around the site and at various electrode depths.

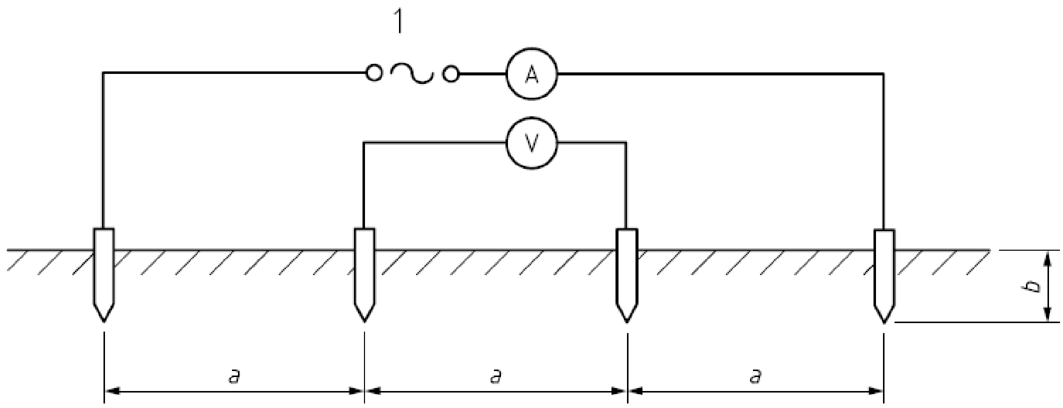
### Soil resistivity – Wenner test

In a technique developed by Dr Frank Wenner of the U.S. Bureau of Standards (now NIST); it was demonstrated that provided the electrode depth B is small with respect to the spacing, the electrodes the average soil resistivity ρ to a depth a in Ωcm may be found from: [17]

$$\rho = 2\,\pi\,a\,R$$

where:

- π is the constant 3.1416
- a is the distance between the electrodes in cm
- R (V/A) is the reading obtained from the Earth tester in ohms (Ω).




Key
1 Current source
A Ammeter
V Voltmeter

Figure IV. 1: Measurement of earth resistivity

## IV.1.4. Assumptions And Requirements :

The following assumptions have been made for the purposes of this calculation:

- Nominal voltage: 48V.
- The maximum grounding resistance is 1Ω et each site.
- The grounding rod dimensions as in the detail in figure IV.2.a : L=3600mm Diameter =3/4” =19.050mm.
- The grounding Loop will be routed along the site fence in addition to four earth rods, as in details in figure IV.2.b.
- The grounding bar conductor to be installed is 95mm² (D=11.3mm).
- The earth resistivity is given : 67.8 Ωm

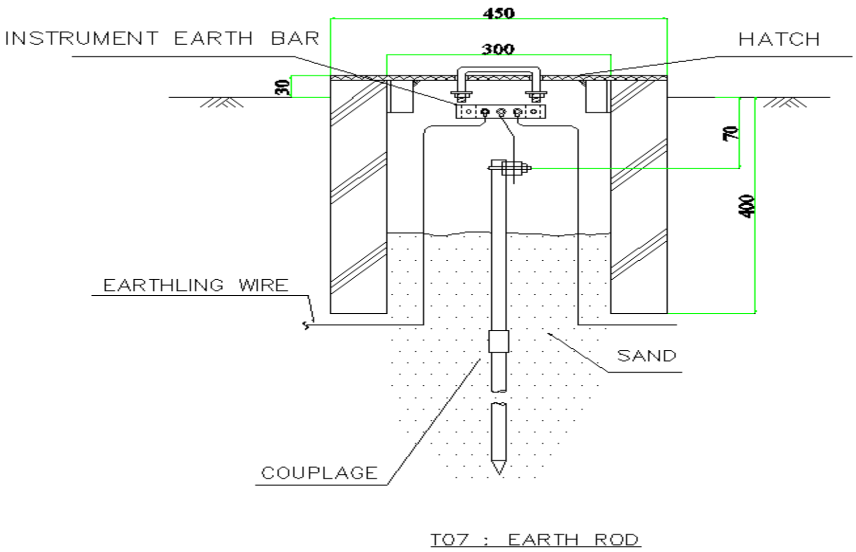


Figure IV. 2: earth rod details


Figure IV. 3: earthing loop layout

### IV.1.5. Earth Fault Current Calculation

The Battery Fault current calculation is made using the following equations:

$$I_{bc} = \frac{V}{R_b} = \frac{48 * 10^3}{2.85} = 16.85KA$$

Where:

- V : Battery Voltage

- $R_b$ : Battery Resistance

### IV.1.6. Ground Conductor (Electrode) Size

The required conductor size can be calculated using the equation below: [18]

$$S = \frac{1}{1{,}974} I \,.K_f \,.\sqrt{t_c}$$

Where:

- S - [mm²] Conductor cross sectional area
- I - [kA] rms fault current.
- t - [sec] Fault current duration (considered as 400 ms)
- Kf – Material Constant from Table 2 of IEEE Std 80 (Kf = 7.00 for copper)

$S = \frac{1}{1{,}974}\, 16.85 \,.K_f \,.\sqrt{t_c} = 37.8\, mm^2$

The minimum standard grounding conductor cross section area is 37.8 $mm^2$

### IV.1.7. Single Ground Rod Resistances

Based on the resistivity of the ground the resistance of earth rods of various depths can be calculated, using equation: [19]

$$R_{rod} = \frac{\rho}{2\pi L}[\ln\left(\frac{8L}{d}\right) - 1]$$

Where:

- ρ - [Ωm] Ground resistivity
- L - [m] Length of rod
- d - [m] Diameter of rod = 20mm

$$R_{rod} = 18.70\Omega$$

### IV.1.8. Multiple Ground Rod Resistances

Using the single earth rod resistances in Section IV.1.8 (Above), the values of groups of earth rods can be calculated.

Section 9.5.4 of BS7430-2011 allows the resistance of a group of earth rods connected in a straight line to be calculated using the equations: [19]

$$R_{t-rod} = \frac{1}{n}\frac{\rho}{2\pi L}\left[\ln\left(\frac{8L}{d}\right) - 1 + \frac{L}{S}\ln\left(\frac{1.78n}{2.718}\right)\right]$$

Where:

- ρ is the resistivity of soil, in ohm metres (Ωm);
- L is the length of the electrode, in metres (m);
- n is the number of rods;
- s is the spacing between the rods, in metres (m).

$$R_{t-rod} = 3.14\Omega$$

### IV.1.9. Ground Conductor Resistances

Using the cross-section area of the main earth conductor in Section IV.1.6 (Above), the resistance of the earth conductor can be calculated.

Section 9.5.5 of BS7430-2011 allows the resistance of round earth conductor to be calculated using the equations: [19]

$$R_{cond} = \frac{\rho}{2\pi L} \ln\left(\frac{L^2}{1.85hd}\right)$$

Where:

- ρ is the resistivity of soil, in ohm metres (Ω.m);
- L is the length of the main earth conductor, in metres (m);
- h is the depth of the main earth conductor, in metres (m);
- d is the diameter of the main earth conductor, in metres (m).

For the two 100m conductors: $R_{cond1} = 1.43\Omega$

For the three 130m conductors: $R_{cond2} = 1.14\Omega$

When two or more strips in straight lengths, each of length L in metres (m) and a separation distance s metres are laid parallel to each other, the combined resistance may be calculated from the following equation[19]:

$$R_{n-cond} = F.R_{cond}$$

Where:

- Rn is the resistance of n conductors in parallel, in ohms (Ω)
- $R_{cond}$ is the resistance of a single strip of length L, calculated from the preceding $R_{cond}$ equation, in ohms (Ω).

F has the following values:[19]

For Three lengths, $F3 = 0.33 + \left[0.071\left(\frac{s}{L}\right)\right]^{-0.408}$

For Two lengths, $F2 = 0.5 + \left[0.078\left(\frac{s}{L}\right)\right]^{-0.307}$

For the two 100m conductors: $R_{n-cond1} = 3.75\Omega$

For the three 130m conductors: $R_{n-cond2} = 4.84\Omega$

### IV.1.10. Total Resistance Of The Grounding Network

The total resistance of the grounding network is calculated considering the earth conductor running in parallel with the earth rods' resistance.[19]

$$\frac{1}{R} = \frac{1}{R_{t-rod}} + \frac{1}{R_{n-cond1}} + \frac{1}{R_{n-cond2}}$$

$$R = 1.26\Omega$$

This resistance can be reduced by encasing the earth rods in low resistivity materials as suggested in BS 7430 (2011) section 9.5.7

### IV.1.11. Calculation Via Software:

Computer software packages can be used to assist in earthing grid design by modelling and simulation of different earthing grid configurations. CYMGrd 6.3 a software based on IEEE-std 80 is used to get the grounding network resistance.

- First the structure layout is imported from AutoCAD in (.dwg) format then details of the earth conductor and rods are entered.
- The earth layers and each layer's resistivity are specified.

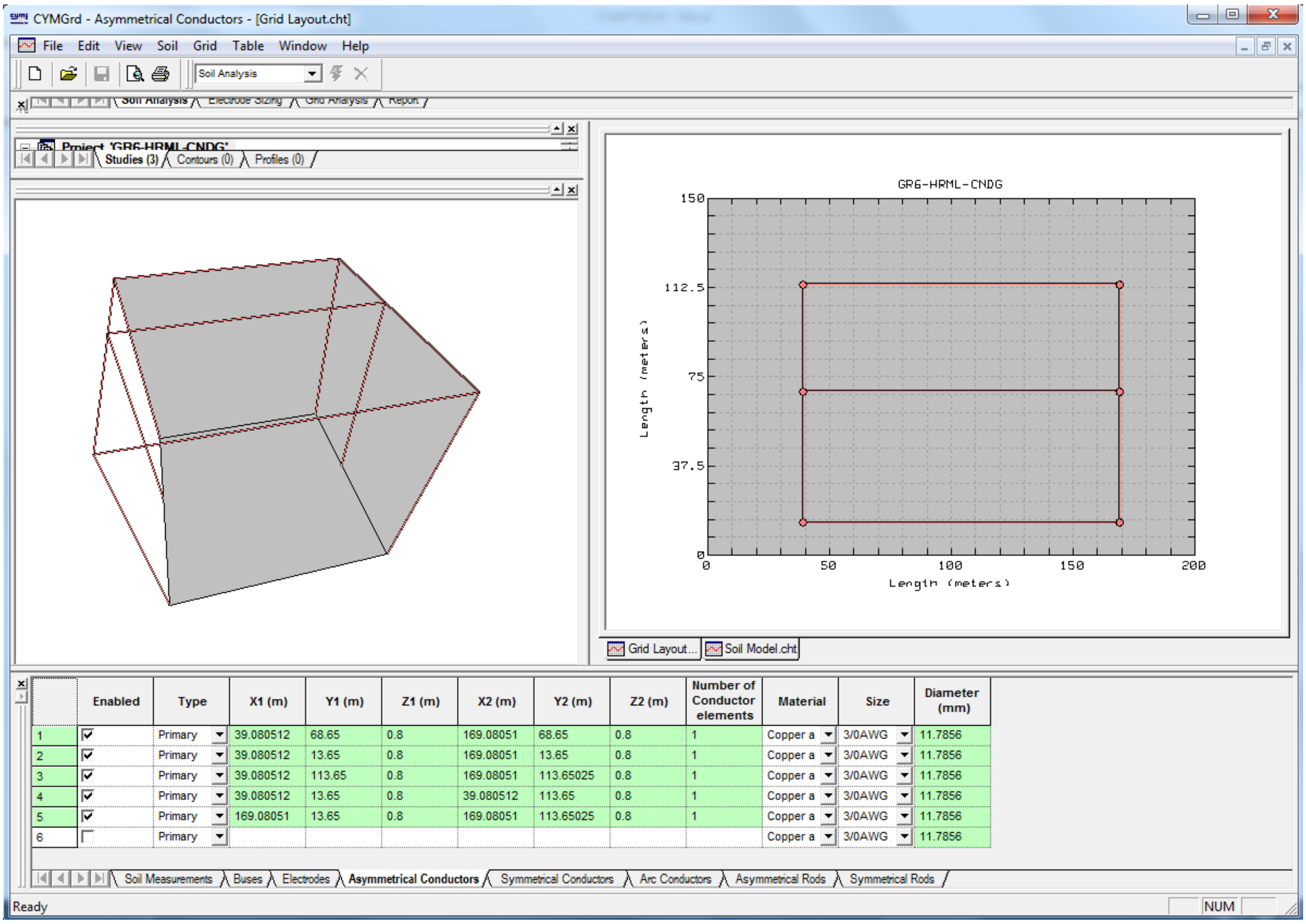



Figure IV. 4: calculating earth loop resistance using CYMGrd

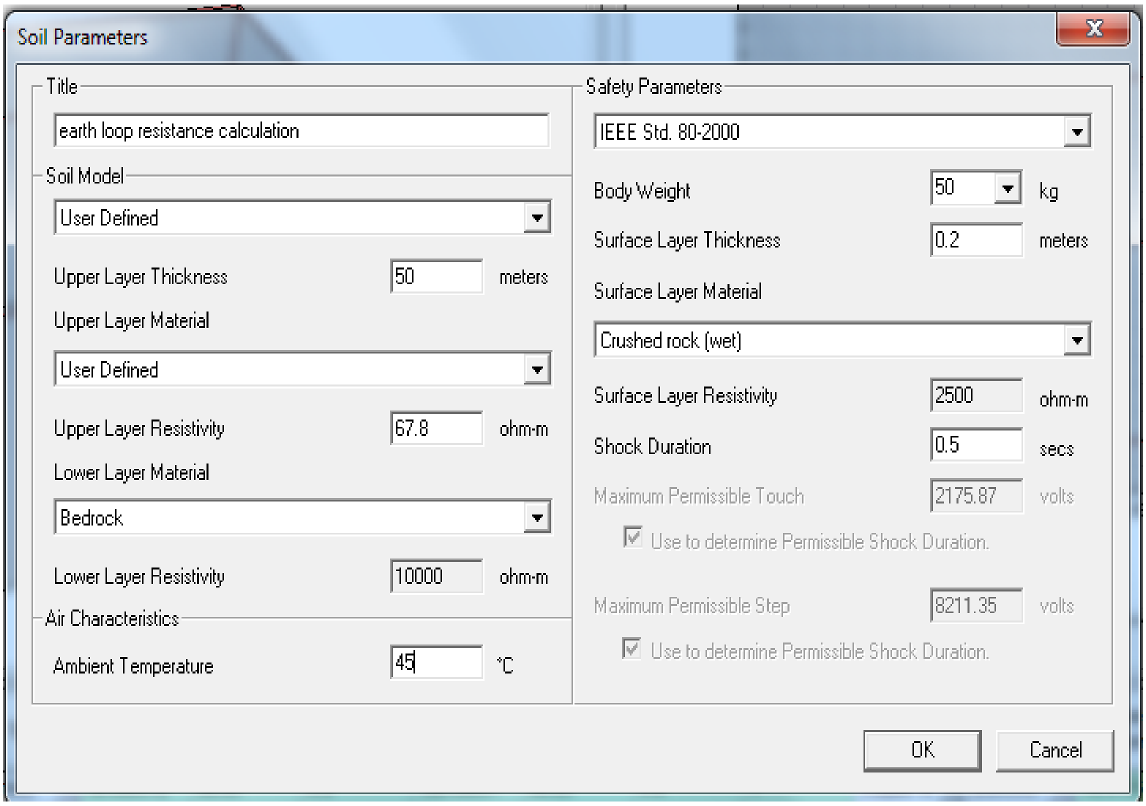



Figure IV. 5: soil parameters

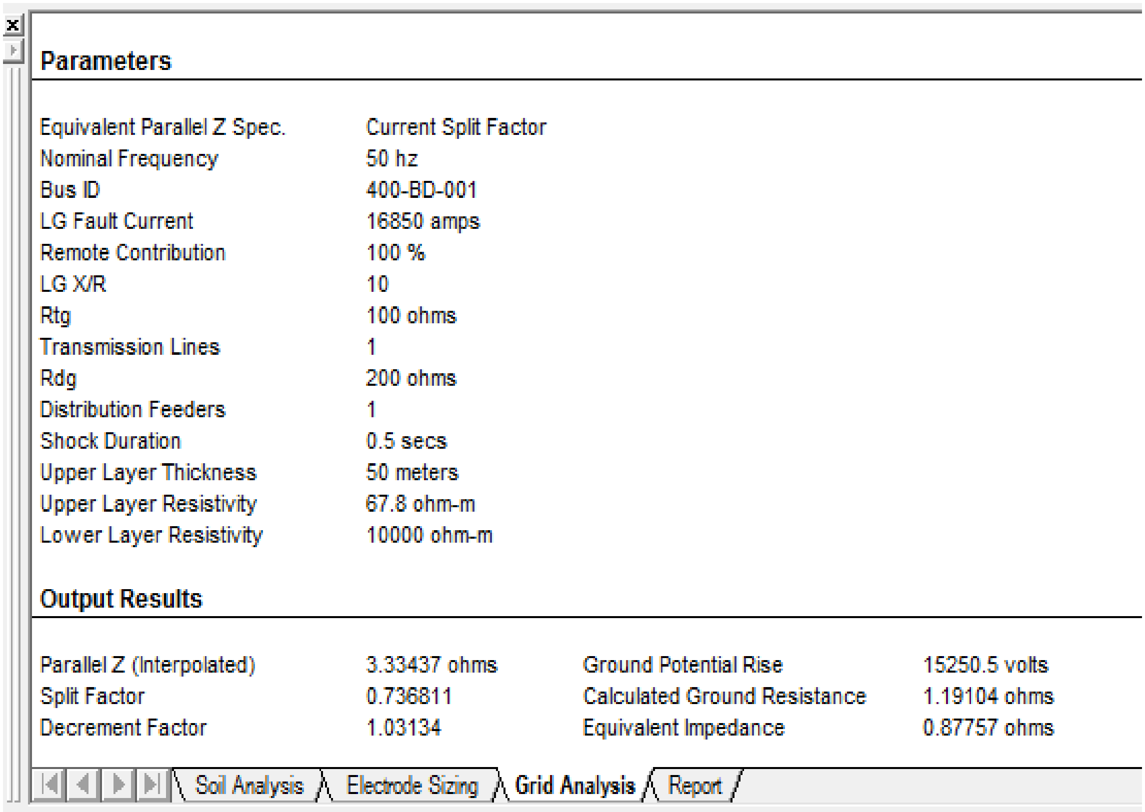



Figure IV. 6: simulation output results

## IV.2. Lightning Protection:

### IV.2.1. Introduction:

As per Project document specifications, the lightning protection system will be carried out by means of lightning rod placed out of hazardous areas with a protection radius sufficiently protecting. It will be used to protect against lightning strikes of all equipment and structures installed.

### IV.2.2. Early Streamer Emission Air Terminal ESEAT:

An Early Streamer Emission air terminal, also known as ESE or as an ionizing lightning rod, is an external lightning protection system with innovative technology. This ESE air terminal is also known as active lightning rod. At its start, the lightning bolt travels through a downward leader that propagates in jumps in any direction. When the bolt approaches the ground it can hit any object. The aim of the lightning rod is to become the point of discharge of the bolt in order to achieve a controlled impact without damage.

The ESE air terminal emits a continuous upward leader with time of advance to anticipate the descent of lightning and capture it before any other object within its protection area. The time of advance of the ESE determines the protection radius of the ESE air terminal: the more the upward leader anticipates, the higher the downward leader is captured and prevents lightning strikes in a larger area.[20]

Figure IV. 7: models of an ESE air terminal

### IV.2.3. Scope of Lightning Design

The lightning system will consist mainly of:

**Lightning rod**: will be of the type of initiation devices with a large radius of action allowing to cover widely the site and their roads, it should be installed on the solar panel pole.

**Copper Cable braid:** from the lightning rod to the grounding pits laid in PVC pipe.

**Lightning earth pits:** The grounding device of Triangle type with a resistance value of less than ten (10) ohms according to standard NF C 17-102. It will consist mainly of earth pits. This earth ground will be connected to the general earth ground.

The document concerns to determine the different parameters of lightning protection such as

- Required level of protection
- The choice of protection system

The study of lightning protection requires taking account for the local geographical condition and the exposure of the structure at the risk of lightning to size the necessary power of protection device.

For that and as per NF C 17-102 , The keraunic **Nk** level expresses the average annual value of thunderstorm number at days. The lightning density **Ng** expresses the average annual value of lightning strikes number at $km^2$.

The site conditions are as follow:

| | |
|---|---|
| Height of structure | H=14meters |
| Keraunic level | Nk=3.8 |
| Site dimensions | 100mx130m |

### IV.2.4. Determination Level of Protection

Following standard NFC 17-100, the protection level is evaluated according to two parameters:

- Nd : expected frequency of lightning strikes on the structure
- Nc : accepted frequency of lightning strikes on the structure

If **Nd ≤ Nc** the lightning protection system is not necessary [21]

If **Nd** >**Nc** lightning protection system must be installed

### IV.2.5. Calculation of Nd

The calculation of the expected frequency of direct lightning strikes on structure depends on the following data:

- The equivalent capture surface of the structure

- Local lightning density
- The surrounding environment around the considered structure

The average annual frequency Nd of direct hits on a structure is evaluated from the expression:[21]

$$\mathbf{Nd = Ng\ max.\ Ae\ .C1.\ 10\text{-}6}$$

**Ng**: local lightning density, with :

$$\mathbf{Ng\ max = 0{,}04\ Nk^{(1{,}25)}}$$

**Nk** the keraunic level: is the number of times that thunder was heard in the year, It was the only reference indicator before the appearance of lightning detection networks.[21]

**Ae:** equivalent capture area

**C1:** Coefficient of environment (around the structure), defined in the table below (according to NFC 17 100):

| | | |
|---|---|---|
| C1 = | Structure located in a space where there are structures or trees of the same height or higher. | 0,25 |
| | Structure surrounded by small structures | 0,50 |
| | Isolated structure | 1 |
| | Structure at the top of a hill or on a promontory | 2 |

Table IV. 1: Coefficient of environment

### IV.2.6. Calculation Of The Equivalent Area Of Capture Of The Site

The lightning catchment area of a structure is calculated with the formula extracted from the standard NFC 17-100 such that:[21]

$$\mathbf{Ae = L.l + 6\ h_1\ (L+l) + 9\ \pi.(h_1)^2}$$

With :

- L : length of the structure to be protected (L=80m)
- I : width of the structure to be protected (I=80m)
- h1 : height of the structure to be protected (h1=12m)

Then

$$\mathbf{Ae = 37861.77\ m^2}$$

With

**Nk** : 3.8 **, C1** : 1 **, Ng max =** 0,212

Then

**Nd =** 0.21222 x 21989,44 x 1 x $10^{-6}$

**Nd= 8.02 x $10^{-3}$**

## IV.2.7. Calculation of Nc

The accepted frequency of direct lightning strikes on a Nc structure is calculated from four parameters defined in the following table extracted from the NFC 17-100 standard. (or NFC17-102).

Parameters: C2, C3, C4, C5 aim to assess the severity of the damage associated with a direct lightning strike.

$N_C = \frac{5.5.\ 10^{-3}}{C}$ where: C= C2 x C3 x C4 x C5 [21]

| | | Roof | | |
|---|---|---|---|---|
| **C2 : Structure coefficient** | Structure | Metal | Common | Flammable |
| | Metal | 0,5 | 1 | 2 |
| | Current | 1 | 1 | 2,5 |
| | Flammable | 2 | 2,5 | 3 |

Table IV. 2: construction of structure coefficient

| | Content of the structure | |
|---|---|---|
| **C3 : content coefficient of structure** | Without flammable value | 0,5 |
| | Current or normally flammable value | 1 |
| | High value or particularly flammable | 2 |
| | Outstanding value non replaceable or highly flammable, explosive | 3 |

Table IV. 3: content of structure coefficient

| | Occupation of structure | |
|---|---|---|
| **C4 : Occupation of the coefficient structure** | unoccupied | 0,5 |
| | Normally busy | 1 |
| | Difficult evacuation, risk of panic, public | 2 |

Table IV. 4: occupation of structure coefficient

| | Environmental impact | |
|---|---|---|
| **C5 : Environmental impact coefficient** | No need for continuity of service and no impact on the environment | 1 |
| | Need continuity of service and no impact on the environment | 5 |
| | Consequence on the environment | 10 |

Table IV. 5: environnemental impact coefficient

Takin into account the structure's features:

- Metallic walls and roofs
- Content of the structure: Outstanding value non replaceable or highly flammable, explosive.
- Occupation of structure: unoccupied
- Environmental impact: Need continuity of service and no impact on the environment

Then: C2 = 1, C3 = 3, C4 = 0.5, C5=5 implies that C = 0.5 x 2 x 0.5 x 5= 2.5

$$N_C = \frac{5.5\ x\ 10^{-3}}{C} = \frac{5.5\ x\ 10^{-3}}{2.5} = 2.22\ \text{x}10^{-3}$$

Since Nd > Nc the lightning protection system must be installed.

### IV.2.8. Calculation Of Efficiency And The Level Of Protection

The Efficiency is calculated according to NFC17-102 is

$$E = 1 - \frac{N_C}{N_d}$$

By replacing the Nc and Nd values calculated above

$$E = 1 - \frac{7.34X\ 10^{-4}}{8.02\ X\ 10^{-3}} = 0.72$$

Since 0<E<0.8 so, the corresponding protection level [21] is: Level 4

| Protection efficiency E | Protection level | boot distance (m) |
|---|---|---|
| E>0.98 | Level I + complementary measures | - |
| 0.95<E<0.98 | I | 20 |
| 0.90<E<0.95 | II | 30 |
| 0.80<E<0.90 | III | 45 |
| 0<E<0.80 | IV | 60 |

Table IV. 6: protection levels and boot distances

### IV.2.9. Radius Of Protection Of ESEAT:

The standard NFC 17-102 defines the protection radius of LPD with the following equation:

$$\boldsymbol{R_P} = \sqrt{(\mathbf{h}(\mathbf{2D} - \mathbf{h})\ + \boldsymbol{\Delta}\mathbf{L}(\mathbf{2D} + \boldsymbol{\Delta}\mathbf{L}))}$$

- D : fictional sphere radius or boot distance: is the distance in which the device can capture the lightning[21]

D=20m for level 1

D=30m for level 2

D=45m for level 3

D=60m for level 4

- ΔL : Gain of length defined by ΔL = v. ΔT (v is considered constant v=106 m/s)
- ΔT : time of advance (Chosen 60 µs)
- h : Height of ESE rod (=14m)
- Rp : Radius of protection

The result of protection radius calculation is then:

**Rp= 110.8 m**

The lightning design is shown below alongside with the grounding design with AutoCAD:

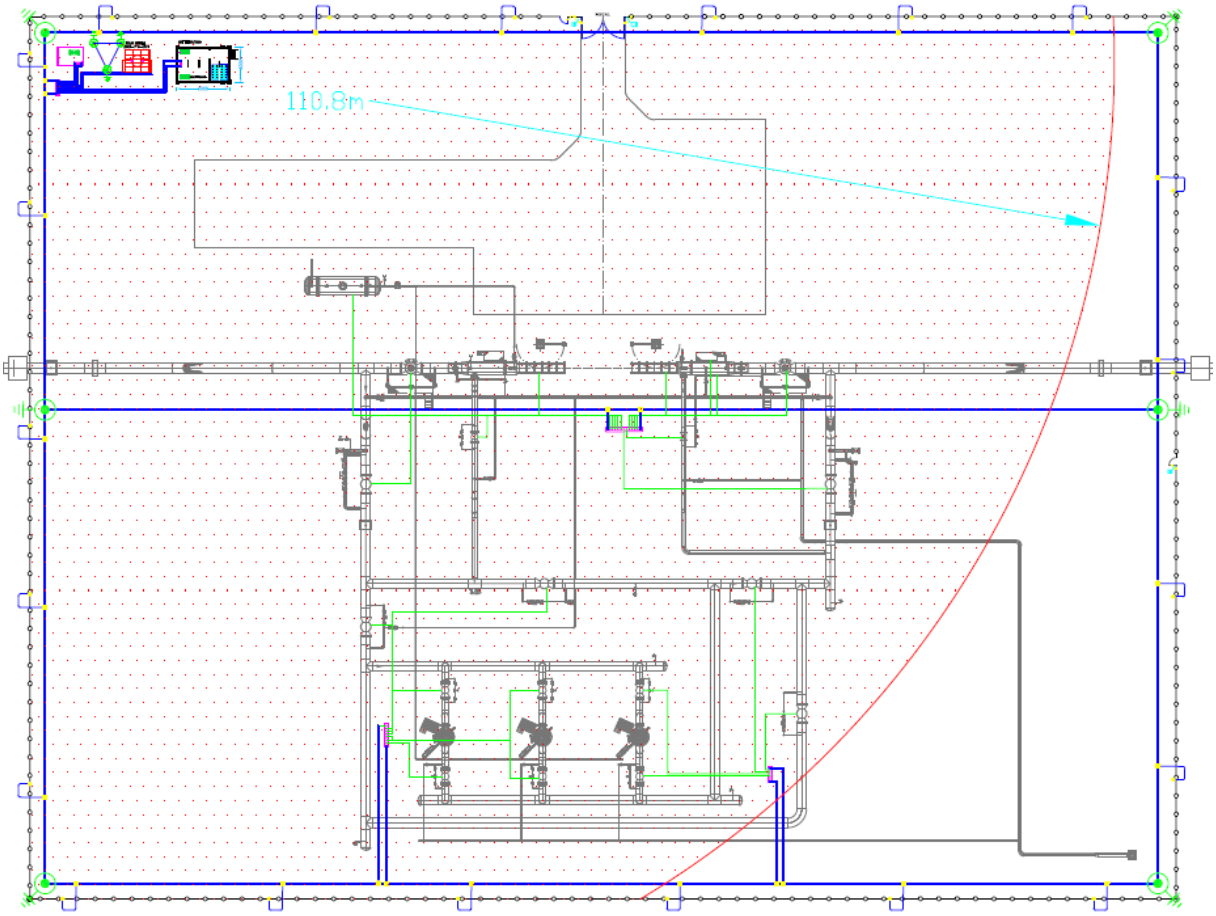



Figure IV. 8: design of the grounding and lightning protection using AutoCAD

### IV.2.10. Design The Lightning Protection With A Software: Pulsar Designer

This design was also obtained using the Pulsar Designer software:

- First the structure layout was imported then the scale was specified.

- The structures to be protected were implanted and their corresponding dimensions were specified as well as their construction material (metallic, concrete …)
- Finally the protection will be chosen according to the advance time.

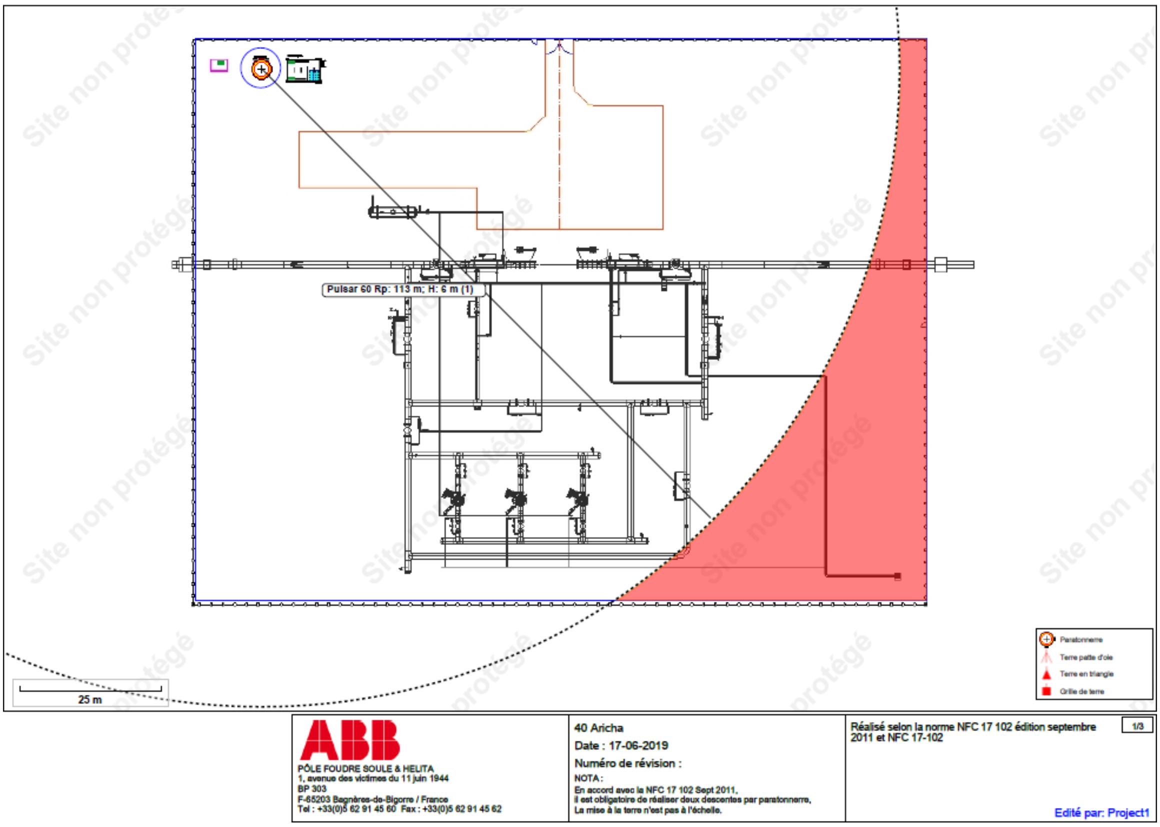



Figure IV. 9: Design result of the lightning protection using ABB Pulsar software

## IV.2.11. Conclusion

Grounding and lightning protection are both of great importance and priority when designing electrical systems, and learning their basics is needed in electrical engineering, this chapter chiefly dealt with these two introducing manual calculating methods using international standard and comparing the results with those obtained with the simulation software .

## General Conclusion:

The project bore fruit to acquire knowledge and get more familiar with the various problems related to electrical engineering such as feeding stations and structures at remote areas but also to make the best use of other sources of energy in order to supply a gas production field at a lower possible price.

Then the cable layout of power cables was designed and installation details and cables parameters were obtained; this gave us all information needed to size the electrical cables as well as the protection circuit breakers.

Furthermore, earthling and lightning protection that are such irreplaceable means to protect both equipment and personals against shocks and lightning strikes were of high priority to have under study and get more familiar with. Most importantly, it was a huge opportunity to become better acquainted with the different standards of calculation and sizing.

As part of the execution of this project the following achievements we and accomplishments were covered:

- learning to undertake a real-life project by interacting with the engineering office
- Mastering several computer design software such as AUTOCAD, CYMGrd, Pulsar, e-Design and PVSYST.
- Learning the design and the complete study of a project by referring to a given specification.
- Therefore enriching theoretical capacities in the field of technical operations.

## References:

[1]: https://algerieonline.info/sonatrach-lancement-de-lextension-du-gazoduc-pedro-duran-farell/

[2]: AS 4509.2-2002 Stand-alone power systems - System design guidelines.

[3]: TOTAL electric base-base-to IEC-standard, EXP-MN-SE080-EN, (29-09-2008)

[4]: Handbook of Electrical Engineering: For Practitioners in the Oil, Gas and Petrochemical Industry. Alan L. Sheldrake 2003

[5]: Book: Analysis and Design of Low-Voltage Power Systems. Ismail Kasikci Copyright © 2004 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim ISBN: 3-527-30483-5

[6]: http://www.phasewire.com/electricalsystemdesign/load-list/

[7]: https://wiki.openelectrical.org/index.php?title=Load_Schedule

[8]: NF X 50-106-2 1993 terminology in industrial engineering contracts

[9]: AS 4509.2-2002 Stand-alone power systems - System design guidelines.

[10]: IEEE Std 485(1997, R2003) Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications

[11]: https://wiki.openelectrical.org/index.php?title=AC_UPS_Sizing

[12]: UC XLPE Catalogue. Universal Cable (M) Berhad- XLPE Insulated Power Cables

[13]: BS 7671 _2011 Requirements for Electrical Installations

[14]: IEC 60364-5-52 2009. Low-voltage electrical installations –Part 5-52: Selection and erection of electrical equipment – Wiring systems

[15]: Cable Catalogue (2015). Elsewedy Cables Algeria

[16]: IEC 60 364 electrical installations requirements

[17]: BS 7430 2011 Code of practice for protective earthing of electrical installations

[18]: IEEE Std 80-2000 Guide for Safety in AC Substation Grounding part 11.3.1.2

[19]: BS 7430 2011 Code of practice for protective earthing of electrical installations

[20]: https://lightningprotection-at3w.com/company/news/what-is-an-ese-lightning-rod-all-we-need-to-know-about-the-lightning-rods-with-ese-arrester/s33c420

[21]: NFC17102 (1997) protection of structures against lightning