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**Study and sizing tamsa 220MW power plant integrated
in the network with protection coordination overcurrent
relay**

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With profound gratitude, I dedicate this work to my father and mother, whose boundless love and dedication have made everything possible.

To my sisters “Amira & Fatima” and nephews “Rayane & Amir”, whose laughter and unwavering support have been my strength.

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Assia

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Saber

Résumé

Une étude propose une analyse de la centrale photovoltaïque de Tamsa 220 MW située sur la région de Msila en Algérie, elle couvre les technologies de base de l'énergie photovoltaïque telles que la protection et la coordination avec des relais de surintensité dans les réseaux de systèmes électriques à différents niveaux de tension (0,315/30/60 kV), ainsi que diverses spécifications techniques et études de cas. Le logiciel ETAP est utilisé pour étudier, concevoir, dimensionner et protéger cette centrale électrique qui est intégrée sur le réseau avec 60 kV.

Mots clés :

Panneau Solar, onduleur, transformateur de puissance, transformateur de courant, relais, disjoncteur, connexion réseau, ETAP.

ملخص

تقدم الدراسة تحليلاً لمحطة الطاقة الكهروضوئية بقدرة 220 ميغاوات في تامسة بمنطقة المسيلة في الجزائر، وتغطي التقنيات الأساسية للطاقة الكهروضوئية مثل الحماية والتنسيق مع المرحلات ذات التيار الزائد في شبكات الأنظمة الكهربائية عند مستويات الجهد المختلفة (60/30/0.315) كيلوفولت، وكذلك المواصفات الفنية المتنوعة وحالات الدراسة. تم استخدام برنامج ETAP لدراسة وتصميم وتحديد الحجم وحماية هذه المحطة التي تم دمجها في الشبكة بجهد 60 كيلوفولت.

الكلمات المفتاحية:

لوحة شمسية، موج ، محول طاقة، محول تيار، مرحل، قاطع دائرة، اتصال بالشبكة، ETAP.

Abstract

A study offers an analysis of the photovoltaic power plant for Tamsa 220 MW located on Msila region in Algeria , it is covering the basic technologies of photovoltaic energy such the protection and coordination with overcurrent relays (51) in electrical systems networks at different level of voltages (0.315/30/60 kV), also a various technical specifications and cases studies. ETAP software is used to study, design, sizing and protection this power plant which is integrated on the grid with 60 kV.

Key words:

Solar panel, inverter, power transformer, current transformer, relay, circuit breaker, grid connection, ETAP.

Liste of acronyms

PV: Photovoltaic

OCR: Overcurrent Relay

DG: Distributed Generations

SC: Short Circuit

ETAP: Electrical Transient Analyzer Program

AC: Alternating Current

DC: Direct Current

PV: Photovoltaic

MW: Megawatt

STC: Standard Test Conditions

MPPT: Maximum Power Point Tracking

V: Voltage

I: Current

kW: Kilowatt

kWh: Kilowatt-hour

G: Solar Irradiance

T: Temperature

ISC: Short Circuit Current

VOC: Open Circuit Voltage

IEC: International Electrotechnical Commission

IEEE: Institute of Electrical and Electronics Engineers

O&M: Operation and Maintenance

PR: Performance Ratio

ROI: Return on Investment

IRR: Internal Rate of Return

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GENERAL INTRODUCTION

General Introduction

The increasing demand for sustainable and renewable energy sources has led to significant advancements in photovoltaic (PV) technology, making it a cornerstone in the global effort to reduce carbon emissions and dependence on fossil fuels.

The 220 MW Tamsa photovoltaic plant is a prime example of large-scale PV installations (After the state handed over the solar projects, we choose Tamsa as the nearest region where the projects are distributed) that contribute substantially to the energy grid. Located in a region with high solar potential, the Tamsa plant leverages advanced PV technologies to optimize energy production. The plant's design includes numerous PV modules arranged in arrays, sophisticated inverter technologies, and robust protection mechanisms to ensure efficient and continuous operation.

This study exploring the fundamental concepts of PV energy, including the structure and functionality of PV modules and arrays[1]. It delves into the various methods and technologies used to protect these modules, focusing on the performance metrics critical to their operation. Protection strategies, such as the use of bypass diodes and reverse-blocking diodes, are detailed to illustrate how PV systems can be safeguarded against common issues like shading and overcurrent[2].

A significant portion of the document is dedicated to the detailed description of the Tamsa photovoltaic plant. This includes its geographical location, technical specifications, and the various components that comprise the 220 MW installation. The plant's design and implementation showcase modern advancements in PV technology, including the use of high-efficiency inverters and step-up transformers, which are critical for scaling up the generated power to meet grid requirements.

In first chapter, the study touches upon the methodologies used for estimating PV electricity generation and solar radiation at the Tamsa station.

After that, protection is recognized in electrical networks and devices used in them.

Then, by employing ETAP software modeling and simulation techniques, this study provides insights into the expected performance of the plant under different environmental conditions.

In the last chapter, getting the results of the protection coordination of the 220mW Tamsa station, which are the aim of this study.

**Chapter I: Foundations and Technologies of PV
Energy of Tamsa Photovoltaic Plant**

Part One

I.1. Introduction

In this chapter, we begin by exploring the fundamental concepts of photovoltaic (PV) energy. We will cover the structure and functionality of PV modules and arrays, delve into the various methods and technologies used to protect these modules and arrays, and examine the key characteristics and performance metrics of PV arrays.

Following this, we will discuss the different types of PV systems in detail [3]. This includes standalone PV systems, which operate independently of the grid; hybrid systems, which combine PV with other energy sources; PV systems used for water pumping; and grid-connected systems that feed electricity directly into the power grid[4].

Finally, we will provide a description of the Tamsa PV central, highlighting its significant capacity of 220 megawatts.

I.2. PV energy

I.2.1. Definition

Photovoltaic (PV) energy is a method of generating electrical power by converting sunlight directly into electricity using semiconducting materials that exhibit the photovoltaic effect. This process involves the use of solar panels composed of numerous solar cells, typically made from silicon, which absorb photons from sunlight and release electrons, thereby creating an electric current. PV energy is a renewable, sustainable, and environmentally friendly source of power, contributing to the reduction of greenhouse gas emissions and dependence on fossil fuels. It is widely used in various applications, from small-scale residential systems to large-scale solar farms.

I.2.2. Photovoltaic module and Array

I.2.2.1. Photovoltaic Module

A photovoltaic (PV) module, commonly known as a solar panel, is a device that converts sunlight into electrical energy through the photovoltaic effect. It consists of multiple solar cells connected in series or parallel to increase the voltage and current output. These cells are made from semiconductor materials, most commonly silicon, which absorb sunlight and generate direct current (DC) electricity[5]. The PV module is designed to be durable and weather-resistant, typically encapsulated in a protective frame with a glass cover to protect the cells from environmental damage[6]. PV modules are the building blocks of larger solar power systems and can be used individually or combined to form arrays.

I.2.2.2. Photovoltaic Array

A PV array is a system composed of multiple PV modules connected together to increase the overall power output. These modules are arranged in a series and/or parallel configuration to meet specific voltage and current requirements. PV arrays can range in size from small residential rooftop installations to large commercial solar farms. By combining multiple modules, PV arrays can generate sufficient electricity to power homes, businesses, or feed into the electrical grid. The configuration and design of a PV array are crucial for optimizing the performance and efficiency of a solar power system, taking into consideration factors such as shading, orientation, and tilt angle to maximize sunlight exposure[7].

I.2.2.3. From Module to Array

The process of scaling up from a single photovoltaic (PV) module to a full PV array involves several steps[8], which ensure that the system is designed to meet specific power requirements and operate efficiently. Here's a detailed breakdown:

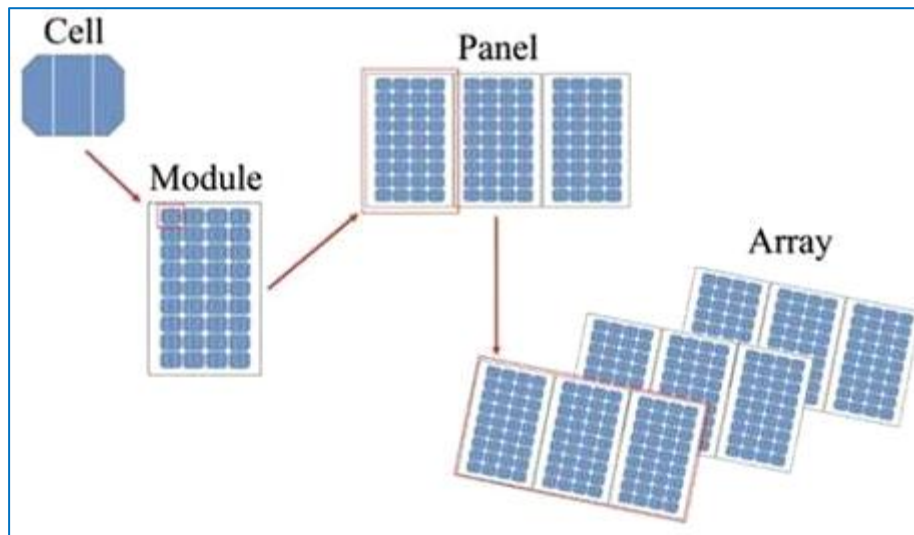


Figure 1 : From PV module to PV array

I.2.3. Connecting Modules

➤ Series Connection

Purpose: Increases the voltage of the system.

Method: Connect the positive terminal of one module to the negative terminal of the next module[9]. The voltage of the modules adds up, while the current remains the same as that of a single module.

➤ Parallel Connection

Purpose: Increases the current of the system.

Method: Connect the positive terminals of multiple modules together and the negative terminals together. The current of the modules adds up, while the voltage remains the same as

that of a single module[9, 10].

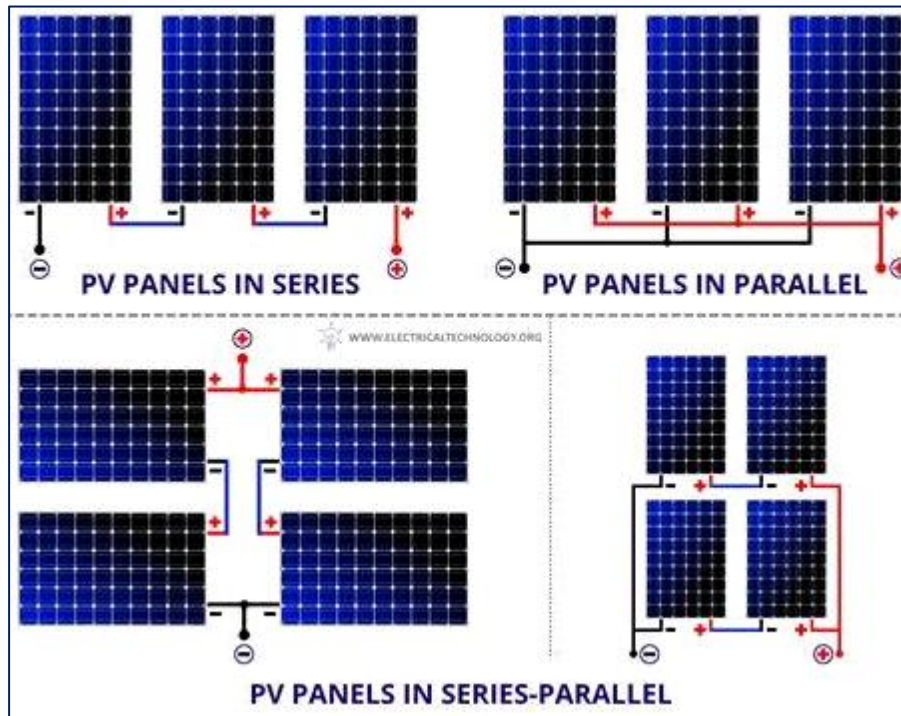


Figure 2 : Series, Parallel & Series-Parallel Connection of PV Panels

➤ **Designing the Array Layout**

➤ **Configuration**

Determine the number of modules in series (string) to meet the required system voltage.

Determine the number of series strings connected in parallel to meet the required system current and power output.

➤ **Physical Layout**

Arrange modules to minimize shading and optimize space usage.

Consider the orientation and tilt angle to maximize exposure to sunlight based on geographic location.

➤ **Mounting Systems**

➤ **Types of Mounting**

Fixed Mounts: Hold modules at a fixed angle.

Adjustable Mounts: Allow the angle to be changed periodically to optimize sunlight exposure.

Tracking Systems: Automatically adjust the orientation to follow the sun's path across the sky.

➤ **Structural Considerations**

Ensure the mounting system can withstand local weather conditions such as wind, snow, and

seismic activity.

Use durable materials to ensure long-term stability and safety.

➤ **Electrical Integration**

➤ **Combiner Boxes**

Consolidate the output of multiple strings of modules into a single electrical output.

Provide overcurrent protection with fuses or circuit breakers.

➤ **Inverters**

Convert the DC electricity generated by the modules into AC electricity used by most household and commercial appliances[11].

Types of inverters include string inverters (one per string) and central inverters (one for the entire array).

➤ **Wiring**

Use appropriate gauge wires to handle the current without significant voltage drop.

Ensure proper insulation and protection to prevent short circuits and electrical hazards.

➤ **Connectors**

Use weather-resistant and reliable connectors to maintain strong electrical connections.

➤ **Protection of the Photovoltaic Module**

Recent photovoltaic modules contain protective elements called bypass diodes, which protect them against unwanted current resulting from partial shading influence. Thus, to ensure the operational safety of the complete PV module, each bypass diode must be connected antiparallel to a single PV cell[12]. This protection method is costly; therefore, manufacturers place each bypass diode with a group of cells (2 to 3 bypass diodes per PV module). A simulation methodology for studying different configurations of bypass diodes in a PV module is provided. Figure below shows the arrangement of these bypass diodes for a module containing 36 cells.

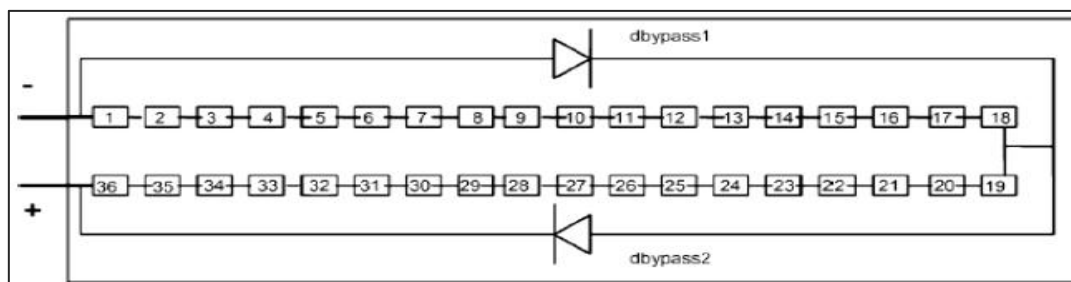


Figure 3 : Serial PV cells in the module with the two by-pass diodes

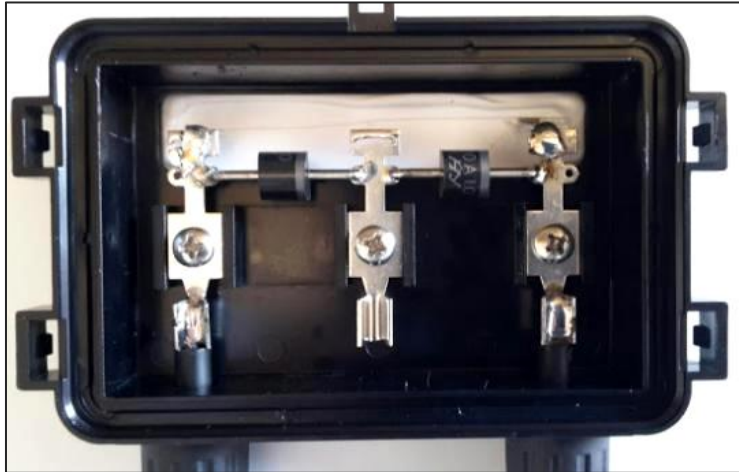


Figure 4 : PV module by-pass diode connection box

➤ **Classic Protections of a PV Array**

To ensure the reliability and durability of a photovoltaic installation, electrical protections must be added to PV modules to prevent destructive failures associated with the series and parallel connection of modules, especially when operating under partial shading conditions[13]. For this purpose, two types of classic protections are commonly used in current installations:

- The reverse-blocking diode prevents reverse current from other PV strings when connected in parallel. In the case of direct connection of a PV module to a load, which can switch from receiver mode to generator mode (as in the case of a battery).
- The bypass diode isolates each PV module in a string, which is not well illuminated compared to others, to prevent its destruction by the hot spot phenomenon.

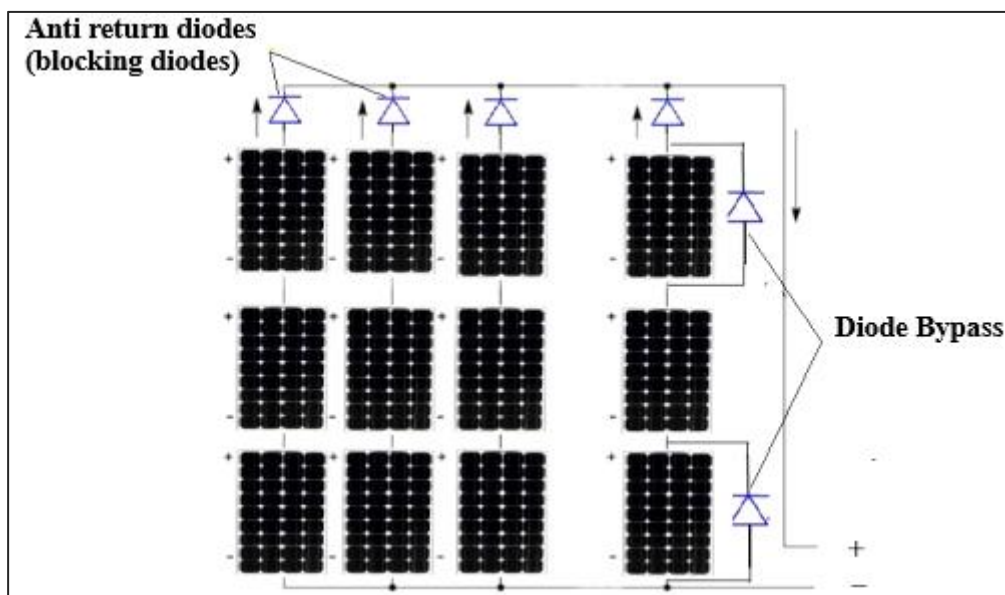


Figure 5 : A photovoltaic field

I.2.4. Performance of a Photovoltaic Array and Characteristics

I.2.4.1. Characteristics of the PV Module

The evaluation of the PV module and cell is provided under standard test conditions to compare solar cells and modules on an identical basis. A set of standard test conditions (STC) has been defined according to IEC 60904-3 as follows:

- * Solar irradiance of 1000 W/m^2
- * Device temperature of 25°C
- * Defined solar spectrum (spectral distribution of reference solar irradiance according to IEC 60904-3) with an air mass AM 1.5.

PV module manufacturers provide general information on electrical parameters and the I-V characteristic under standard test conditions (STC).

a. Influence of Solar Irradiance

The primary environmental factor influencing photovoltaic performance is the solar irradiance incident on the surface of the PV module. An increase in the light intensity reaching the photovoltaic device leads to an increase in the photocurrent (the PV module short-circuit current) and thus increases the output power[14]. This is illustrated in Figure.

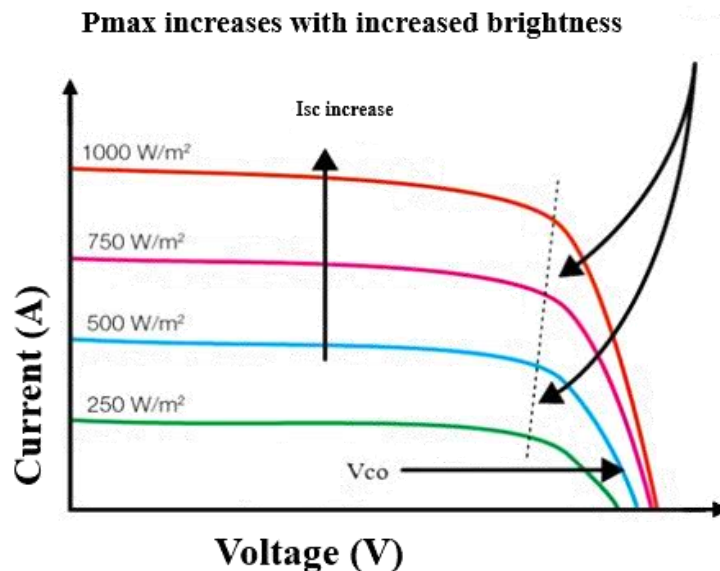


Figure 6 : Solar Illuminance Effect on PV Module Feature I-V

b. Influence of PV Module Temperature

The operating temperature of the PV module depends on ambient temperature and other factors such as increased levels of solar irradiance and wind speed. An increase in the temperature of the PV module leads to a reduction in the open-circuit voltage (Voc) and

consequently the maximum power (P_{max}) due to the reduction in forbidden energy, but it also causes a slight increase in the short-circuit current (I_{sc}). The figure below illustrates the effects of temperature on the I-V characteristic of solar energy[15].

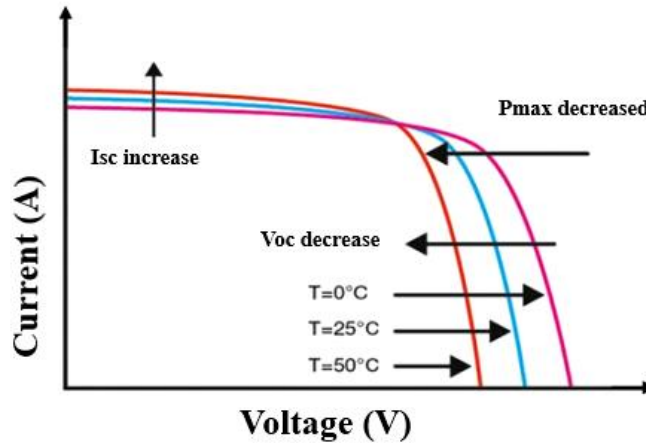


Figure 7 : Effect of temperature on PV module I-V characteristic

c. Influence of Shading

Partial shading occurs when a cell receives a lower amount of light compared to others connected in series. Consequently, the current flowing through the entire array is limited by the shaded cell[16]. As a result, the shaded cell dissipates some of the energy produced by the rest of the cell array. The greater the shading, the more energy is dissipated. This effect is depicted in figure.

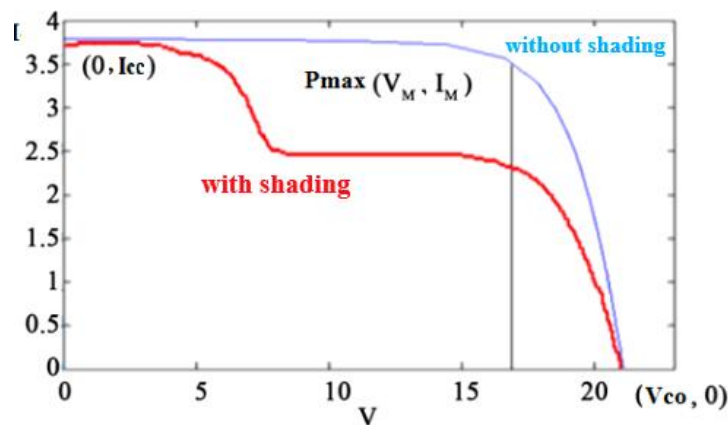


Figure 8 : Shading effect on PV module I-V

1.2.5. Defects of Protection Diodes

1.2.5.1 Bypass Diode Failure

The bypass diode is connected antiparallel with a set of photovoltaic cells connected in series to

protect them from the hot spot phenomenon. When the diode is in good condition, it becomes conductive and isolates the shaded cells (the voltage across the shaded cells becomes negative due to shading)[17]. However, in the case of diode failure, the protection of the PV cells is not guaranteed, leading to the destruction of the PV module.

Three types of bypass diode defects are distinguished: short-circuit, open-circuit, and reverse diode. These defects are caused by cell assembly to build a module, transportation or module mounting (installation), or humidity. Figure illustrates the three cases of defective bypass diodes.

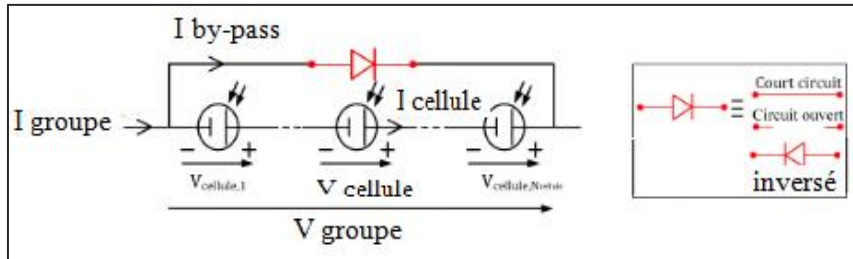


Figure 9 : Différentes situations de la diode by-pass défailante

I.2.5.2. Reverse Diode Failure

The primary role of the reverse diode in a photovoltaic array is to protect the PV string against reverse current. The reversal of the current results from the lower voltage of the shaded string compared to the other PV strings. In the case where the diode is functioning properly, it blocks and isolates the shaded string[18]. However, if it is defective, the shaded string absorbs the current produced by the other strings of the PV array and can cause premature failure of the cells. Figure illustrates the different defects of the reverse diode.

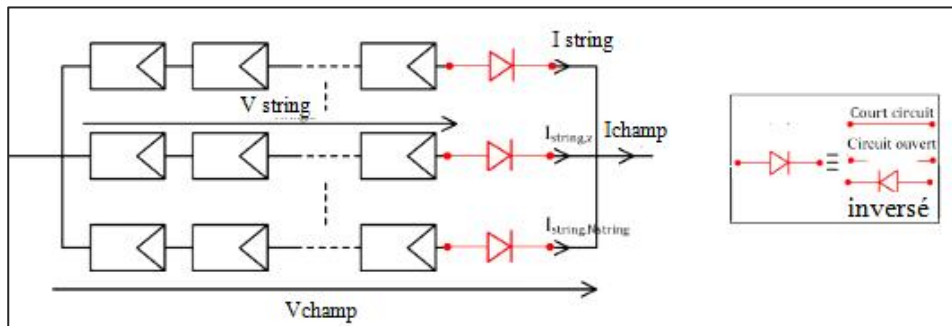


Figure 10 : Different Situations of the Failed Non-return Diode

I.3. Photovoltaic systems

Photovoltaic (PV) systems are designed to convert sunlight into electrical energy using solar cells. These systems can vary in size and complexity, from small residential setups to large-scale commercial installations[19].

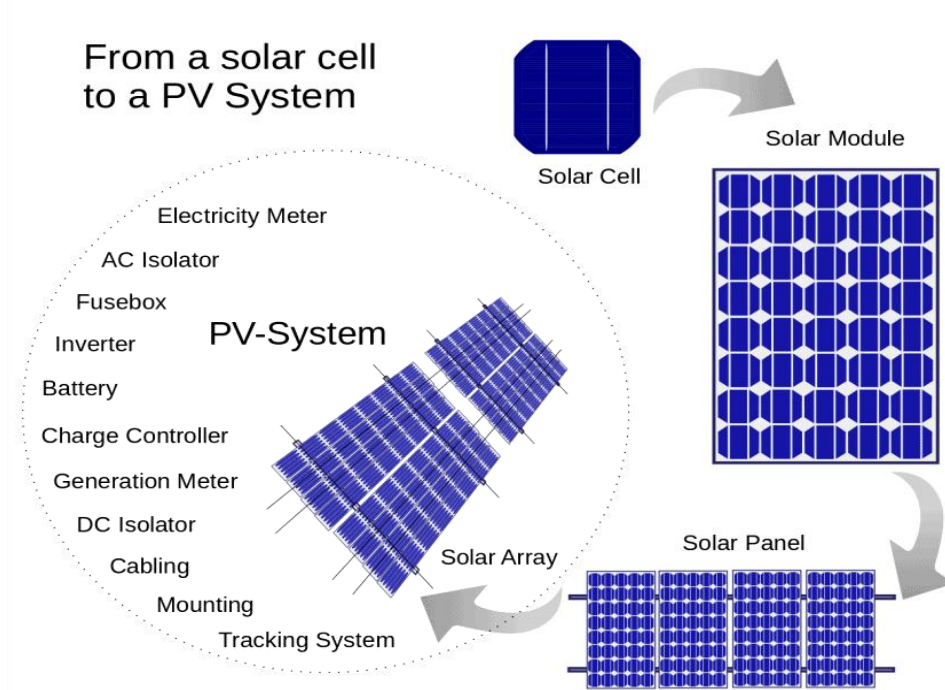
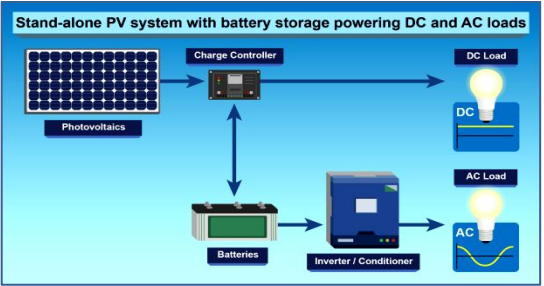
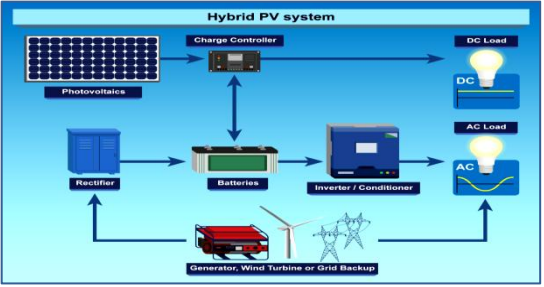
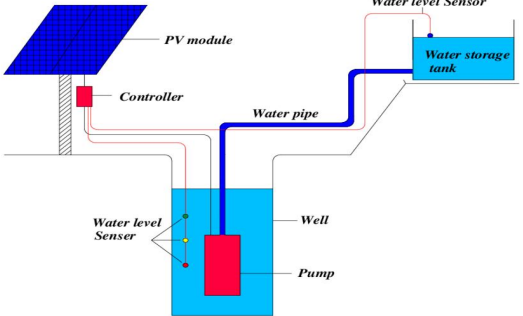
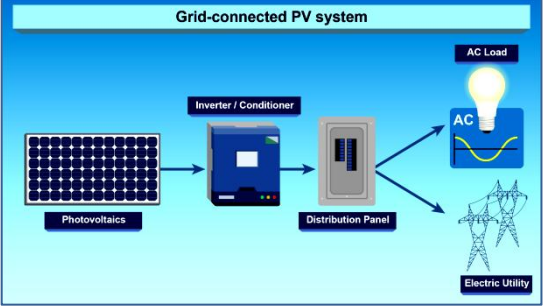


Figure 11 : from a solar cell to a PV system

PV systems can be classified based on their configuration and application into standalone systems, hybrid systems, pumping systems, and grid-connected systems. Each type serves different energy needs and applications[20].

Figure 12 PV system types

<p>1. Standalone PV System</p>	 <p>Figure 13 : Standalone PV System</p>
<p>2. Hybrid PV System</p>	 <p>Figure 14 : Hybrid PV System</p>
<p>3. PV Pumping System</p>	 <p>Figure 15 : PV Pumping System</p>
<p>4. Grid-Connected PV System</p>	 <p>Figure 16 : Grid-Connected PV System</p>

The Grid-connected PV systems, also known as grid-tied systems, are directly connected to the public electricity grid. These systems allow for the transfer of excess electricity generated by the PV panels to the grid, and in return, electricity can be drawn from the grid when solar power

is insufficient. Key components of grid-connected systems include:

- **PV Panels:** Generate DC electricity from sunlight.
- **Inverter:** Converts DC electricity to AC electricity for use in household appliances and for feeding into the grid.
- **Metering System:** Measures the amount of electricity exported to and imported from the grid.
- **Connection to Grid:** Allows for seamless integration with the public electricity supply.

Grid-connected systems are popular in residential and commercial applications where users can benefit from net metering or feed-in tariffs, which provide financial incentives for generating solar power[20].

The Tamsa PV central, with a capacity of 220 megawatts, serves as an example of a large-scale grid-connected PV system. This installation involves numerous PV modules arranged in arrays, connected to central inverters that convert the generated DC power to AC power suitable for the grid. The Tamsa PV plant includes advanced monitoring and control systems to optimize performance and ensure efficient operation. The electricity generated contributes significantly to the local grid, supporting the region's energy needs with clean, renewable power[19].

I.4. Adaptation and Control of the PV Inverter Connected to the Electrical Grid

To ensure proper connection of the photovoltaic system to the electrical grid without disturbing its characteristics[21], the output voltage of the photovoltaic inverter must have the same parameters as the electrical grid (waveform, frequency, and phase)[22]:

- The waveform of the output voltage of the PV inverter must be sinusoidal.
- The frequency of the output voltage and current must be equal to the frequency of the electrical grid (50 Hz).
- The currents injected into the electrical grid must be in phase with the corresponding grid voltages.

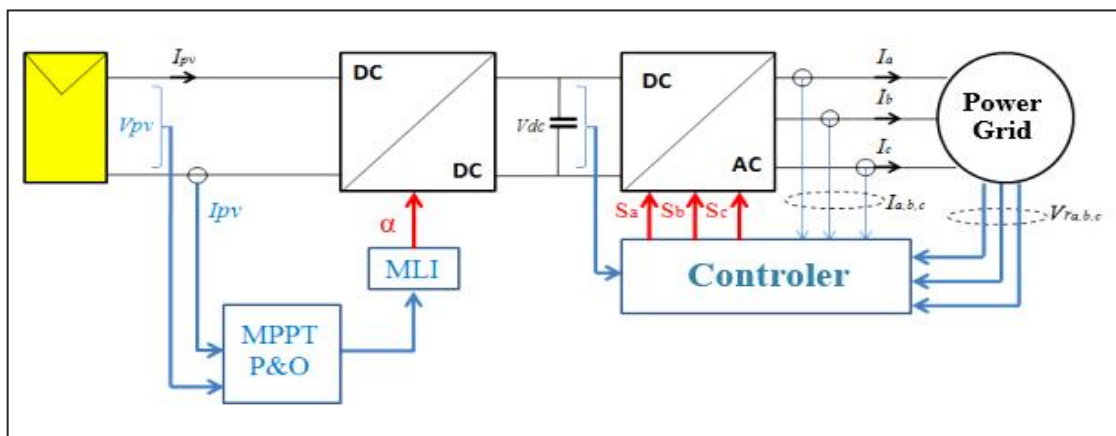


Figure 17 : Overall diagram of the photovoltaic system connected to the electricity grid

I.4.1. PV Inverter Technologies

Different topologies of inverters are distinguished for PV applications, depending on the scale of the installation, efficiency, and power requirements[23].

I.4.1.1. Modular Inverters (Module Inverter)

In this concept, each solar module has its individual inverter. For larger installations, all inverters are connected in parallel on the AC side. Modular inverters are installed in close proximity to the corresponding solar module[24].

I.4.1.2. Centralized Inverters (Central Inverter)

A high-power centralized inverter converts all the DC current produced by a solar cell array into AC current. The solar cell array typically consists of multiple rows connected in parallel. Each row is composed of several solar modules connected in series to minimize cable losses and achieve high efficiency.

I.4.1.3. String Inverters

String inverters are the most commonly used. Typically, eight (or more) solar modules are connected in series[25]. As only one series connection is required, installation costs are reduced. It is important to note that in case of partial shading of the solar modules, there is no loss, and the use of bypass diodes is highly recommended.

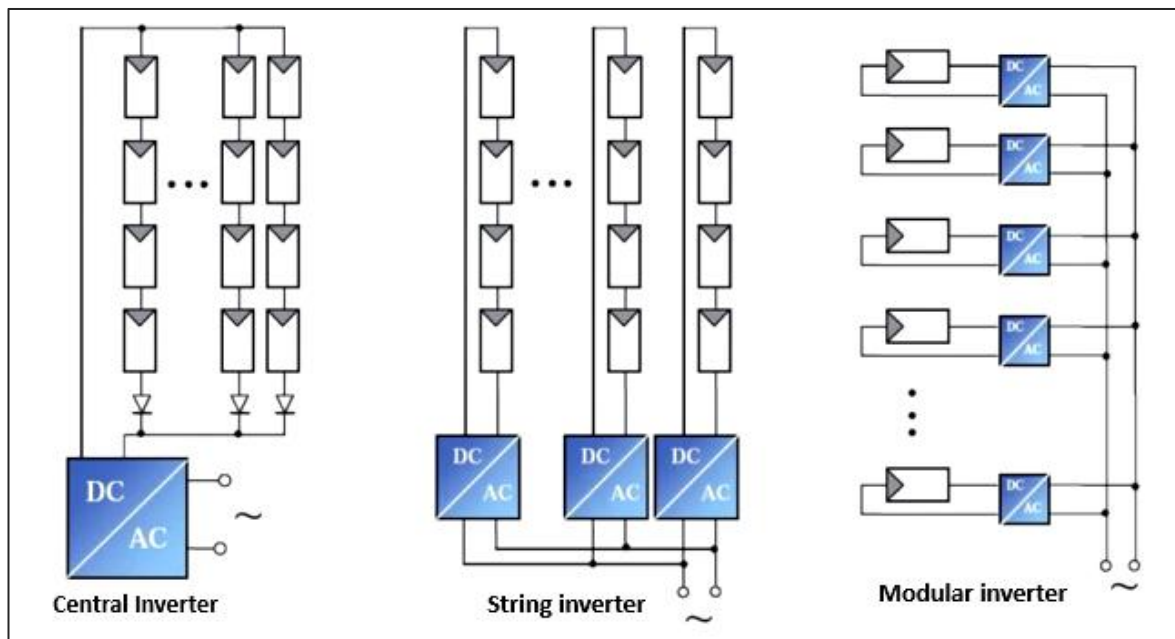


Figure 18 : Classification of grid-connected PV inverters

Part Two

II.1. Description of Tamsa photovoltaic plant with a capacity of 220 megawatts

The Tamsa control plant could be a control era plant from photovoltaic sun based boards with an generally capacity of 220 MW, an infusion voltage of 60 kV, and an zone of 452.80 hectares (almost double 11x41.16 hectares times of the Ain El Melh power plant), and whose realization required the mobilization of an speculation of about 3.9 billion dinars.

This station is found 23,45 km west of the state of Bou Saada. It is a region exceptionally wealthy in potential sun-based vitality due to its geology. It is one of the offices built by the renewable vitality company of the open vitality provider Sonelgaz (SKTM).

The location comprises 220 photovoltaic subfields of 1MWp, and each department has two inverters and one step-up transformer. Control plant hardware and major components, they are displayed underneath in Table.

Table 1 configuration of the Tamsa 220MW power plant

Equipement	Numbers
255 W modules	80080
Numbers of Under Field panels	4004
Numbers of string/subfield	91
Numbers of panel/chain	440
Junction boxes	440
1 MW subfields	220
500 kW inverters	440
315 V / 31.5 kV / 1 MW Transformers elevator	220
MT evacuation station (31.5 kV /60 kV/ 40 MW transformer)	11
Control room	01

II.2. Geographical location of the site

The Tamsa 220 MW solar power plant is located at a latitude of 35.1737° or $35^\circ 10' 25''$ North, a longitude of 3.92553° or $3^\circ 55' 32''$ East. At an elevation of 761 m (2,497 ft)[25]. It is found in a topographically great area where it can assimilate more solar radiation for the whole year as power produced by the solar plant totally depends up on its sun's insolation [24].

II.3. Description of the 1MW subfields

Each sub-field is equipped with 4004 sun-oriented panels ideally dispersed (divided or spaced) to maintain a strategic distance from (avoid) shadowing. And are spread over two inverters that change over DC into AC (yield (output) voltage 315 VAC) and send it through AC cables to a 1,250 kVA step-up transformer bringing the voltage to 0.315 kVA. And the coordinate current from the solar panels is collected through the collector boxes in arrange (order) to decrease the overall length of the DC cables and ohmic misfortunes(losses) in them and make strides(improve) energy efficiency. And the 20 subfields are associated with the 60 kV step-up transformer and discharge the power delivered to the national lattice (grid).

The characteristics of the 1 MW subfield hardware of the PV power plant are summarized in Table.

Table 2 characteristics of the 1 MW subfield equipment of the PV power plant

DESIGN PARAMETER	CHARACTERISTICS
Module type	Poly-crystalline silicon
Photovoltaic module efficiency	15%
Orientation and tilt	29.3 south
Installation type	fixed
Distance between photovoltaic rows	8 m
Inverters	500 kW
Transformers	VA, 47-52 Hz, 315 V/31.5 kV

II.4. Description of the Photovoltaic modules

The boards distinguished by SKTM contain China-made Yingli series sun-powered (solar) cells made from squares (or pieces) of polycrystalline silicon. The cost of fabricating these cells is less than Monocrystalline, but its vitality misfortune (loss energy) is huge (large) in heat. The characteristics of the solar modules are appeared in Table.

Table 3 power plant panel characteristics

Module type	Characteristics
The brand	YINGLI SOLAR
Module type	YL 255 P- 32b
Measured power	260.2 W (0/+5W)
Measured voltage Vmp	32.65 V
Measured current Imp	7.97 A
Open-circuit voltage Voc	40.57 V
Short circuit voltage Isc	8.49 A
An irradiance	1000W / m ²
Fire resistance class	C
Application class	A
The cell temperature	25°C
Tension system Max	1000 V

II.5. Inverters

The inverter is an electronic gadget that changes over (converts) direct current delivered by photovoltaic modules to alternating current using control and security circuitry. It can accept the maximal current and voltage produced by the photovoltaic field.

The efficiency compares to the ratio between the output power and the input power, it is expressed as a percentage. Too high a temperature diminishes the efficiency of the inverter.

The power station is equipped with 40 (440) Chinese-made inverters of the brand SUNGROW of 500 kW DC/AC, 2 per subfield. The ~520–820 VDC input range guarantees AC output voltage

stability with a maximal current of 1008 A at high effectiveness of 98%. The DC side of the inverters has 4 two polarity inputs each equipped with direct current fuse protection, a general disconnect switch, and a DC lightning arrester. The technical details of the inverters are appeared in Table.

Table 4 technical specifications of the inverter

Inverter	Specification
The Brand	SUNGROW
Type Of	SG500MX
Operating Temperature	-30 C / 50 C
IP Protection	IP 21
DC Input	
Max Voltage	1000 V
Isc	1344 A
Voltage Vmpp min	500 V
Voltage Vmpp max	850 V
Max Input Current	1120 A
OverVoltage Category	//
AC Output	
Rated Output Power	500 kW
Rated Output Voltage	3-315 V
Rated Output Frequency	50 Hz
Max Output Current	1008 A
Power Factor	-0.9/0.9
OverVoltage	//

II.6. MW step-up transformer

Used transformers are state-of-the-art machines specifically ordered by SKTM whose installation required large capital expenditures, due to complex manufacturing processes. It also requires lengthy expenditures to monitor and maintain these transformers. The failure of a single unit may result in interruption of service and significant loss of revenue as well as replacement costs and other additional costs . It is a very important electrical equipment for AC transformer and transmission system. It transforms LV voltage into HV. The equipment is surrounded by a shelter envelope, equipped on the four sides with heat radiation fans, operating according to the temperature[26]. The technical characteristics of the transformers chosen by the company SKTM are indicated in table.

Table 5 technical specifications of the transformer

The Brand	SUNTEN
Type Of	ZBW10N 1250 / 31.5 / 0.315-0.315
Rated Capacity	1250 kVA
Rated Voltage	31.5 kV / 0.315 kV
Rated Frequency	50 Hz
Aspect Dimensions	4700*2438*2896 mm
Cooling Mode	AN
Rated Input Voltage	315 V / 315 V
Rated Input Current	1146 A / 1146 A
Rated Output Voltage	30000V
Rated Output Current	24.1A

II.7. Estimation PV Electricity and Solar Radiation in the Tamsa station

➤ The first method

Using numerical modeling tools, an understanding of meteorological and radiative characteristics, including wind, insolation, temperature, relative humidity, pressure, and solar radiation components, is necessary to assess the long-term performance of the Tamsa solar energy conversion plant systems.

Tamsa is an excellent location for a photovoltaic project due to its pleasant environment and abundant solar radiation, according to the study's findings, which were derived from an analysis of the meteorological data and a comparison between the solar radiation values measured at Tamsa station and the values estimated by Leo Jordan's theoretical model. Figure displays the findings from the estimation of solar radiation for a few clear and foggy days.

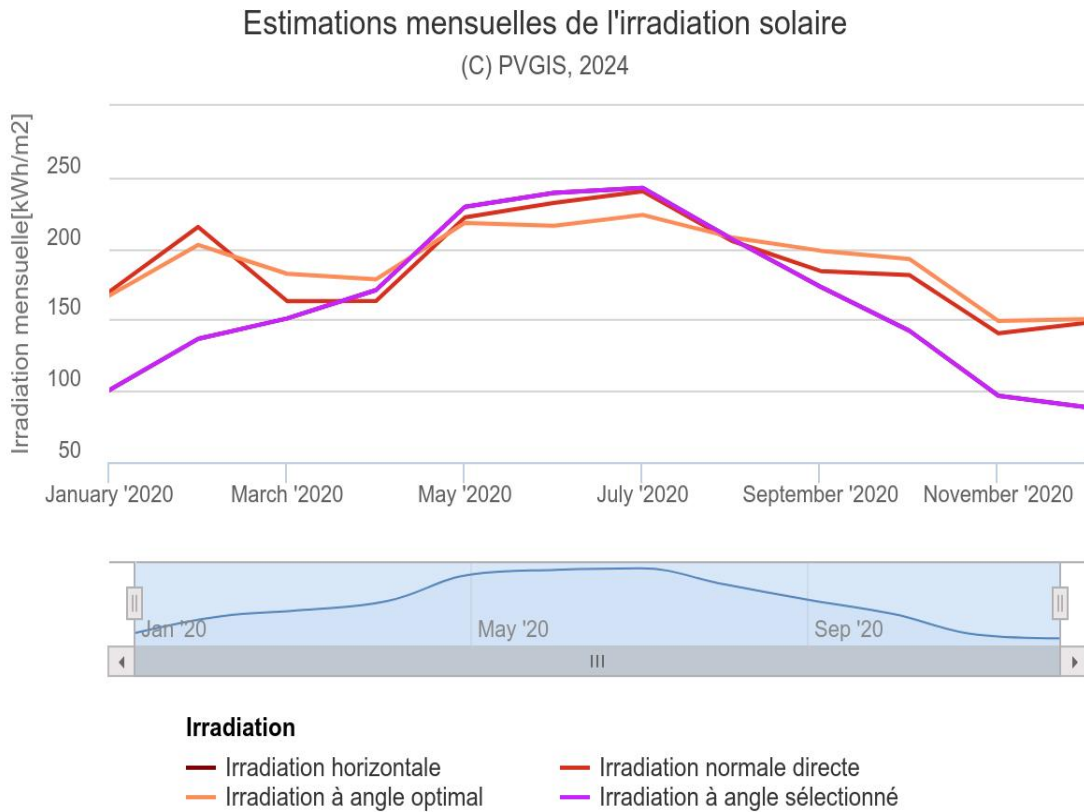


Figure 19 Solar Irradiance Calculator (with Map) - PVGIS

Irradiation moyenne quotidienne

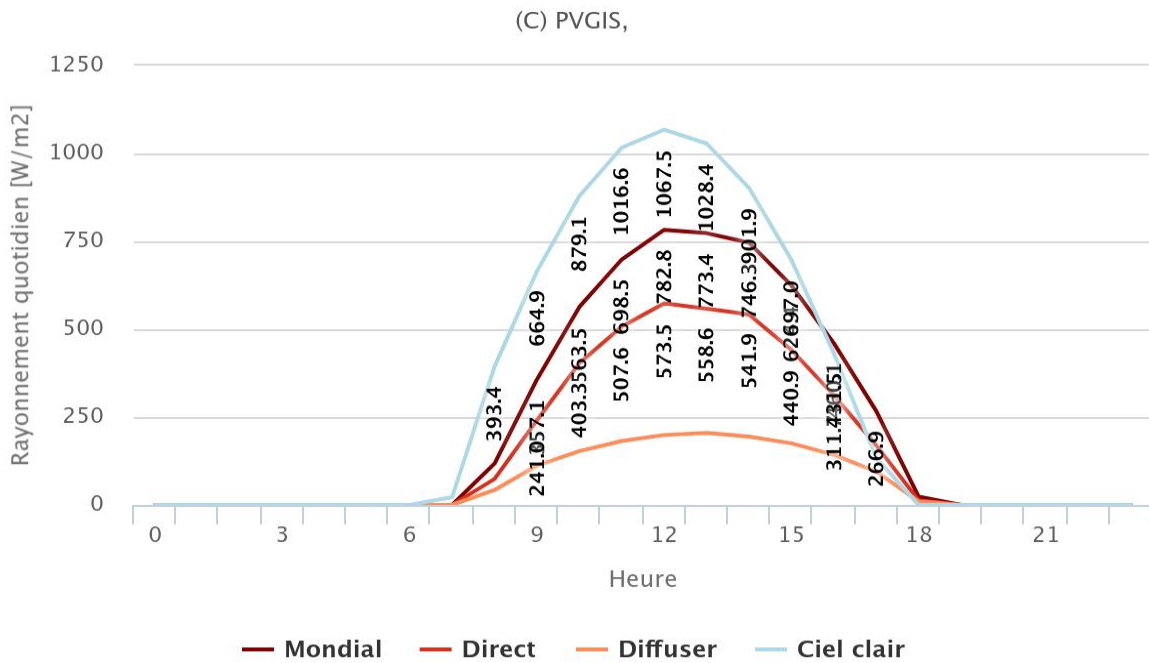


Figure 20 Average daily irradiance

➤ The second method

Data about sun brightness is gathered and automatically generated into this report, called the "Work." On the location (M'Sila, Tamsa). It was derived from the Global Solar Atlas web application [19], which was created by Solargis on behalf of The World Bank using a database of solar resources that Solargis owns and keeps up to date. It offers information on air temperature, possible solar power output, and estimated solar resource for the chosen site, as well as input parameters for photovoltaic (PV) power systems.

Because the site-specific solar energy yield estimates provided by the Global Solar Atlas take into account default values for numerous crucial parameters that affect photovoltaic system design, they are appropriate for initial research.

It is advised to use technologies that enable more precise configuration of solar power projects and to feed the simulation with more precise solar and meteorological data in order to obtain more detailed estimations. The study includes Tamsa City's daily average bright sunshine hours and monthly worldwide solar insolation.

Tamsa

35.173373°, 003.927612°

unnamed road, Tamsa, M'Sila,

Algeria Time zone : UTC+01, Africa/Algiers [CET]

Report generated: 23 Mar 2024

PV ELECTRICITY AND SOLAR RADIATION

Annual averages

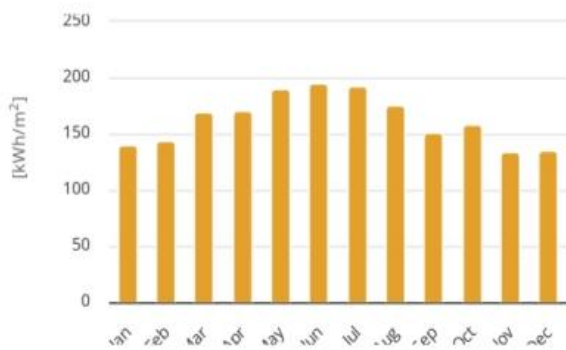
Direct normal irradiation

1958.6

kWh/m² per year

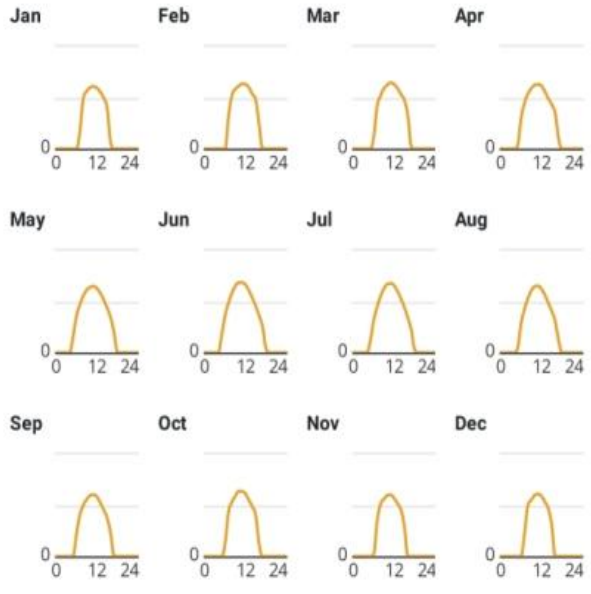
Monthly averages

Direct normal irradiation



Average hourly profiles

Direct normal irradiation [Wh/m²]



UTC+01

Average hourly profiles

Direct normal irradiation [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6				32	152	169	113	42	7			
6 - 7			114	292	354	360	314	283	216	126	22	
7 - 8	167	310	416	445	468	484	446	422	404	432	342	219
8 - 9	488	518	518	536	554	580	551	529	500	530	510	497
9 - 10	562	584	589	591	611	652	626	604	557	591	560	550
10 - 11	599	613	625	623	639	684	669	646	596	636	597	599
11 - 12	610	636	648	629	649	684	677	652	603	635	602	611
12 - 13	594	631	630	614	627	663	655	621	583	611	567	588
13 - 14	555	598	590	558	581	607	597	562	523	549	516	533
14 - 15	496	533	531	491	516	534	525	484	455	485	453	465
15 - 16	399	476	475	431	437	453	440	405	376	396	291	304
16 - 17	67	231	326	348	345	359	340	308	231	113	4	5
17 - 18		2	24	100	200	248	223	119	10			
18 - 19					8	41	31					
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4,535	5,132	5,486	5,692	6,142	6,517	6,207	5,677	5,052	5,104	4,463	4,372

II.8. Conclusion

The chapter concludes with a comprehensive understanding of photovoltaic energy and its applications. By examining the structure and operation of PV modules and arrays, as well as the various types of PV systems, we gain insights into how solar power can be harnessed effectively. The detailed discussion on the Tamsa PV central underscores the potential of large-scale solar power installations to contribute significantly to renewable energy production. This chapter sets the stage for further exploration into the technologies and strategies like the protection strategies to enhance the efficiency and reliability of PV systems, and that we will see it in the next chapters.

**Chapter II: Protection & Coordination of
OCR in Power System Networks**

II.1. Introduction

The protection and coordination of Overcurrent Relays (OCR) are essential for the stability and reliability of power system networks, especially with the integration of Distributed Generations (DG)[27]. Electrical network protection includes techniques, devices, and protocols designed to safeguard grids from faults and anomalies, ensuring continuous electricity delivery and minimizing damage. The primary objectives are the safety of personnel, equipment and the public, as well as maintaining reliable power supply by swiftly detecting and isolating faults[28].

II.2. Definition of electrical network protection

refers to the set of techniques, devices, and protocols employed to safeguard electrical grids from various faults, disturbances, and anomalies, thereby ensuring the uninterrupted delivery of electricity to consumers while minimizing the risk of damage to equipment and infrastructure[29].

II.3. Protection Objectives

The primary objectives of electrical network protection are to ensure the safety of personnel, equipment, and the public, as well as to maintain the reliability and continuity of power supply. Protection systems are designed to swiftly detect and isolate faults, such as short circuits, overloads, and ground faults, to prevent damage to equipment, minimize downtime, and mitigate the risk of widespread outages. Additionally, protection aims to limit the magnitude and duration of fault currents, thereby reducing stress on the electrical system and enhancing its overall stability[30]. By achieving these objectives, protection systems contribute to the efficient and secure operation of electrical networks, supporting critical infrastructure and facilitating economic development.

II.4. Types of Faults in Electrical Networks

Understanding these types of faults is essential for designing and implementing effective protection schemes that can detect and mitigate abnormalities in electrical networks, thereby ensuring the safety, reliability, and continuity of power supply[31, 32].

II.4.1. Short Circuits

Short circuits occur when a low-resistance path is created between conductors, resulting in an excessive flow of current. These faults can lead to overheating, equipment damage, and in severe cases, fires or explosions[31].

II.4.2. Overloads

Overloads occur when the current flowing through a conductor exceeds its rated capacity. This can be caused by excessive demand, equipment malfunction, or inadequate conductor sizing. Overloads can result in overheating, insulation degradation, and equipment failure[33].

II.4.3. Ground Faults

Ground faults occur when an unintended connection is established between an energized conductor and ground. This can happen due to insulation failure, equipment damage, or accidental contact with conductive surfaces. Ground faults pose a risk of electric shock to personnel and can lead to equipment damage and service interruptions[34].

II.5. Basic elements of a protection system

The protection arrangement for any power system must take into account the following basic principles: reliability (including dependability and safety), speed and selectivity[35].

The reduction in the number and duration of the interruptions to the electricity users can enhance the reliability of the power supply. Power quality can also be improved with a faster pick up time to minimize the likelihood of voltage sags, voltage flicker etc[36].

The protective relay is the most frequently used protection device and a basic element in a protection system[37]. The role of a protective relay is to detect system abnormalities and to selectively execute appropriate commands to isolate only the faulty component from the healthy system. Protective relays are connected to the power system over instrument transformers: the current transformer (CT) and the voltage transformer (VT). Figure below shows a typical single line diagram in which a protective relay is connected to the power system. The relay itself is also connected to the circuit breaker, which receives trip commands to selectively eliminate the fault. VT is optional, but essential for directional and distance relays.

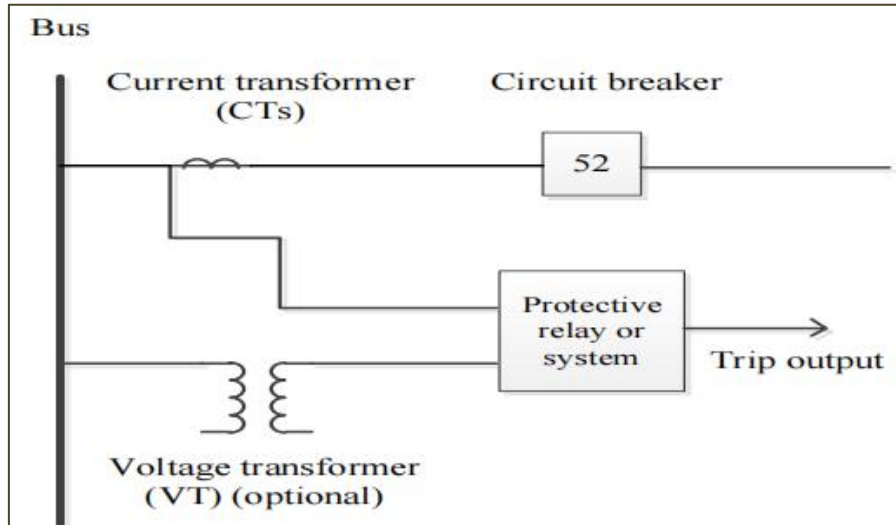


Figure 21 : Single-line connection of protective relay

Protection relays can be classified in accordance with their function:

1. Overcurrent
2. Directional overcurrent
3. Distance
4. Differential
5. Overvoltage
6. Others

The overcurrent (OC) relaying is the most widely used type for its protection due to the large current and the low cost for OC relays. However, OC relays and fuses may not be enough to protect power system networks with distributed generators (DGs) connected to the grid.

II.6. Protection Devices in Electrical Networks

These protection devices work in concert to detect, isolate, and mitigate faults and disturbances in electrical networks, ensuring the safety, reliability, and continuity of power supply to consumers[38].

The process of choosing relay settings that offer a selected reaction in the event of a malfunction is known as time overcurrent relay coordination [8][39]. Users can access the protection analysis application through PowerFactory. For instance, the Global Library offers a variety of relay types (direction, distance, and OC) for usage, and the computation of fault current is relevant. The appropriate protection system is chosen based on the features of the protective system. The overcurrent protection devices (fuses, OC relays) in this network are described, and the ETAP user's handbook has further details on alternative forms of

protection, That's what we'll see in the next chapter[40].

II.6.1. Relays

Relays are electronic devices that monitor electrical parameters, such as current, voltage, and frequency, and initiate protective actions when abnormal conditions are detected. They act as the "brains" of protection systems, providing intelligence and decision-making capabilities to ensure timely and selective fault detection and isolation[41].

II.6.2. Circuit Breakers

Circuit breakers are mechanical switches that automatically interrupt the flow of electrical current in the event of a fault or overload. They provide both short-circuit and overload protection by opening the circuit when excessive current is detected, thereby isolating the faulted portion of the network and preventing damage to equipment[35].



Figure 20 : Low voltage Circuit Breaker

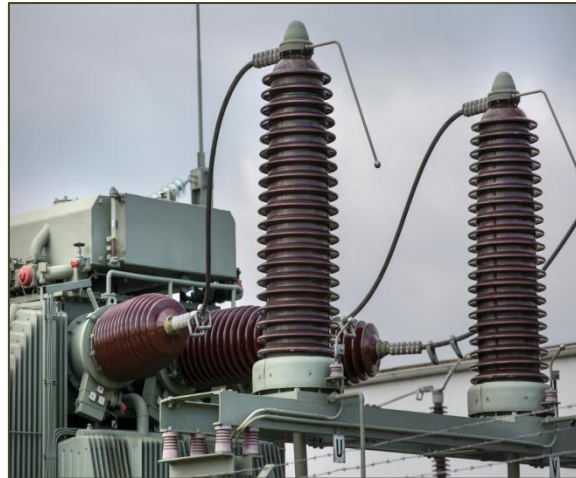


Figure 21 : High voltage Circuit Breaker

II.6.3. Fuses

Fuses are passive devices that provide overcurrent protection by melting a fusible element when current exceeds a predetermined threshold[35]. This interrupts the circuit and clears the fault by opening the electrical path. Fuses are commonly used as backup protection devices or as primary protection in low-

voltage applications.



Figure 22 : Fuses symbol

Types

➤ gG class

These fuses are designed for general applications where overload and short circuit protection is required.

They are used in a wide range of electrical equipment and circuits, including switchboards, control panels and industrial devices.

Class gG fuses have a relatively high cut-off capacity for effective overload and short circuit protection.

➤ aM class

These fuses are mainly used for the protection of electric motors and associated circuits.

They are designed to withstand high motor starting currents without triggering unexpectedly, while providing effective protection against overloads and short circuits.

Class aM fuses are widely used in industrial and commercial applications where electric motors are present, such as pumps, compressors and fans.

➤ gL class

This class of fuses is specifically designed for luminaire applications, such as public, commercial and residential lighting.

They offer precise overcurrent protection for lighting circuits, with features adapted to the requirements of luminaires and lighting installations.

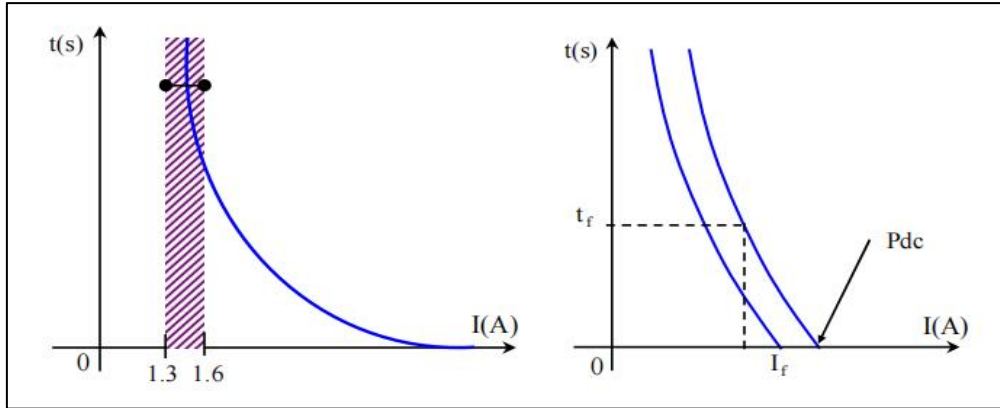


Figure 23 : Melting time curves

II.6.4. Protective Relays

Protective relays are specialized devices designed to respond to specific fault conditions and provide targeted protection for various components of the electrical network, such as transformers, motors, generators, and transmission lines. They offer advanced functionality, including adjustable settings, communication capabilities, and coordination with other protection devices[30].



Protection Relay

Figure 24 protection relays

II.6.5. Measurement Transformers

Measurement transformers play a crucial role in transmitting electrical signals with precise accuracy while ensuring isolation between the primary circuit and the secondary circuit (measuring circuit). This insulation must withstand network voltage, overvoltage, and fault currents.

The primary types of measurement transformers are voltage transformers (VT) and current transformers (CT), also known as measuring reducers. Their primary functions include:

- Measurement and display of electrical parameters.
- Utilization in metering installations for calculating power (P) and reactive power (Q), among other measurements.
- Provision of power to electrical protection circuits or regulators.

These transformers are designed to reduce voltages and currents from the main circuits to lower and more manageable levels, facilitating various measurement and control tasks within electrical systems.

II.6.5.1. Current Transformers (CT)

The currents within the electrical grid often exceed the capacity of measuring devices to handle directly. Current transformers (CTs) serve to reduce these high currents to levels suitable for most devices, typically around 1 or 5 amps. These transformers function by providing the secondary circuit with a current that is proportional to the primary current being measured. Their utility extends to both measurement and protection applications[42].



Figure 25 current transformer

The transformation ratio of a CT is expressed as:

$$\mathbf{m} = \frac{\mathbf{I1}}{\mathbf{I2}}$$

However, to ensure optimal performance and accurate readings, it is essential to operate CTs within their linear range, thus avoiding saturation due to high voltages and currents. To achieve this:

- Never leave the secondary circuit of a current transformer open.
- Avoid using a DC current transformer.
- Install a current transformer in each phase of the power grid to ensure comprehensive coverage and accurate measurement.

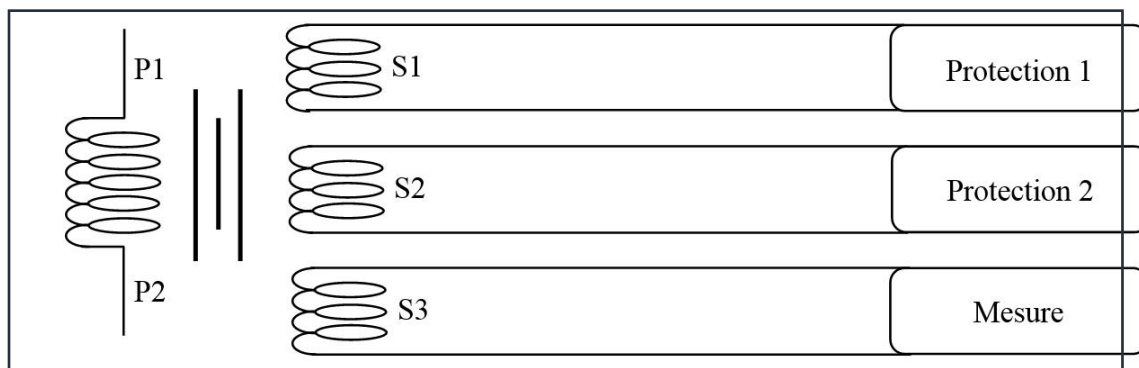


Figure 26 : Designation of the current transformer terminals

Current Transformer Parameters According to IEC 185

The current transformer (CT) must be tailored to the specific requirements of its intended application, which could include protective, measuring, or metering purposes. The designated use of the CT dictates the determination of parameters such as assigned primary and secondary currents, power ratings, and accuracy class. It's important to note that the characteristics of CTs are applicable only under normal operating conditions. Downgrading of performance may occur based on factors such as ambient temperature and altitude[27].

1. Assigned Primary Current

The assigned primary current is determined by the standard and chosen from specified values such as 10, 12.5, 15, 20, 25, 30, 40, 50, 60, 75, and their multiples, including decimal multiples.

2. Assigned Secondary Current

This parameter is typically set to either 1A or 5A.

3. Precision Power

5, 10, 15, and 30 VA.

4. Accuracy class

Refers to the specified error limits on the transformation ratio of current transformers under defined power and current conditions. For current measurement accuracy, it's determined by the assigned accuracy class, which dictates the allowable error in phase and magnitude across a range typically spanning from 5% to 120% of the rated primary current. The standardized accuracy classes according to the International Electrotechnical Commission (IEC) are 0.1, 0.2, 0.5, 1, 3, and 5.

In practical applications, accuracy classes 0.5 and 1 are most commonly utilized. Accuracy class 0.2 is specifically reserved for precise measurements. On the other hand, accuracy classes 0.1, 3, and 5 see minimal usage.

II.6.5.2. Voltage Transformation (VT)

The function of a voltage transformer (VT) is to replicate the voltage applied to its primary circuit onto its secondary circuit. Voltage transformers are utilized for both measurement and protection purposes. They typically consist of two windings, primary and secondary, linked by a magnetic circuit. Connections can be established between phases or between a phase and neutral (neutral to ground).

It is strictly prohibited to short-circuit the secondary of a voltage transformer. The secondary circuit must always remain open, presenting an infinitely large load. This is in contrast to current transformers (CTs), which require short-circuiting of the secondary for proper operation.

The operational principle of a voltage transformer is depicted in the figure below.

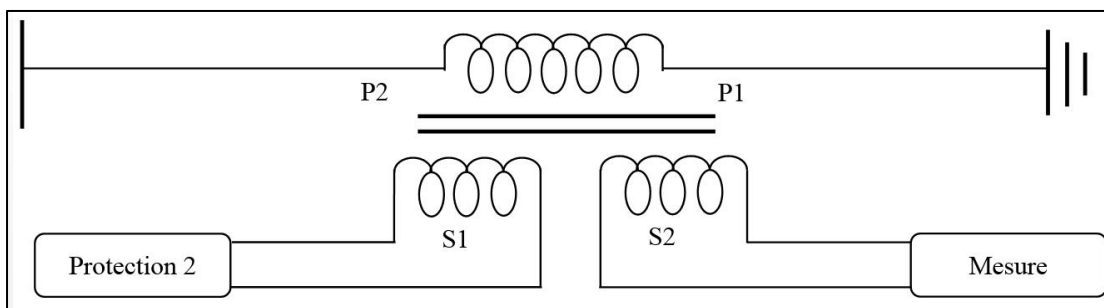


Figure 27 : Diagram of a voltage transformer

II.7. Overcurrent protection

Overcurrent relaying

Overcurrent relaying is the most common form of protection used to eliminate system faults followed by excessive currents. Based on the relay operating characteristics[43], overcurrent relays can be classified into three major groups[39] :



Figure 28 overcurrent relay "ABB REF 630"

1. Definite-current or instantaneous

Instantaneous overcurrent relays, also known as definite-current relays, operate without any intentional time delay. They trip instantly when the current exceeds a predetermined threshold. Instantaneous relays are designed to provide rapid and immediate protection against short circuits and other severe faults, minimizing the risk of damage to equipment and ensuring system safety[37].



Figure 29 : Definite current "instantaneous" overcurrent relay Curve

2. Definite-time

Definite-time overcurrent relays operate with a fixed time delay before tripping once the current exceeds a preset threshold. Unlike inverse-time relays, the tripping time of definite-time relays remains constant regardless of the magnitude of the fault current. These relays are typically used in applications where a fixed time delay is desired, such as protecting backup generators or capacitor banks.

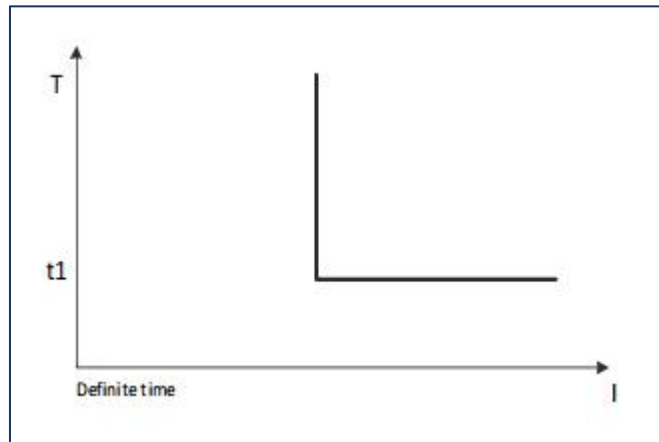


Figure 30 : Definite time overcurrent relay Curve

3. Inverse time

Inverse-time overcurrent relays operate with a characteristic where the tripping time decreases as the magnitude of the fault current increases. This means that for higher levels of fault current, the relay trips faster, providing quick response to severe faults. The inverse-time characteristic is often represented by a curve, such as the Inverse, Very Inverse, Extremely Inverse, or Definite Time (IDMT) curves.

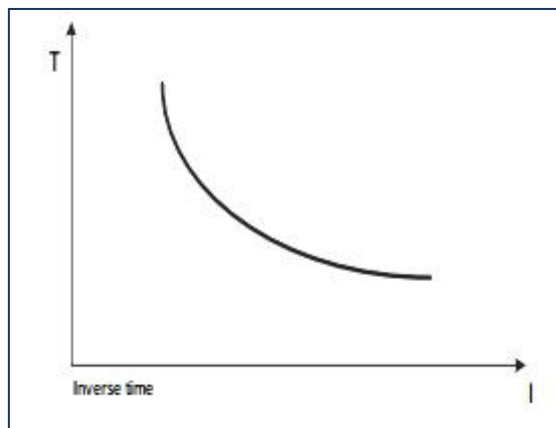


Figure 31 : Inverse time overcurrent relay Curve

4. Inverse time with instantaneous unit

Inverse time with instantaneous unit" refers to an advanced type of overcurrent relay used in electrical protection systems. This relay combines the characteristics of both inverse-time and instantaneous overcurrent relays into a single device.

The "inverse-time" aspect of this relay means that its tripping time decreases as the magnitude of the fault current increases. This ensures rapid response to severe faults, as the relay trips faster for higher levels of fault current.

Additionally, the relay features an "instantaneous unit," allowing it to trip instantaneously when the current exceeds a predetermined threshold, regardless of the fault current magnitude. This instantaneous tripping capability provides swift and decisive protection against short circuits and other critical fault conditions.

By integrating both inverse-time and instantaneous tripping capabilities, the inverse time with instantaneous unit relay offers enhanced versatility and flexibility in safeguarding electrical systems against a wide range of fault scenarios, thereby ensuring system reliability and safety.

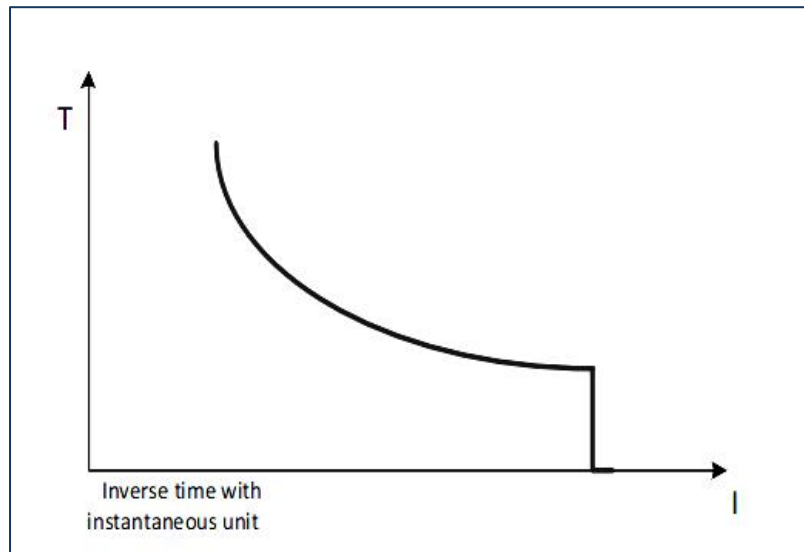


Figure 32 : Inverse time & Instantaneous overcurrent relay curve

The characteristics curves of these types, the horizontal axis (I) is the current and the vertical axis (T) is the time, t_1 is the tripping time when the current reaches the pick-up value[44]. Additionally, the combination of an instantaneous with inverse time characteristic is also illustrated.

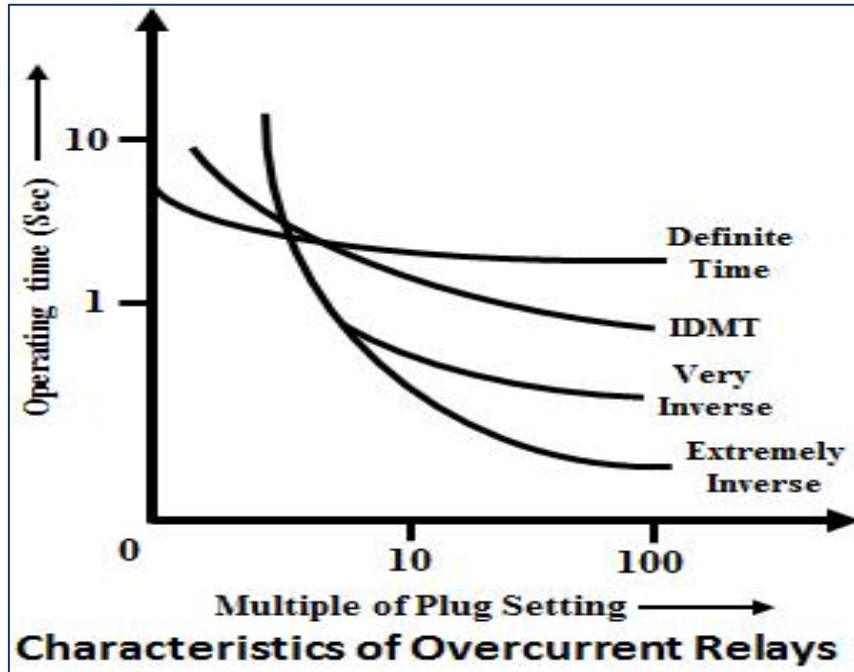


Figure 33 characteristics of overcurrent relays

II. 8. Operating Principles of Electrical Network Protection

The operating principles of electrical network protection revolve around the timely detection, selective isolation, and rapid clearance of faults or abnormalities within the system. Protection devices, such as relays, circuit breakers, and fuses, are strategically deployed throughout the network to monitor electrical parameters and respond appropriately to deviations from normal operating conditions.

1. Sensing and Detection

Protection devices continuously monitor electrical parameters, such as voltage, current, and frequency, to detect anomalies indicative of faults or disturbances[45].

2. Decision Making

Upon detecting a fault, protection devices analyze the measured parameters and determine the appropriate response based on predefined settings and logic algorithms.

3. Selective Operation

Protection systems are designed to selectively isolate the affected portion of the network while maintaining the continuity of power supply to unaffected areas. This ensures that only the faulty equipment or section of the network is disconnected, minimizing the impact on system performance[46].

4. Coordination

Protection devices are coordinated to operate in a predetermined sequence, with primary protection acting first to isolate faults close to their origin, followed by backup protection devices to provide

additional layers of defense [23].

5. Speed

Protection systems are engineered for rapid response, with trip times measured in milliseconds to minimize the duration of fault-induced disruptions and prevent cascading failures[47].

II.9.Coordination of overcurrent relay

Relay coordination is an integral part of overall system protection and is required to isolate only the faulty circuit of the network. This can be achieved by current graded systems, time graded systems, or a combination of the two. This paper adopts an Inverse Time Definite Minimum Characteristics Relay (**IDMT**) for the coordination of the overcurrent relays with very inverse, extremely inverse, and standard inverse characteristics[46]. The operation time relay can be determined according to the following procedure[48]:

The relay current I_R is determined as:

$$I_R = \frac{I_f}{I_{CT}} \quad (1)$$

Where

I_f is the expected fault current

While

I_{CT} is the current transformer ratio.

The relay pickup current I_P is calculated as:

$$I_P = P_{setting} \times I_{SCT} \quad (2)$$

Where

$P_{setting}$ is the plug setting

While

I_{SCT} is the rated secondary current of CT.

The **PSM** is calculated as:

$$PSM = \frac{I_R}{I_P} \quad (3)$$

The relay operating time is calculated as:

$$T = TSM \left[\frac{A}{PSM^\infty + B} \right] \quad (4)$$

Where

A is a constant whose value can be **0.14**, **13.5**, or **80**,

B is a constant and is equal to **-1**,

And ∞ is a constant that varies from **0.02** to **2**.

K is a TSM that varies from 0.1 at an incremental step of **0.1** to **1**.

The following relay characteristics are used in this work, i.e.:

$$T = TSM \left[\frac{0.14}{PSM^{0.02} + 1} \right] \quad (5)$$

The protection constraints, selective and limit constraints are presented respectively as:

$$T_{backup} - T_{main} \geq CTI \quad (6)$$

$$TSM_{min} \leq TSM \leq TSM_{max} \quad (7)$$

$$I_{p\ min} \leq I \leq I_{p\ max} \quad (8)$$

Where

T_{backup} and T_{main} are the backup and main operation times of the overcurrent relay, respectively.

CTI is the coordination time interval between the primary and backup relays.

TSM_{min} and TSM_{max} , $I_{p\ min}$ and $I_{p\ max}$ are the minimum and maximum limits of TSM and pickup current I_p , respectively.

The limit constraints are the range of relay settings from which feasible solutions are encountered and the CTI value lies between **0.2** and **0.5** second.

Therefore, other constraints should be considered on the limits of relay parameters TSM and I_p .

II.10. Conclusion

Effective protection and coordination of OCR in power systems with DG are crucial for grid stability. Utilizing advanced devices like relays, circuit breakers, and fuses ensures the swift detection and isolation of faults, maintaining electricity delivery and system safety. Proper settings and relay coordination optimize protection schemes, enhancing efficiency and stability. These measures support critical infrastructure and economic development, meeting the demands and challenges of modern electrical networks.

**CHAPTER III: Design and Simulation of Grid-
Connected PV System for the Tamsa power plant
using ETAP Software**

III.1. Introduction

Electrical network protection is essential for safeguarding power systems from various faults and disturbances[37]. This chapter outlines the primary objectives of protection systems, which include ensuring the safety of personnel and equipment, maintaining power supply reliability, and minimizing damage and downtime. We discuss the basic elements of a protection system, such as protective relays[49], circuit breakers, and fuses, and their roles in detecting and isolating faults[50]. Additionally, the chapter covers the classification of protection relays, the significance of measurement transformers, and the different types of faults that can occur in electrical networks. Special emphasis is placed on the coordination of overcurrent relays (OCR)[51].

III.2. Study Procedure of protection & coordination



Figure 34 : Study Procedure of protection & coordination

The Protection Procedure and Coordination Study in ETAP (Electrical Transient Analyzer Program) involves several key steps:

1. Modeling the Electrical System:

Single Line Diagram (SLD):

Create a detailed single line diagram of the electrical network, including all components such as generators, transformers, transmission lines, buses, loads, and protection devices.

Component Data:

Input all necessary data for each component, including ratings, impedances, and operational characteristics.

2. Setting Up Protection Devices:

Protective Relays:

Add protective relays to the system and configure their settings. This includes overcurrent relays, differential relays, distance relays, etc.

Fuses and Circuit Breakers:

Define the characteristics and settings for fuses and circuit breakers.

3. Short Circuit Analysis:

Fault Scenarios:

Simulate various fault conditions, such as three-phase faults, line-to-line faults, line-to-ground faults, and double line-to-ground faults.

Calculation:

Perform short circuit analysis to determine fault currents at different points in the network.

4. Protection Coordination:

Time-Current Curves (TCC):

Plot the time-current characteristics of protective devices to ensure they operate correctly under fault conditions. The goal is to ensure selectivity, meaning the device closest to the fault operates first.

Coordination Study:

Adjust the settings of protective relays and other devices to achieve optimal coordination. This involves setting time delays, pickup currents, and other parameters to ensure proper sequencing of device operation.

5. Verification and Validation:

Simulation:

Run simulations to verify that the protection scheme works as intended. This includes testing different fault conditions and ensuring that the protection devices operate correctly and in the right sequence.

Reporting:

Generate detailed reports that document the protection settings, coordination study results, and any recommendations for adjustments.

Detailed Steps in ETAP:

a) System Modeling:

- Use the ETAP interface to draw the single line diagram of the electrical system.

- Input data for all electrical components, including their electrical parameters and operational limits.

b) Protection Device Setup:

- Select protection devices from ETAP's extensive library.

- Configure device settings based on manufacturer specifications and protection requirements.

c) Short Circuit Analysis:

- Navigate to the Short Circuit Analysis module in ETAP.

- Define fault scenarios and run the analysis to calculate fault currents.

d) Time-Current Curves (TCC):

Access the TCC module to plot the characteristics of all protection devices.

Analyze the TCC plots to identify any miscoordination or overlap.

e) Coordination Study:

Adjust settings of protection devices to eliminate miscoordination.

Use ETAP's coordination tools to fine-tune device settings and ensure selectivity.

f) Simulation and Verification:

Simulate various fault conditions to verify the protection scheme.

Ensure that the correct devices operate within the appropriate time frames.

g) Reporting:

Generate comprehensive reports from ETAP that include all analysis results, settings, and coordination findings.

Review and document any recommendations for changes or improvements.

III.3. Protection & Coordination / Selectivity Analysis

Time-Current Characteristic curve selectivity analysis may be done in an easy-to-understand and rational manner with the help of ETAP Star™ overcurrent device protection and coordination assessment software[48].

ETAP Star provides information on how to resolve miscoordination, erroneous trips, and relay malfunctions.

- Time-Current Characteristic (TCC) Curve
- Protective Device Coordination & Selectivity
- Sequence-of-Operation
- Protection Zone Selection & Viewer

- Automated Protection & Coordination
- Zone Selective Interlock Scheme
- Protective Device Design Assessment
- Verified & Validated Protective Device Libraries

III.4. Sequence of operation

Sequence-of-functioning (SQOP) software uses normalized Time Current Characteristic Curve (TCC) views and the one-line diagram to assess, validate, and check the selectivity and functioning of the protective devices for different kinds of failures at any site.

For an accurate and realistic working time and condition of protective devices, such as relays, fuses, circuit breakers, trip devices, contactors, etc., sequence-of-operation offers a system-wide solution[50]. Every protective device's operating time is determined by taking into account its settings, time current characteristic, and interlocks for a given fault location and kind[52].

3-Phase (Symmetrical) fault on connector between SW1 & Pump1. Adjacent bus: Bus4

Data Rev.: Rev Config: Normal Date: 07-08-2016

Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
10.0	Fuse1	27.689	< 10.0		
15.0	CB-D1	27.689	1.0	15.0	
65.0	CB-C11	27.584	10.0	65.0	Phase
644	REL-BC	3.143	644		Phase - OC1 - 51
727	CB- \times FMR-BC		83.3		Tripped by REL-BC Phase - OC1 - 51
23682	CB-A	0.106	7475	23682	
40185	CB-P2	0.527	20741	40185	Phase
41127	CB-B	0.174	11257	41127	
151825	REL-B	3.143	151825		Phase - OC1 - 51
151909	CB-REL-B		83.3		Tripped by REL-B Phase - OC1 - 51
288000	CB-D2	0.7	211845	> 288000	Phase
669951	REL-A	0.523	> 669951		Phase - OC1 - 51
670035	CB-Gen1		83.3		Tripped by REL-A Phase - OC1 - 51

Figure 35 : protective-device-sequence-of-operation-view

III.4.1. Star - Sequence-of-Operation Key Features

- Graphically drag & drop faults on the one-line diagram
- Coordination via one-line diagram

- View device operation sequence graphically
- Device failure & backup operation
- Detailed relay actions (27, 49, 50, 51, 51V, 59, 67, 79, 87)
- Current summation
- Normalized (shifted) Time Current Characteristic Curves
- Phase & Ground faults (symmetrical & asymmetrical)
- Flashing protective device via the one-line diagram
- Sequence of event viewer

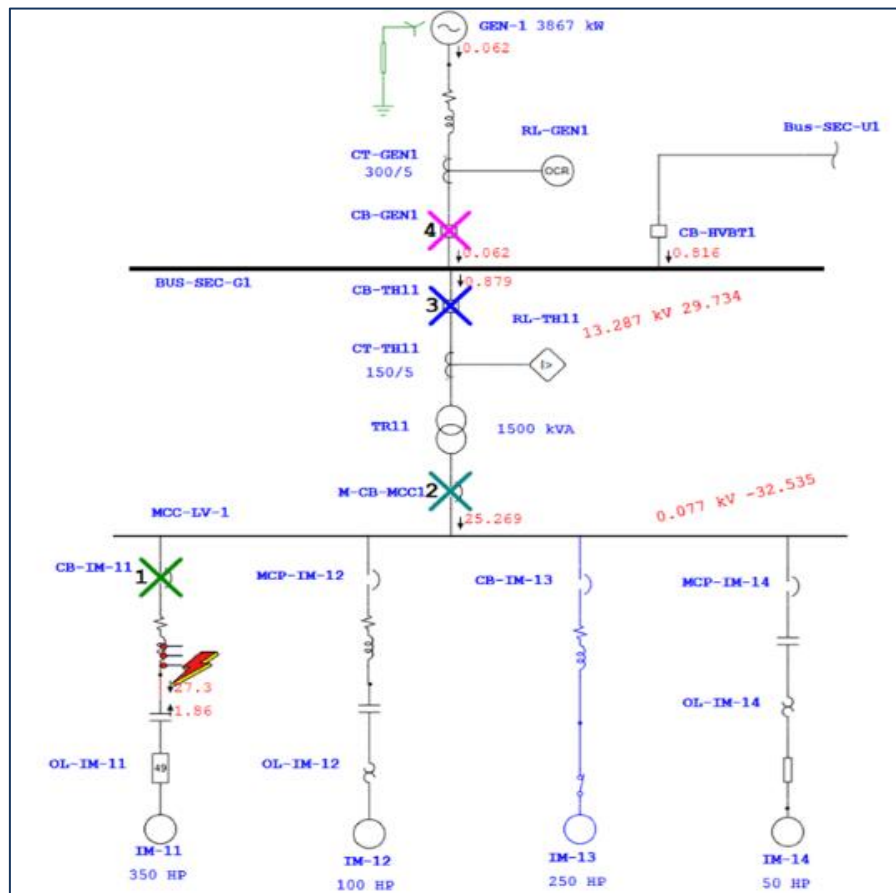


Figure 36 : protective-device-sequence-of-operation-software

III.5. Protection Zone & Path Detection

With the use of automated path detection technologies, ETAP Star may rapidly determine which paths need to be selected in order to confirm or build protection or coordination within the electrical network.

With a single button click, the user may create protective time current characteristic (TCC) curves for the chosen region. This tool also automatically recognizes and tags the items inside conventional zones of protection.

Protection Zone Viewer enables for the sorting and filtering of different zone types and shows the associated protection and selectivity routes for the elements selected on the one-line:

- Branch Zones
- Bus Zones
- Load Zones
- Source Zones

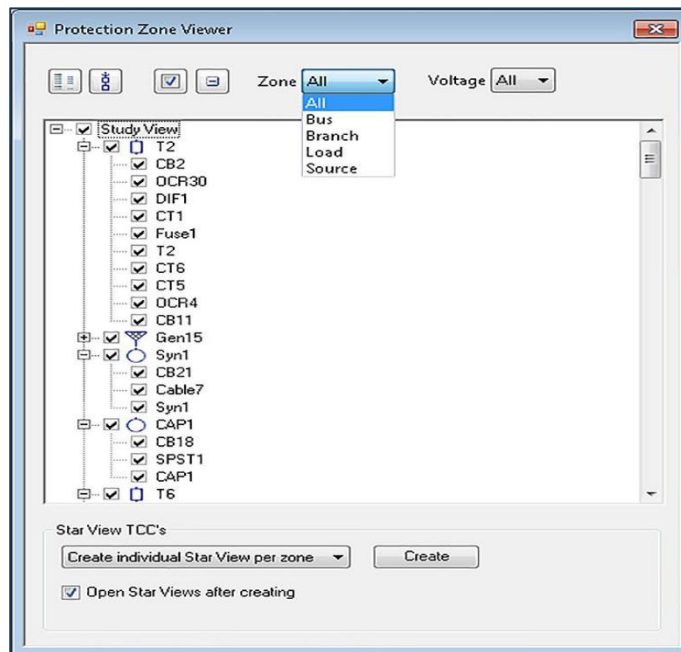


Figure 37 : Protection Zone viewer

III.6. Path Detection Tool

A simple method for automatically defining and identifying a coordination/selectivity and protection path is offered by path detection tools. To find the path, each path selection tool necessitates the selection of certain parts. On the OLV, you may choose between AC 3-phase and 1-phase components. Among the tools for path detection are:

- Extend to nearest source - Once an element is clicked, automatic path detection will extend the selected element to the nearest source
- Shortest connecting path - Selects or highlights the shortest path between two elements
- Extend path by bus level - Path shall be extended by a pre-defined number of bus levels in all directions.

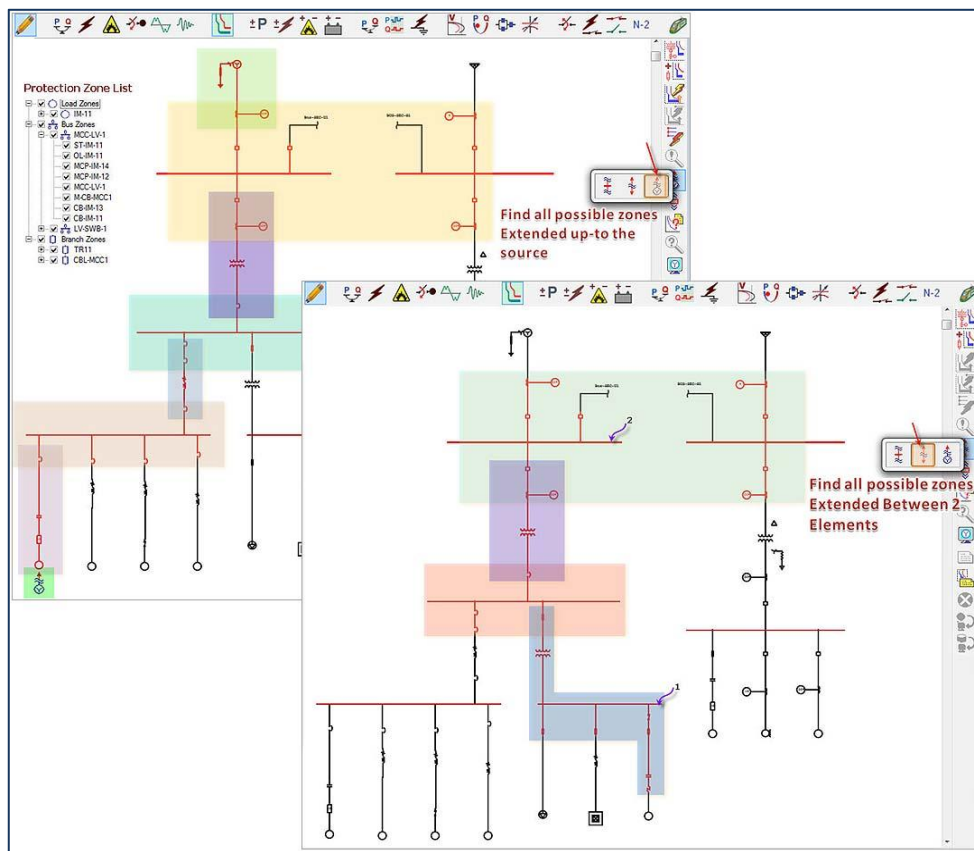


Figure 38 : Selectivity zone path detection

III.7. Tamsa 220MW power plant designed on etap software

This section outlines the design process required for integrating a 220 MW solar PV power system into an existing grid. The design is centered on the generated power capacity of 220 MW, and involves stepping up the voltage from the initial generated voltage of 0.315 kV to 60 kV. The process is divided into two phases:

Beginning Phase: 220 step-up distribution transformers, each with a capacity of 1 MVA, are used to increase the voltage from 0.315 kV to 30 kV.

Ending phase: 11 step-up power transformer with a **20 MVA** rating is then used to further increase the voltage from **30 kV** to **60 kV**.

At Tamsa Main Substation, the output voltage from the power transformer is synchronized with the national grid. To achieve the total power output of 220 MW, the system will utilize 220 PV arrays, with each array generating 1 MW of power.

III.8. System Diagram of the Tamsa Photovoltaic Power Plant Utilizing ETAP

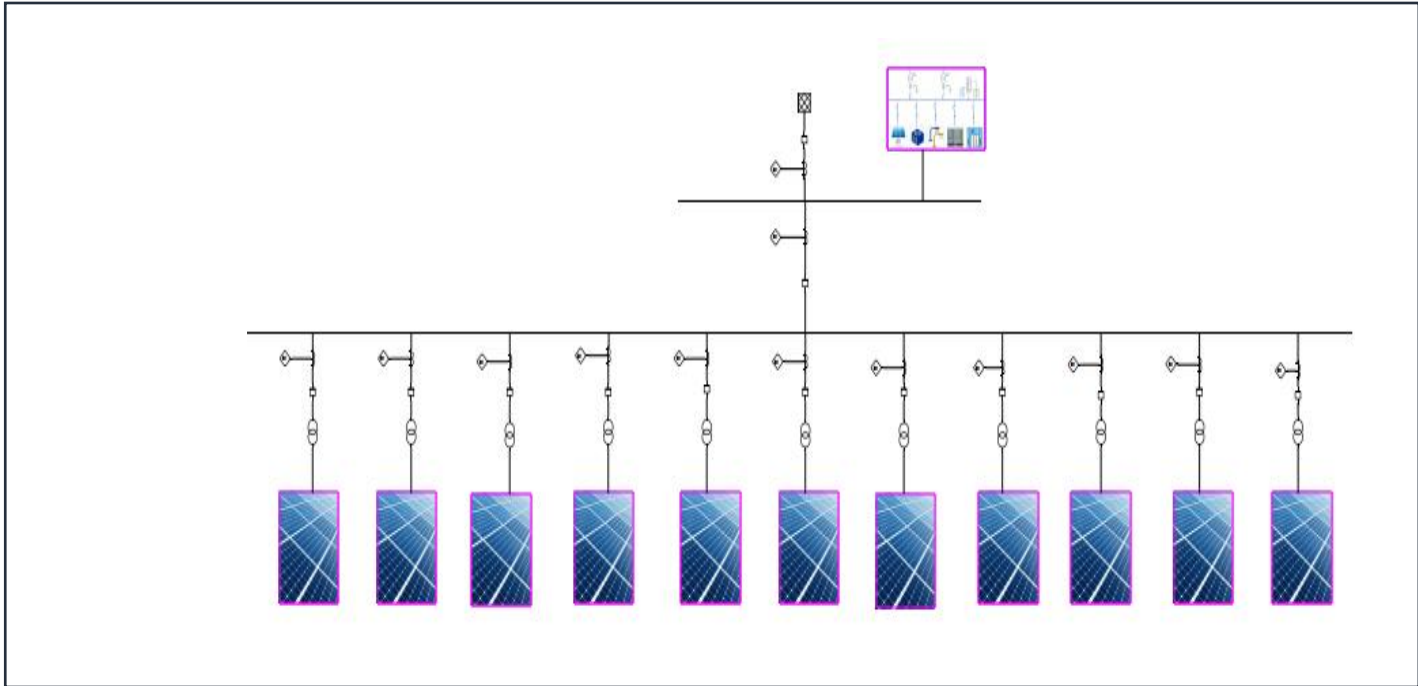


Figure 39 : System Diagram of the Tamsa Photovoltaic Power Plant Utilizing ETAP

III.9. Input Data for Tamsa Photovoltaic Plant Equipment

III.9.1 Modeling of PV Arrays and Solar Panels

You can import current data from the Library page with the available PV array manufacturers on this page. And deliver the simulation's data. The user-configurable ETAP Photovoltaic Library defines photovoltaic characteristics, such as P-V and I-V curves, or specifies the maximum peak power voltage (V_{mpp}), maximum peak power current (I_{mpp}), open circuit voltage (V_{oc}), and short circuit current (I_{sc}).

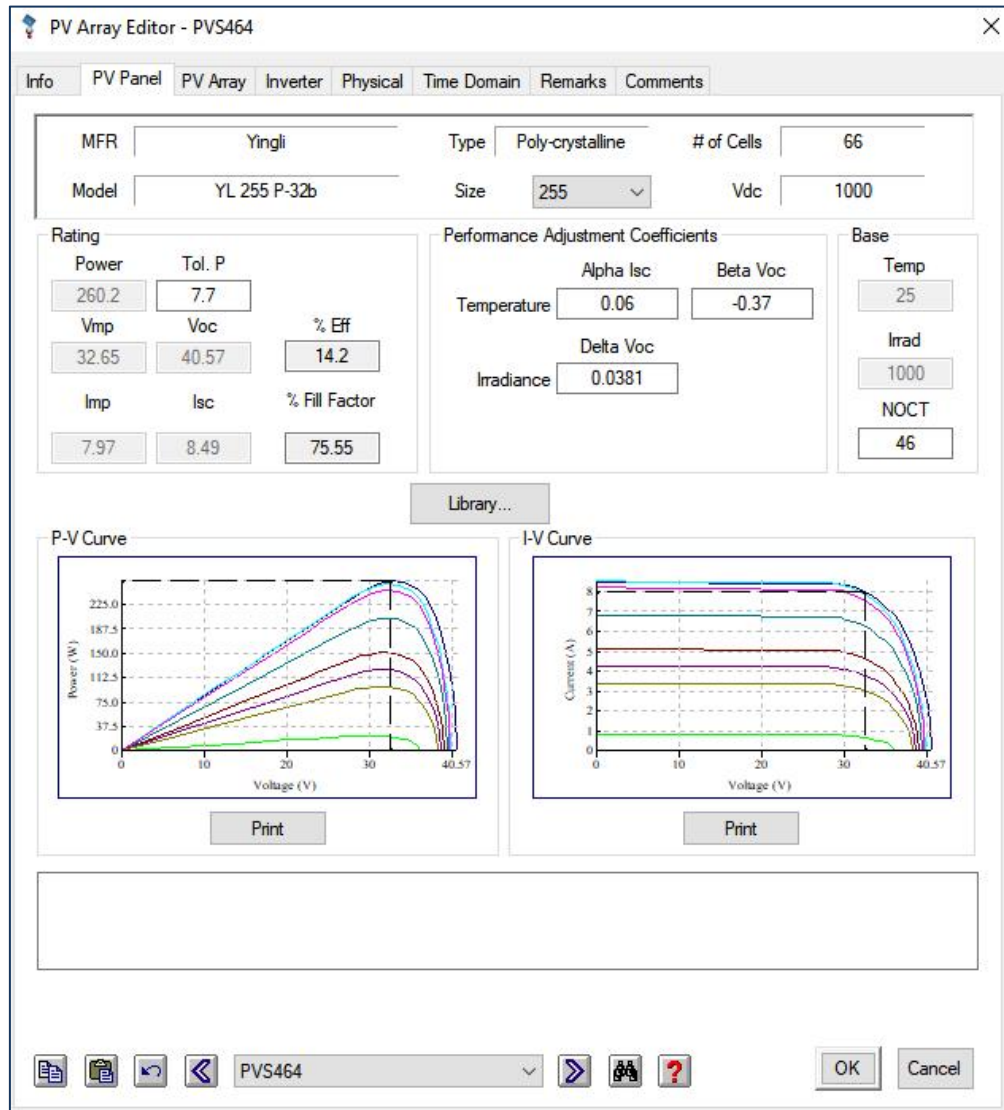


Figure 40 : PV Panel configuration

III.9.2. PV Array Configuration Tool

The user is provided with the opportunity on this page to input the quantity of PV panels that are linked both in series and parallel. Subsequently, the total number of panels is displayed after the calculation is performed. The voltage in Volts is determined by the number of panels connected in series,

While the current in Amps is determined by the number of panels connected in parallel. The user has the ability to input the ambient temperature T_a in degrees Celsius, which is then used to calculate the total DC power in kW.

This calculation takes into account the configuration of the PV array, including the number of panels in series and parallel.

When the irradiance and ambient temperature T_a are altered, the cell temperature T_c is reevaluated. It is important to note that as the T_c increases, the efficiency and power output from the panel decrease.

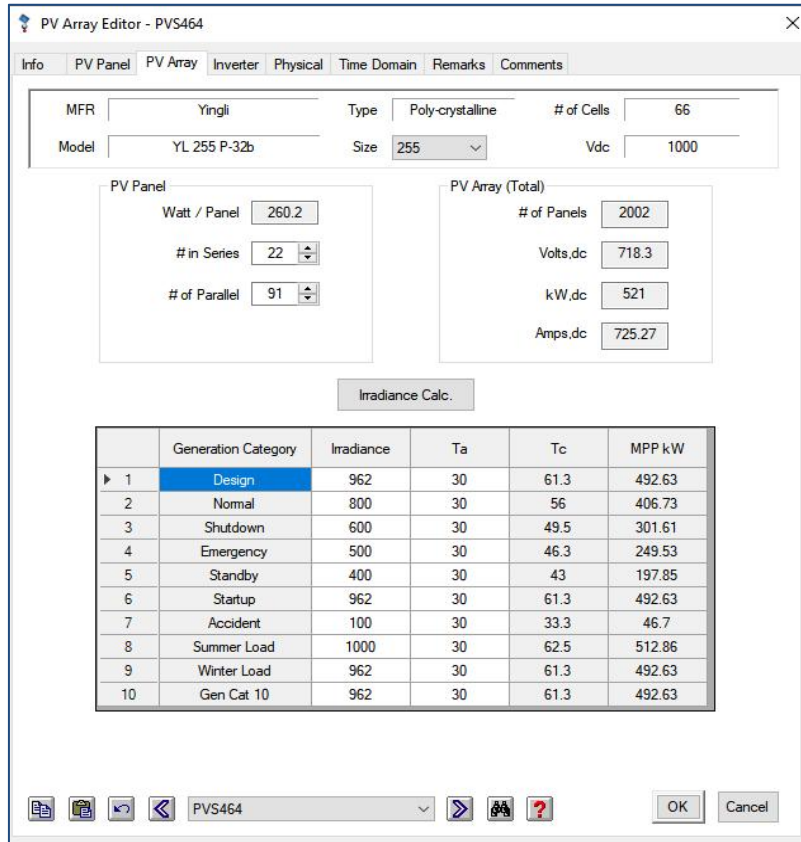


Figure 41 : PV Array configuration

III.9.3. Irradiance Calculator of PV array

Solar Irradiance calculator Photovoltaic Array elements have a built-in calculator that calculates the solar irradiance that is incident on a location, this is especially helpful when designing or estimating the power output from the panels without knowledge of the entire network. The calculator will deduce the theoretical intensity (the direct component of light) in W/m^2 from the user's specified location information (Latitude, Longitude, date, and Time Zone, and Local Time). All calculations are performed at the sea level (Declination, Solar Altitude, Solar Azimuth, Solar Time, Sunrise, Sunset, Air Mass, and Irradiance).

The screenshot shows the 'Irradiance Calculator' window with the following configuration:

Section	Parameter	Value	Unit
Location Information	Latitude	35.2	°
	Longitude	3.9	°
	Time Zone	(UTC+01:00) West Central Africa	
	Local Time	18:21:44	
	Date	2024-05-18	
Calculation	Declination	19.594	°
	Equation of Time	3.837	Minutes
	Solar Altitude	8.11	°
	Solar Azimuth	70.2	°
	Solar Time	17:25	Hours
	Sunrise	06:52	Hours
	Sunset	18:59	Hours
	Air Mass (AM)	6.699	
	Irradiance (W/m ²)	365	
	Buttons: Update Selected, Update All, Cancel		

Figure 42 : Irradiance Calculator configuration

III.9.4. Inverter Configuration Tool

We can define the inverter's capabilities, the short-circuit current that occurs in the AC system, and the AC grounding parameter on this page. We transition into the DC Rating regime (kW, FLA, V_{max} , V_{min}) and the AC Rating regime (kVA, kV, FLA, %PF, K).

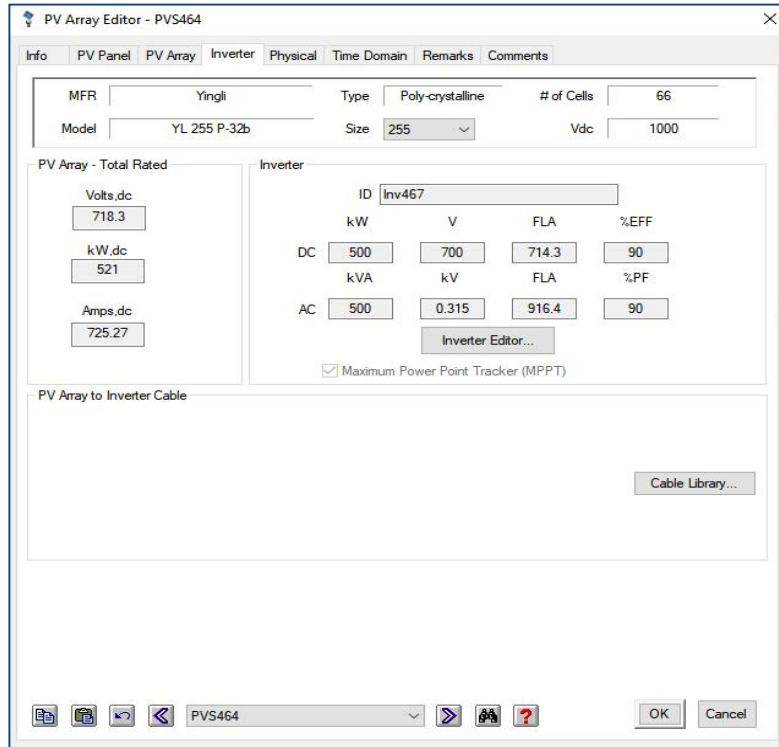


Figure 43 : Inverter configuration

III.9.4.1. Inverter Configuration Tool rating page

We can define the inverter’s capabilities, the short-circuit current that occurs in the AC system, and the AC grounding parameter on this page. We transition into the DC Rating regime (kW, FLA, V_{max} , V_{min}) and the AC Rating regime (kVA, kV, FLA, %PF, K).

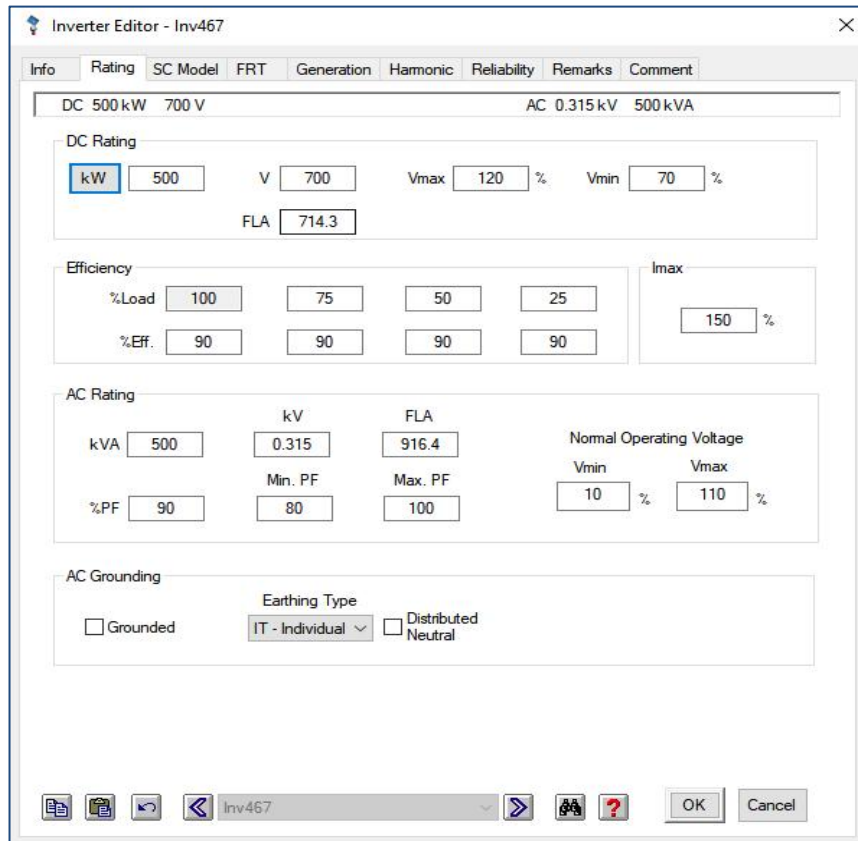


Figure 44 Inverter Configuration Tool rating page

III.9.5. Two Winding Transformer configuration tool

Rating Page - 2-Winding Transformer author On the Rating page, we describe the 2-winding transformer's capacity (prim and sec), and we input primary and secondary voltage and power amounts. We choose the type of transformer from the List of Types box. The following types of transformers are available for both ANSI and IEC standards (Liquid-Fill or Dry).

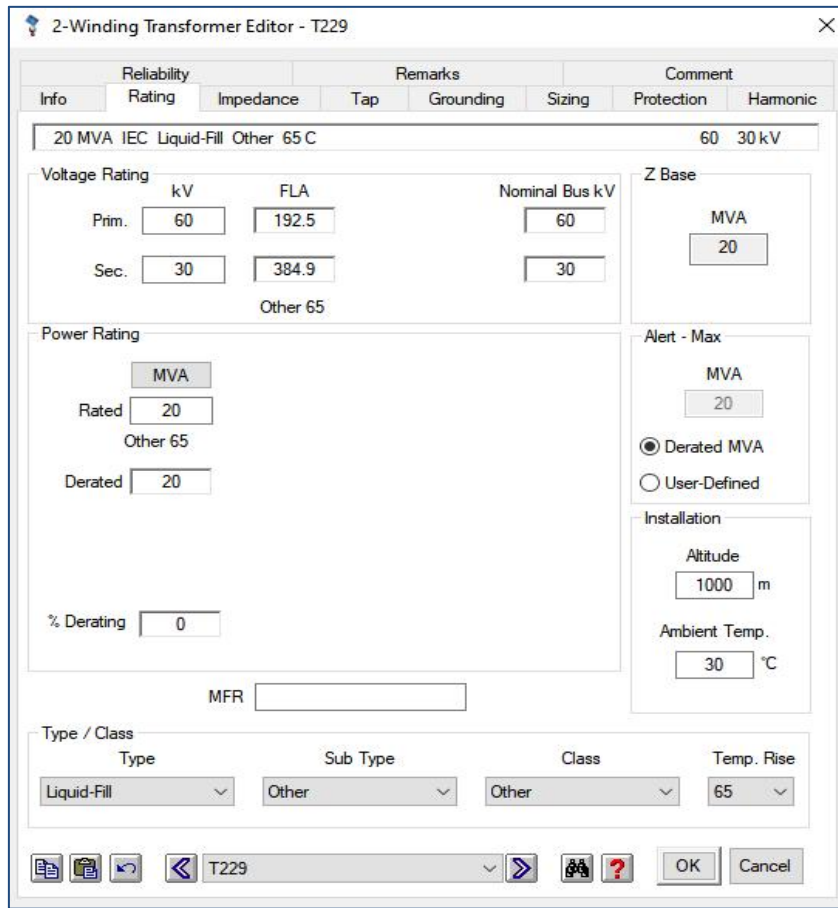


Figure 45 : 2 Winding transformer configuration

III.9.6. Three Winding Transformer configuration tool

In this page, we explore the primary, secondary, and tertiary voltage and the MVA or kVA capacity of the 3-winding transformer. ETAP employs the voltage at the lowest number of swing system as the starting voltage, and calculates the other starting voltages using the transformer ratios. ETAP produces a message that error when it detects a lack of consistency in the voltage bases of parallel or looped systems during the analysis of the system. The Max MVA Capability values, which are used to calculate the percentage of overloading of the transformer's windings, are also used as a foundation for the calculation of the transformer's flow limit in the optimal power flow studies.

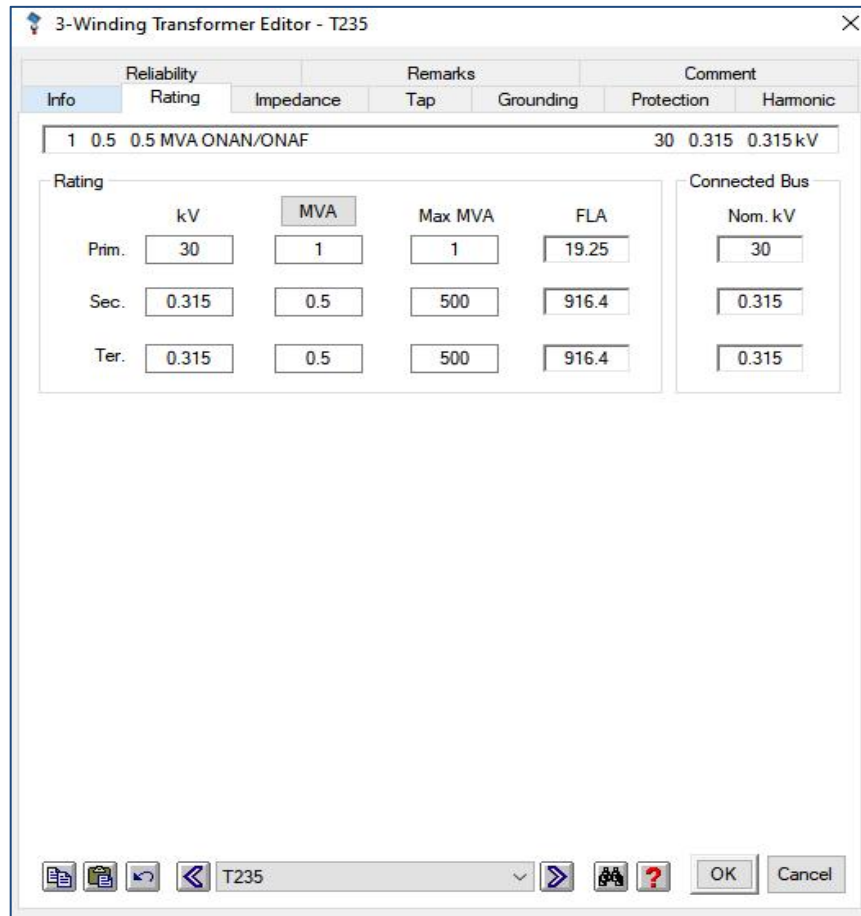


Figure 46 : Three Winding transformer configuration

III.10. Conclusion

The design and simulation of the grid-connected PV system for the Tamsa grid using ETAP software highlight the effectiveness of advanced tools in electrical network protection and coordination. The study outlines the crucial steps and components involved in integrating a 220 MW solar power system, emphasizing the importance of protection systems and the coordination of overcurrent relays. The simulation covers various aspects, from PV array configuration to load flow and short circuit analyses. Overall, the project demonstrates the comprehensive capabilities of ETAP in ensuring efficient and reliable power system integration and operation. In the next chapter, we will see more details and results on this.

**Chapter IV: Coordination of Overcurrent Relays in
Power System Networks**

IV.1. Introduction

In the last part of our project making a comparison study of different categories (design, normal, summer load, emergency shown on the table 1 below) of our system power plant to learn more about the reliability and the quality of this central, by creating some faults as three phase and line to line fault in different bus bars. Then we will obtained results of simulation and protection reports.

IV.2. Simulation and Results

This section outlines the simulations that will be performed using ETAP software, likely to analyze load flow and short circuit conditions.

Types of simulations mentioned include Load Flow Analysis – Short circuit analysis in different voltage levels.

Short Circuit Analysis - 3-Phase and Line-to-Line Faults at different power levels (220MW, 20MW, 5MW)

Table 1 Irradiance and Temperature of generation categorys

Generation category	Irradiance (W/m²)	Temperature (°C)
Design	962	61,3
Normal	800	56
Summer load	1000	62,5
Emergency	500	46,2

For good coordination and avoidance of errors,the chosen relays are kind of ABB-REF 630 - IDMT (normal or standard inverse (SI) curve).In the table below shows us the different values taken for Time Dial and pick up current at each Relay :

Table 2 Data input of each relay

Relays	Time Dial (s)	Pick up cutternt (A)
1	1.4	49
6	1.75	56
8	1.58	42
90	1.78	42
89	1.36	275

The simulation of different faults is depicted in figures (47, 48 and 49)

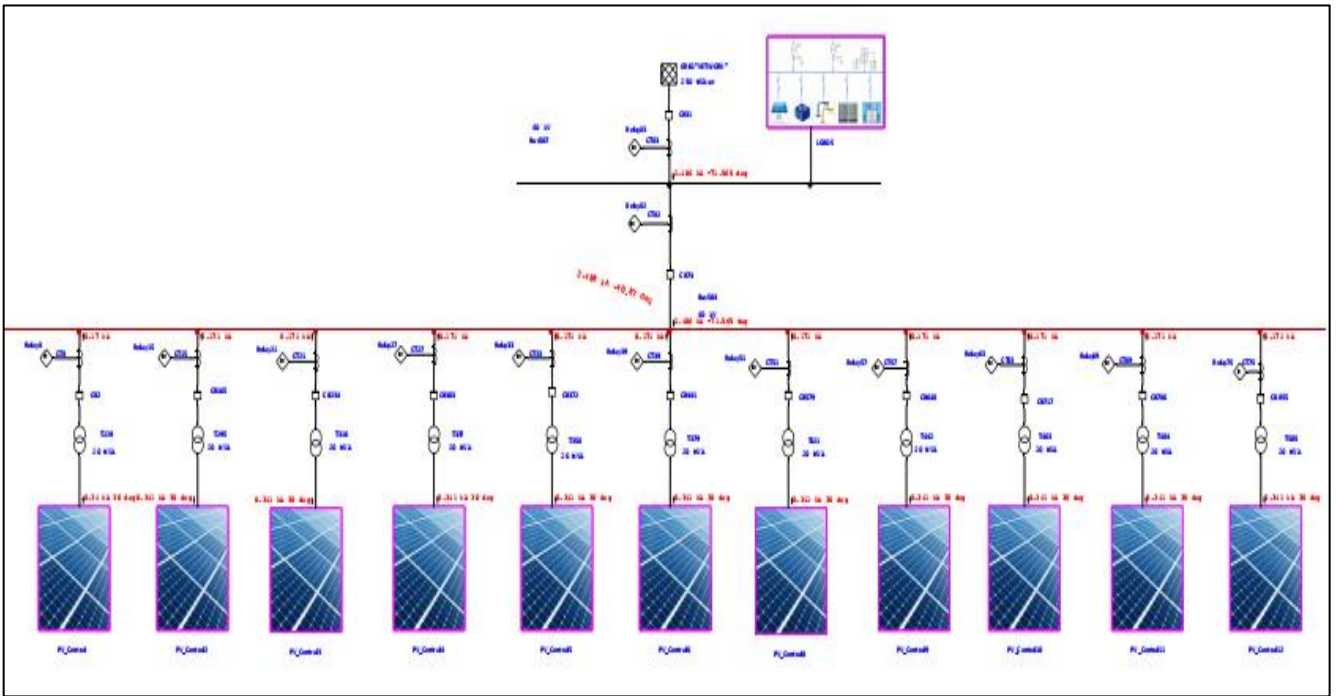


Figure 47 Fault created at Bus Bar 504

This is the main bus bar which is connect the photovoltaic central 220MW with the grid 60kV and loads.

In the inside of each substation we have 20MW, broken on 4 substations as shown in the figure below

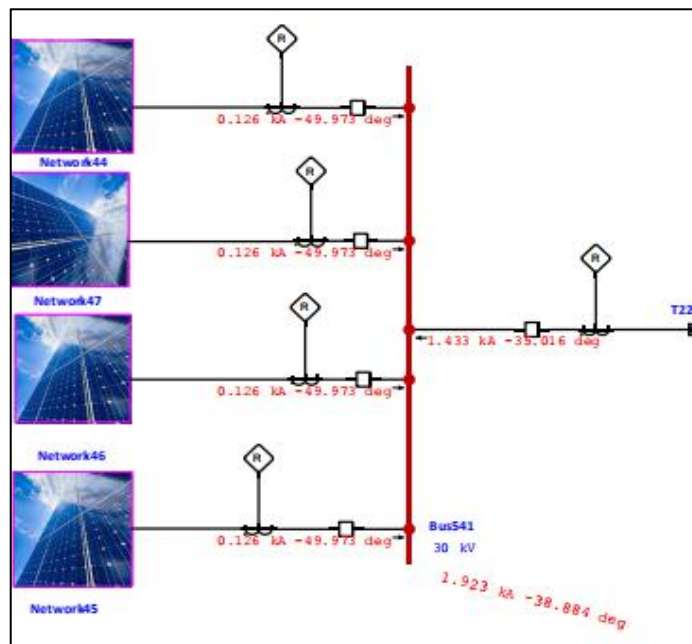


Figure 48 Fault created at Bus Bar 541

And each one from those 4 substations has in the inside 5MW , which is obtained from 10 PV pannels.

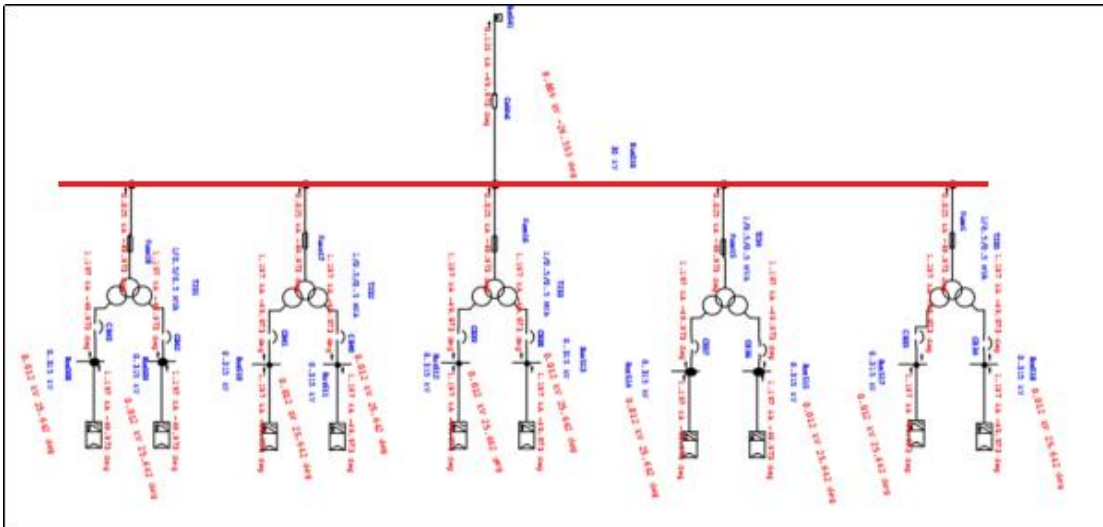


Figure 49 Fault creates at Bus Bar 516

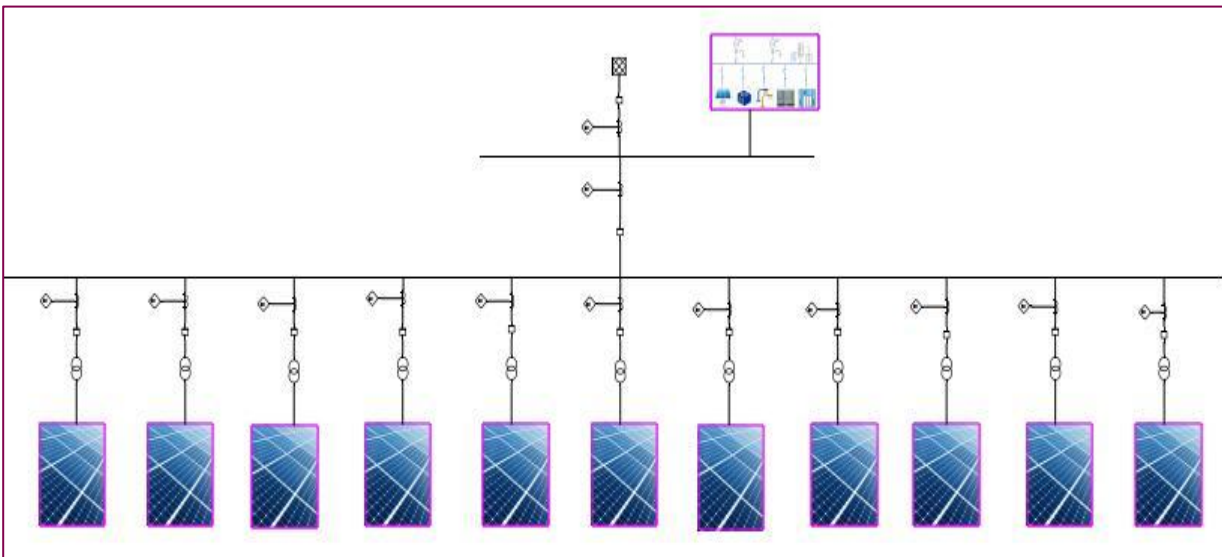


Figure 50 Bus Bar 504

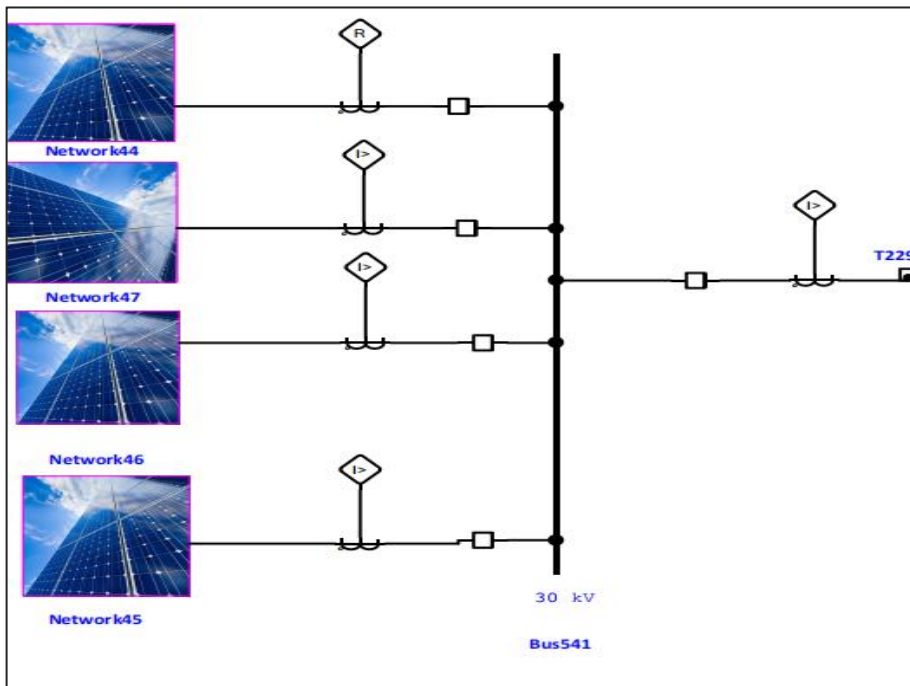


Figure 51 Bus Bar 541

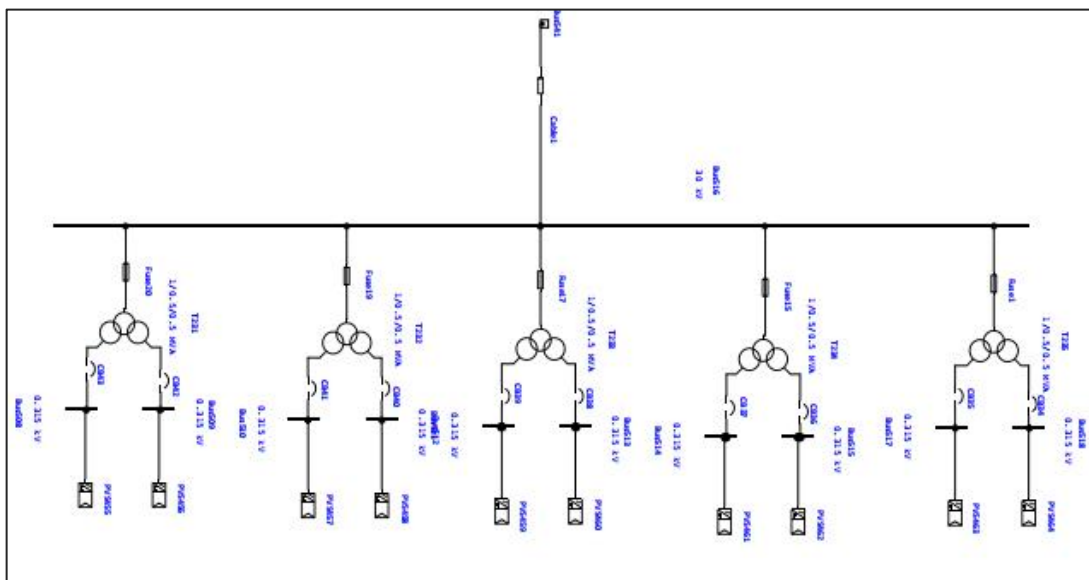


Figure 52 Bus Bar 516

Table 3 Generation Category Characteristics

No of Characteristic	Category Type
1	Design category
2	Normal category
3	Summer load category
4	Emergency category

Case 1 : Design category

Table 4 Load current and Pick up current in Design category

Relay	Load Current	Pick up Current	CT ratio
1	84.9	106.125	100/1
6	339.7	424.625	400/1
8	169.8	212.25	200/1
89	1695	2118.75	200/1
90	1868	2335	250/1

➤ **Three Phase Fault**

Table 5 Three phase fault at bus 516 in design category

Main Relay	Backup Relay	Main relay SC Fault at Bus 516 (A)	Backup relay SC Fault at Bus 516 (A)
1	6	2284	2284

Table 6 Three phase fault at bus 541 in design category

Main Relay	Backup Relay	Main relay SC Fault at Bus 541 (A)	Backup relay SC Fault at Bus 541 (A)
6	8	2290	1145

Table 7 Three phase fault at bus 504 in design category

Main Relay	Backup Relay	Main relay SC Fault at Bus 504 (A)	Backup relay SC Fault at Bus 504 (A)
90	89	2406	2406

Phase Fault Analysis the results for the design category indicate that all relays respond appropriately to three phase faults. The fault currents at different buses are consistent with the expected design values, ensuring the system's robustness under ideal conditions.

➤ L-L Fault

Table 8 Line-Line fault at bus 516 in design category

Main Relay	Backup Relay	Main relay SC Fault at Bus 516 (A)			Backup relay SC Fault at Bus 516 (A)		
		Sequences	Pve	zero	Nve	Pve	zero
1	6	1141	0	1143	1141	0	1143

Table 9 Line-Line fault at bus 541 in design category

Main Relay	Backup Relay	Main relay SC Fault at Bus 541 (A)			Backup relay SC Fault at Bus 541 (A)		
		Sequences	Pve	zero	Nve	Pve	zero
6	8	1144	0	1146	572	0	573

Table 10 Line-Line fault at bus 504 in design category

Main Relay	Backup Relay	Main relay SC Fault at Bus 504 (A)			Backup relay SC Fault at Bus 504 (A)		
		Pve	zero	Nve	Pve	zero	Nve
90	89	1202	0	1204	1202	0	1204

Line-to-Line Fault Analysis In the design category, line-to-line fault currents are within safe limits, demonstrating the system's ability to handle such faults efficiently. The positive, negative, and zero sequence currents indicate balanced fault management.

Case 2: Normal category

Table 11 load current and pick up current in normal category

Relay	Load Current	Pick up Current	CT ratio
1	70.1	87.62	100/1
6	280.4	350.5	400/1
8	140.2	175.25	200/1
89	1368	1710	200/1
90	1542	1927.5	250/1

➤ **Three phase Fault**

Table 12 Three phase fault at bus 516 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 516 (A)	Backup relay SC Fault at Bus 516 (A)
1	6	2284	2284

Table 13 Three pahse fault at bus 541 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 541 (A)	Backup relay SC Fault at Bus 541 (A)
6	8	2290	1145

Table 14 Three pahse fault at bus 504 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 504 (A)	Backup relay SC Fault at Bus 504 (A)
90	89	2406	2406

Three phase Fault Analysis for the normal operating conditions, the system shows reliable performance with all relays activating as required. The fault currents are slightly higher than in the design category, reflecting real-world conditions but still within acceptable limits.

➤ **L-L Fault**

Table 15 Line-Line fault at bus 516 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 516 (A)			Backup relay SC Fault at Bus 516 (A)		
		Pve	zero	Nve	Pve	zero	Nve
1	6	1141	0	1143	1141	0	1143

Table 16 Line-Line fault at bus 541 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 541 (A)			Backup relay SC Fault at Bus 541 (A)		
		Pve	zero	Nve	Pve	zero	Nve
6	8	1144	0	1146	572	0	573

Table 17 Line-Line fault at bus 504 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 504 (A)			Backup relay SC Fault at Bus 504 (A)		
		Pve	zero	Nve	Pve	zero	Nve
90	89	1202	0	1204	1202	0	1204

The line-to-line fault analysis under normal conditions reveals stable performance with manageable fault currents. The sequence currents are well within the thresholds, indicating effective fault isolation and minimal impact on system stability.

Case 3: summer load category

Table 18 load current and pick up current in Summer Load category

Relay	Load Current	Pick up Current	CT ratio
1	88.4	110.5	100/1
6	353.7	442.125	400/1
8	176.8	219.75	200/1
89	1945	2431.25	200/1
90	1945	2431.25	250/1

➤ **Three Phase Fault**

Table 19 Three pahse fault at bus 516 in Summer Load category

Main Relay	Backup Relay	Main relay SC Fault at Bus 516 (A)	Backup relay SC Fault at Bus 516 (A)
1	6	2284	2284

Table 20 Three pahse fault at bus 541 in Summer Load category

Main Relay	Backup Relay	Main relay SC Fault at Bus 541 (A)	Backup relay SC Fault at Bus 541 (A)
6	8	2290	1145

Table 21 Three pahse fault at bus 504 in Summer Load category

Main Relay	Backup Relay	Main relay SC Fault at Bus 504 (A)	Backup relay SC Fault at Bus 504 (A)
90	89	2406	2406

Three Phase Fault Analysis During peak summer load, the fault currents are higher due to increased load demand. However, the relays operate correctly, ensuring that faults are cleared quickly. This indicates the system's resilience even under high load conditions.

➤ L-L Fault

Table 22 Line-Line fault at bus 516 in Summer Load category

Main Relay	Backup Relay	Main relay SC Fault at Bus 516 (A)			Backup relay SC Fault at Bus 516 (A)		
		Pve	zero	Nve	Pve	zero	Nve
1	6	1141	0	1143	1141	0	1143

Table 23 Line-Line fault at bus 541 in Summer Load category

Main Relay	Backup Relay	Main relay SC Fault at Bus 541 (A)			Backup relay SC Fault at Bus 541 (A)		
		Pve	zero	Nve	Pve	zero	Nve
6	8	1144	0	1146	572	0	573

Table 24 Line-Line fault at bus 504 in Summer Load category

Main Relay	Backup Relay	Main relay SC Fault at Bus 504 (A)			Backup relay SC Fault at Bus 504 (A)		
		Pve	zero	Nve	Pve	zero	Nve
90	89	1202	0	1204	1202	0	1204

The line-to-line faults in the summer load category show increased currents, but the system maintains stability. The relay coordination is effective, ensuring that faults are isolated without affecting the overall system performance.

Case 4: emergency category

Table 25 load current and pick up current in emergency category

Relay	Load Current	Pick up Current	CT ratio
1	43	53.75	100/1
6	172.2	215.25	400/1
8	86.1	107.625	200/1
89	946.9	1183.625	200/1
90	946.9	1183.625	250/1

➤ **Three phase Fault**

Table 26 Three pahse fault at bus 516 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 516 (A)	Backup relay SC Fault at Bus 516 (A)
1	6	2284	2284

Table 27 Three pahse fault at bus 541 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 541 (A)	Backup relay SC Fault at Bus 541 (A)
6	8	2290	1145

Table 28 Three pahse fault at bus 504 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 504 (A)	Backup relay SC Fault at Bus 504 (A)
90	89	2406	2406

Three phase Fault Analysis in emergency conditions, the fault currents are at their highest, reflecting the extreme scenarios. Despite this, the relays successfully clear the faults, demonstrating the system's robustness and the effectiveness of the protective measures.

➤ **L-L Fault**

Table 29 Line-Line fault at bus 516 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 516 (A)			Backup relay SC Fault at Bus 516 (A)		
		Sequences	Pve	zero	Nve	Pve	zero
1	6	1141	0	1143	1141	0	1143

Table 30 Line-Line fault at bus 541 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 541 (A)			Backup relay SC Fault at Bus 541 (A)		
		Sequences	Pve	zero	Nve	Pve	zero
6	8	1144	0	1146	572	0	573

Table 31 Line-Line fault at bus 504 in Normal category

Main Relay	Backup Relay	Main relay SC Fault at Bus 504 (A)			Backup relay SC Fault at Bus 504 (A)		
		Sequences	Pve	zero	Nve	Pve	zero
90	89	1202	0	1203	1202	0	1203

Line-to-Line Fault Analysis The emergency category presents the highest line-to-line fault currents. The relay responses are prompt, ensuring that the faults are managed efficiently. This highlights the system's ability to maintain integrity and protect equipment during severe conditions.

IV.3. Load flow analysis report & Short circuit analysis report

IV.3.1. Load Flow Analysis Simulation of Substation Using ETAP

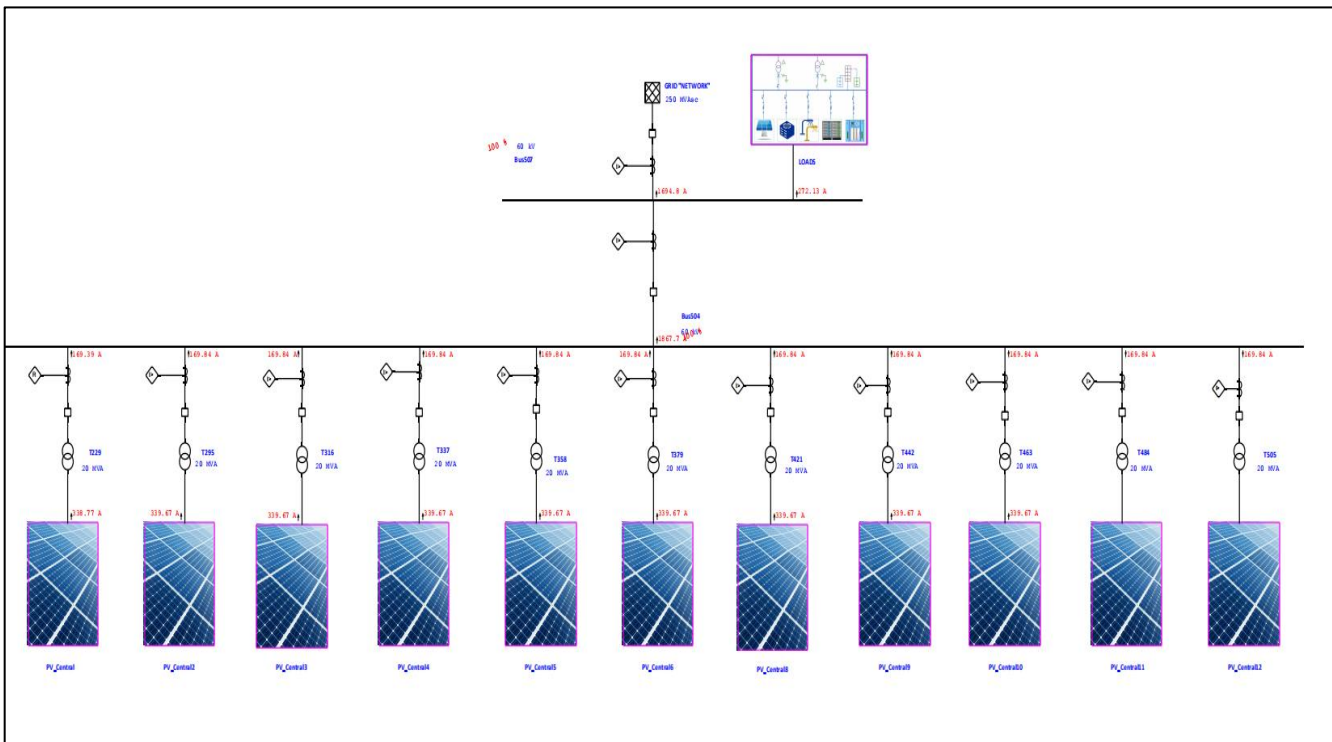


Figure 53 Load Flow Analysis Simulation of Substation

1.1. Load flow analysis of 20MW

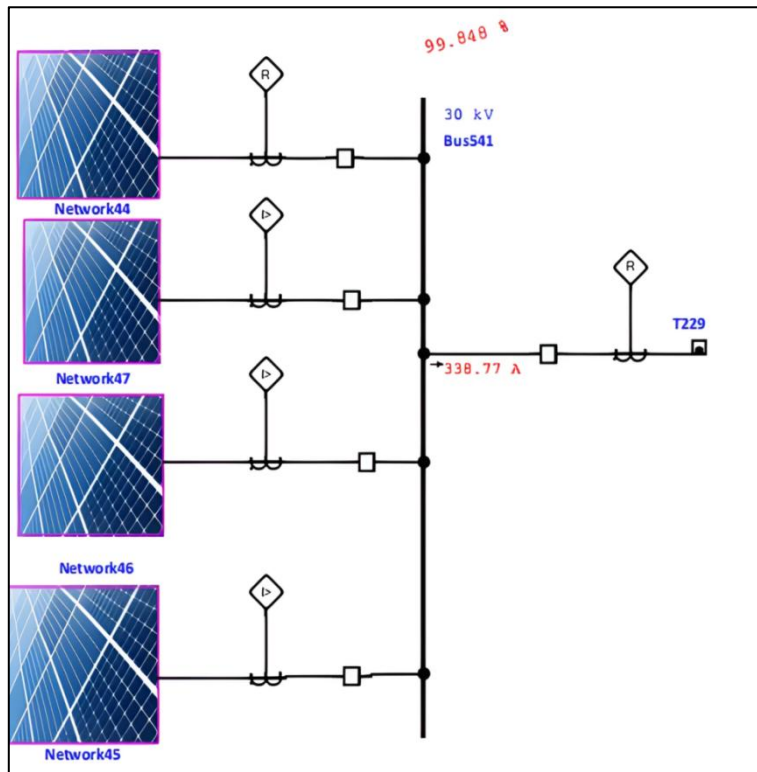


Figure 54 Load flow analysis 20MW

1.2. Load flow analysis of 5MW

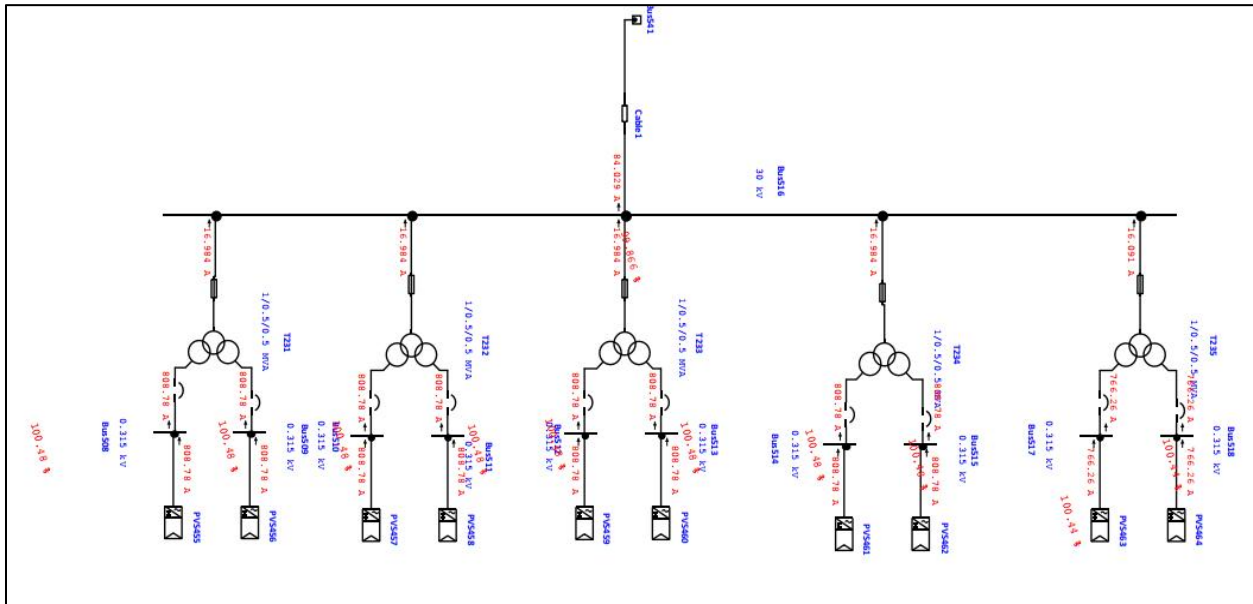


Figure 55 Load flow analysis of 5MW

IV.3.2. Short Circuit Analysis Simulation of Substation

1. Three Phase fault 220MW

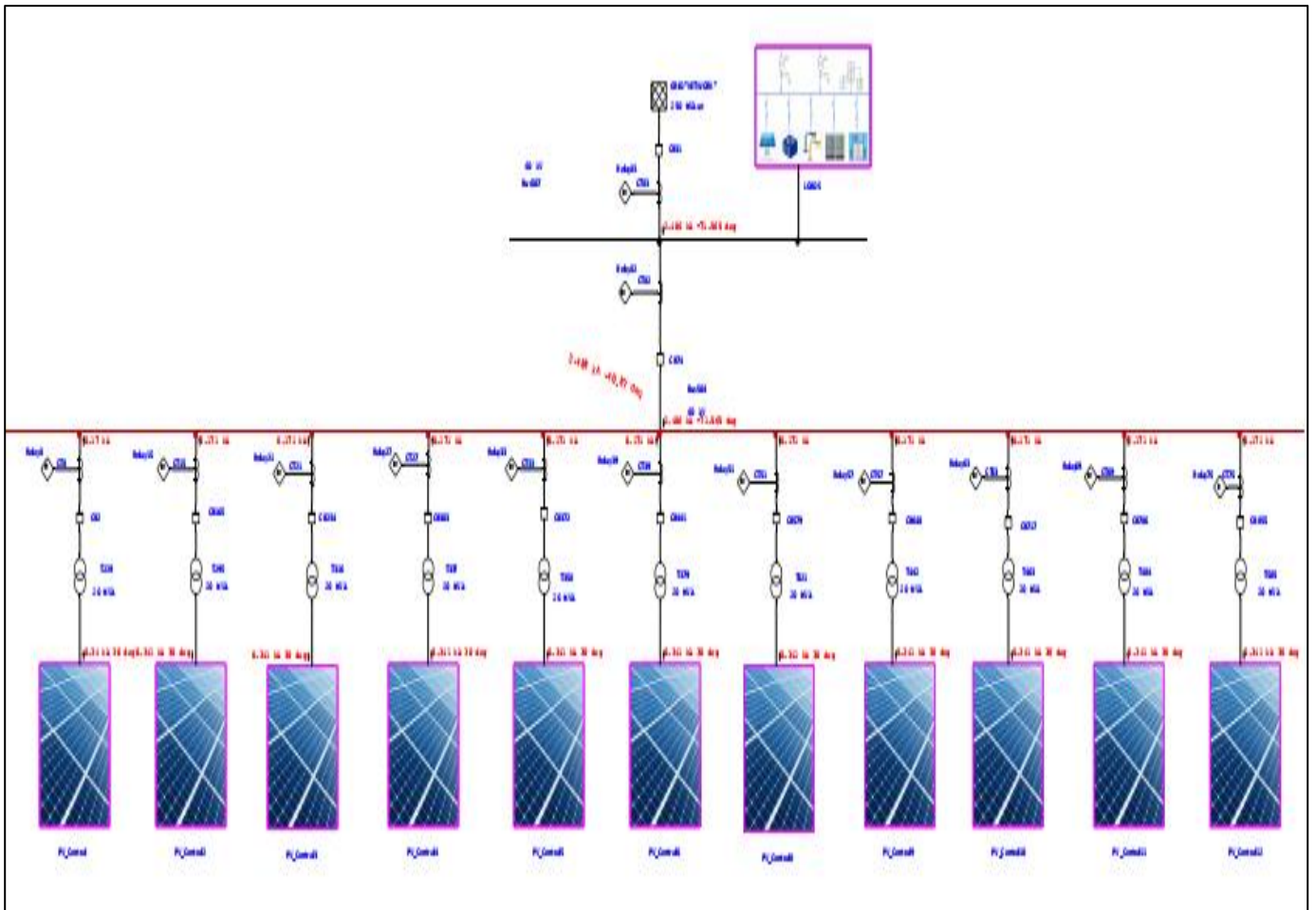


Figure 56 Three Phase fault 220MW

2. Three Phase fault 20MW

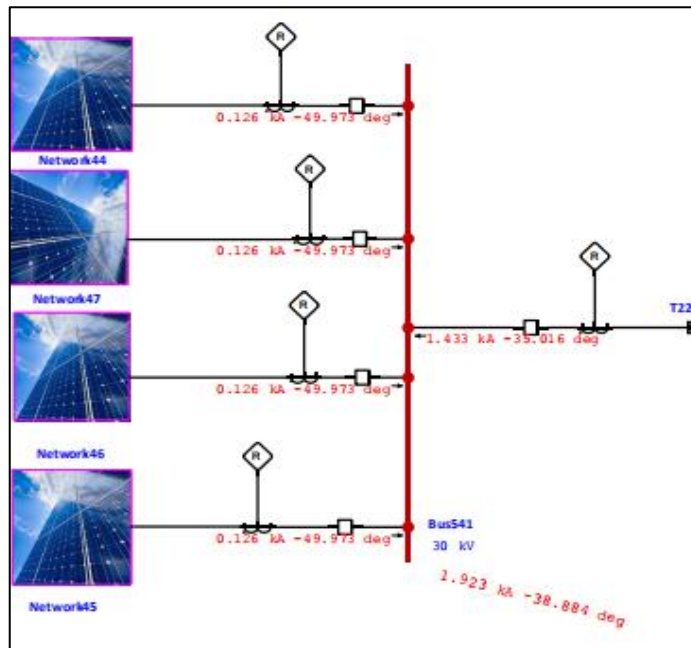


Figure 57 Three Phase fault 20MW

3. Three Phase fault 5MW

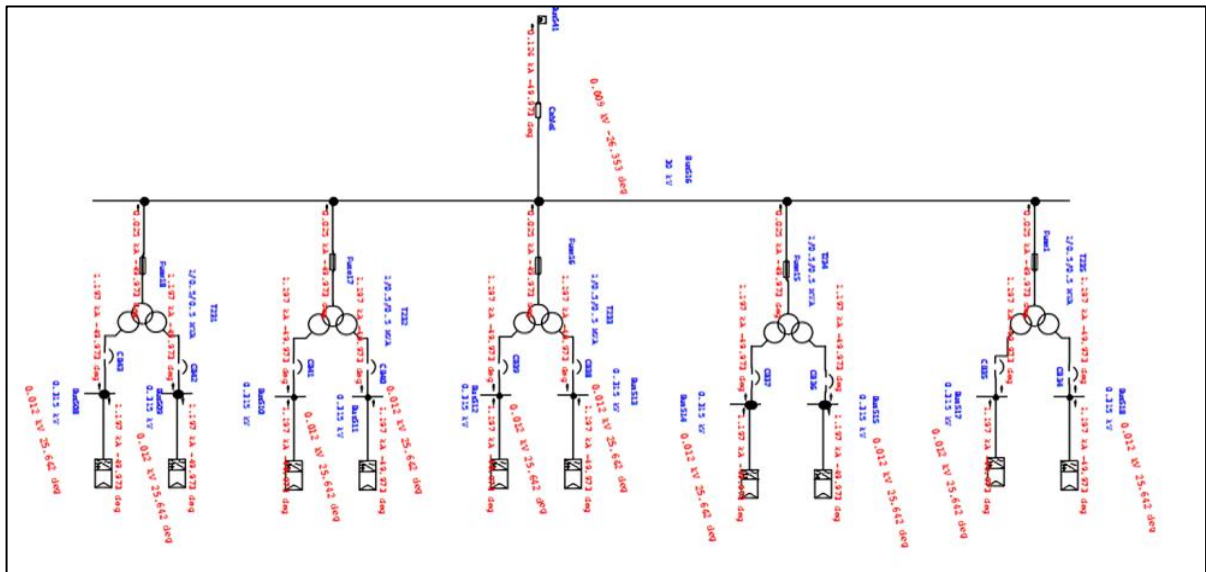


Figure 58 Three Phase fault 5MW

4. Line to line Fault 220MW

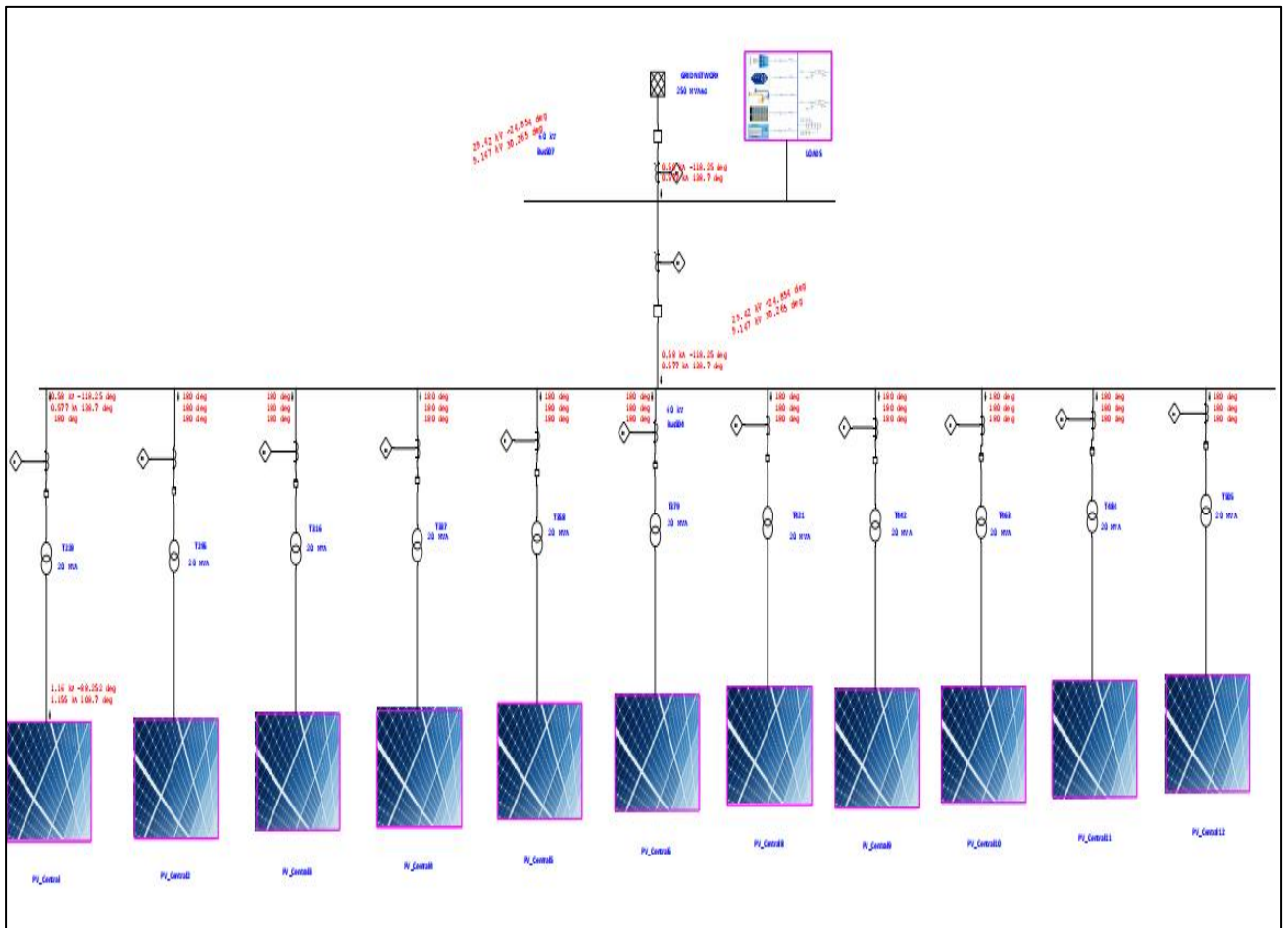


Figure 59 Line-Line fault 220MW

5. Line to Line fault 20MW

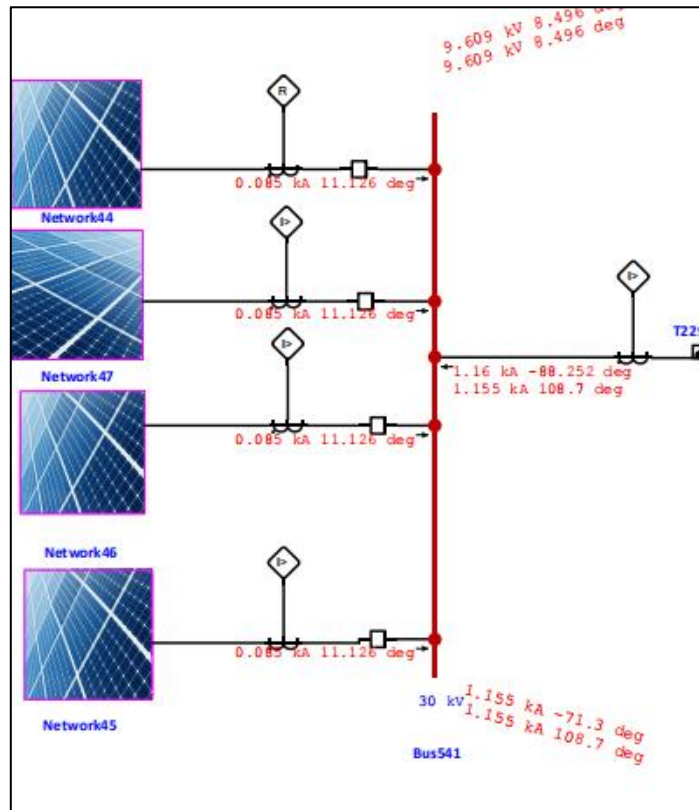


Figure 60 Line-Line fault 20MW

6. Line to Line fault 5 MW :

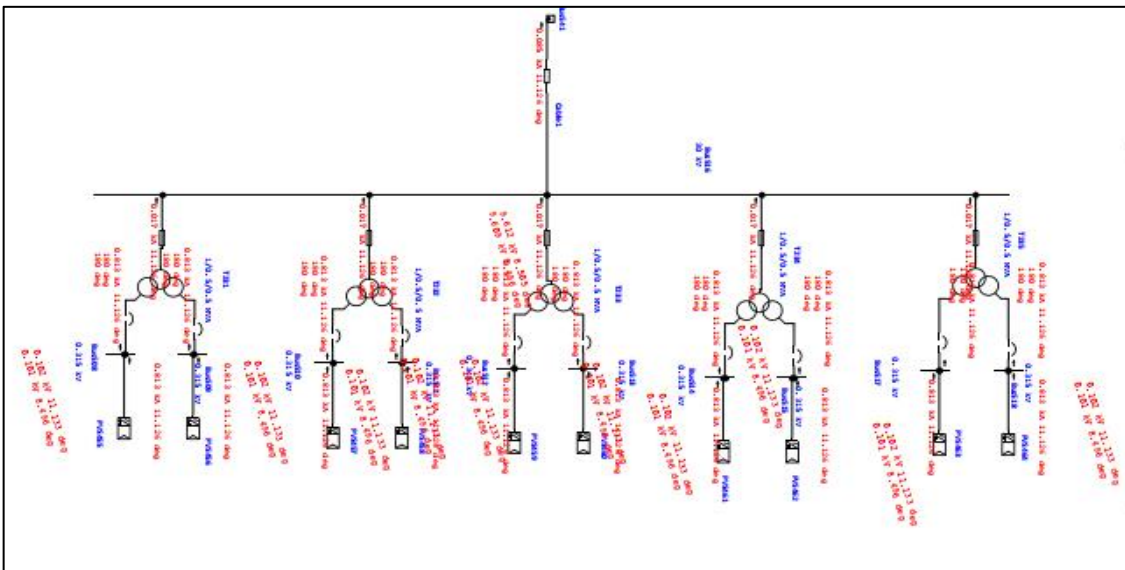


Figure 61 Line-Line fault 5MW

IV.4. Protection & Coordination results:

After the study, analysis of each case and calculation , the results obtained are as follows:

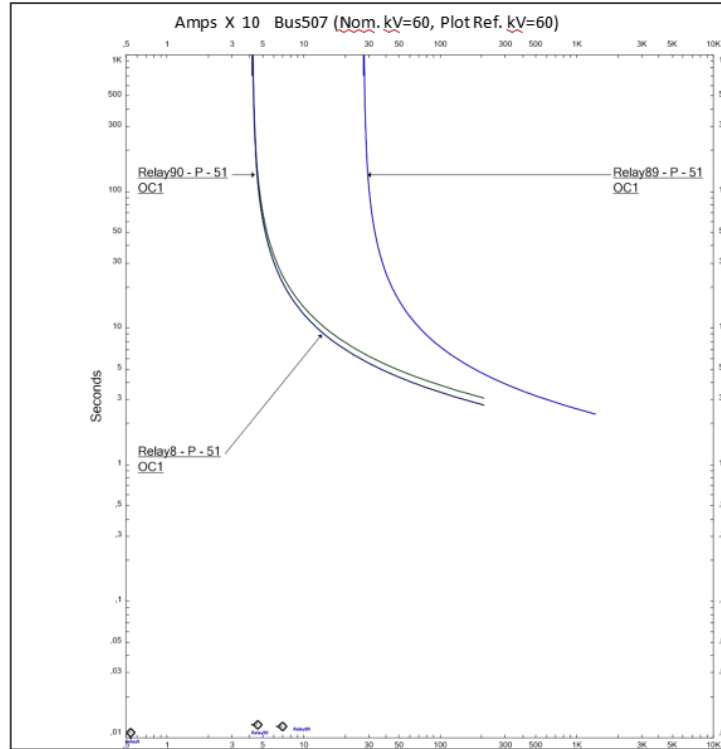


Figure 62 The coordination of IDMT relays (8-90)

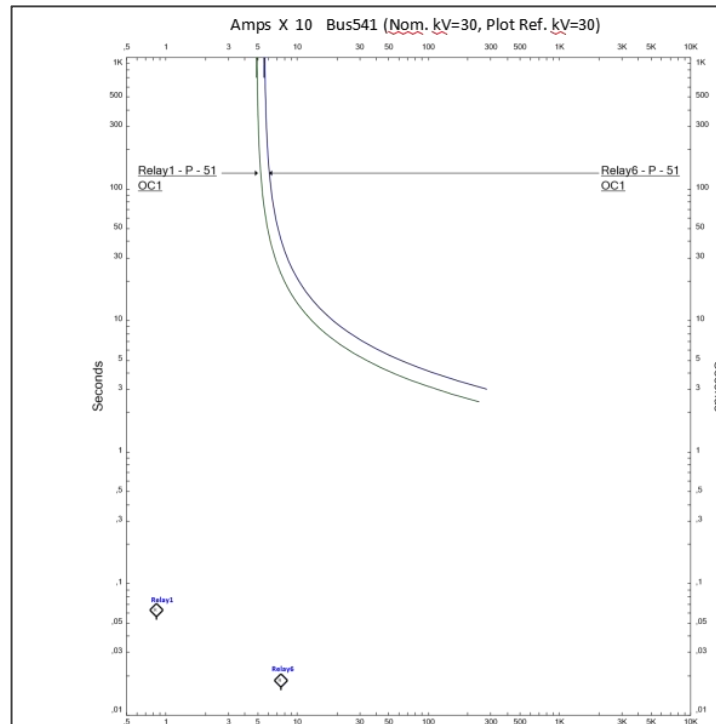


Figure 63 The coordination of IDMT relays (1-6)

In the curves, OC relays 1 and 6 used to protect the photovoltaic central substation of 5MW and 20MW respectively.

Then, OC relay 8 is used to safeguarding the 20MVA-60kV transformer (and each one of the 11 transformers similar to him at other substations are protected by the same way).

OC relay 90 can insulate the 220MW photovoltaic central against overcurrent faults , and the 89 one protect the network.

The shoots taken from the ETAP software can present the good coordination in different bus bars and equipments (three winding transformer and inverter) :

At first we create a fault at the 516 bus bar :

When the fault is at 516 bus bar behind the 5MW the first circuit breaker trip which is connected to the relay 1 after that 6,8,90 and 89 until the fault is completely isolated.

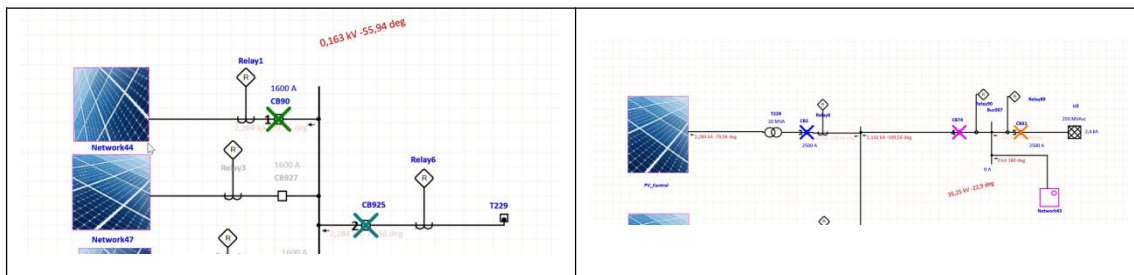


Figure 64 516 bus bar protection coordination from the overcurrent

Then the bus bar 541 :

The fault here is after the 20MW, it means the first one which can trip is the CB connected with relay 6 after that the others by selectivity until isolating the fault.

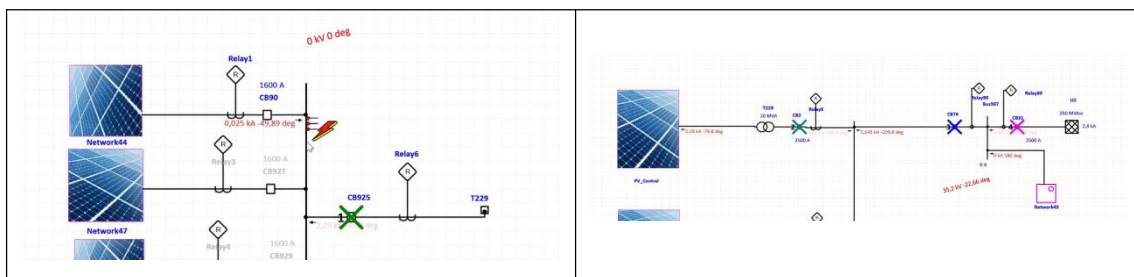


Figure 65 541 bus bar protection coordination from the overcurrent

And the 504 bus bar :

The fault is at bus bar number 504, and the degree of risk is much greater than the previous times. The protection here includes the photovoltaic central 220MW and the network at the same time, any error here may lead the network to instability.

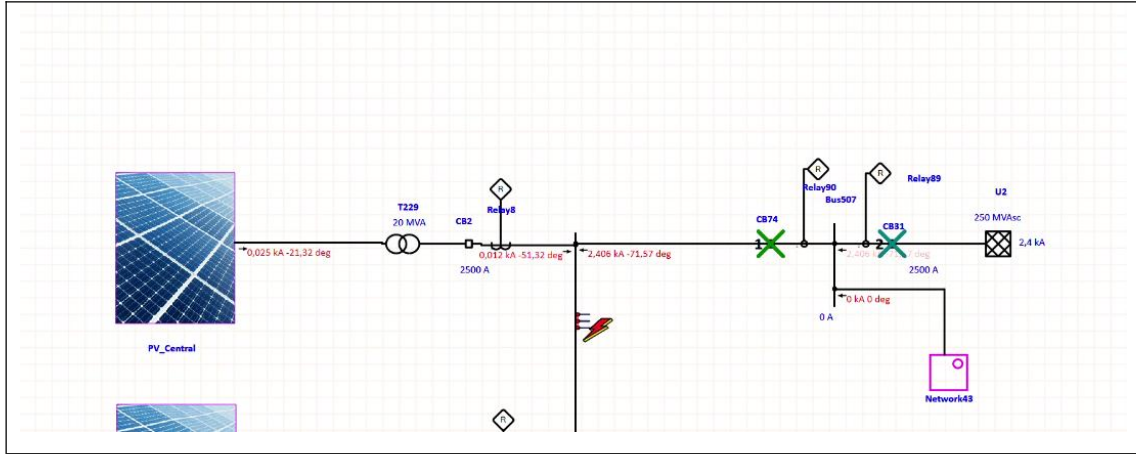


Figure 66 504 bus bar protection coordination from the overcurrent

For ensuring the protection of devices as three winding transformer :

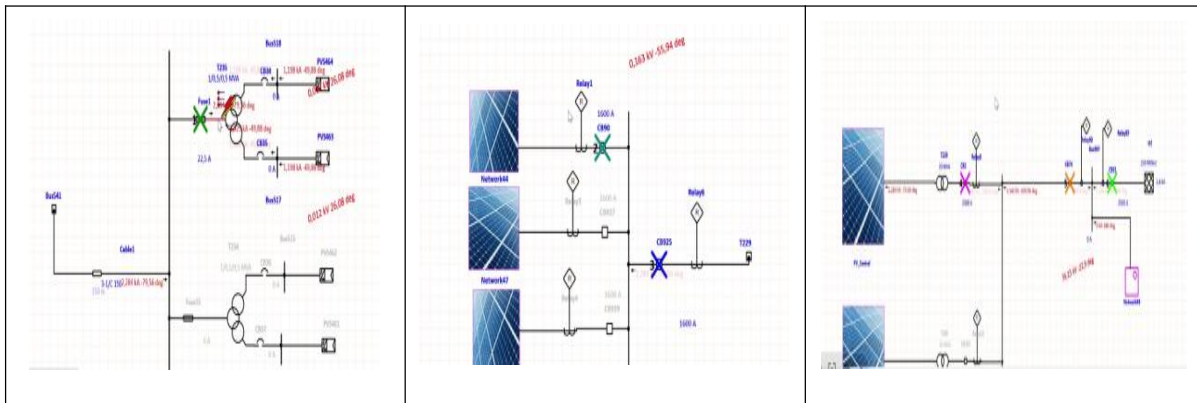


Figure 67 protection coordination of three winding transformer

Or inverter :

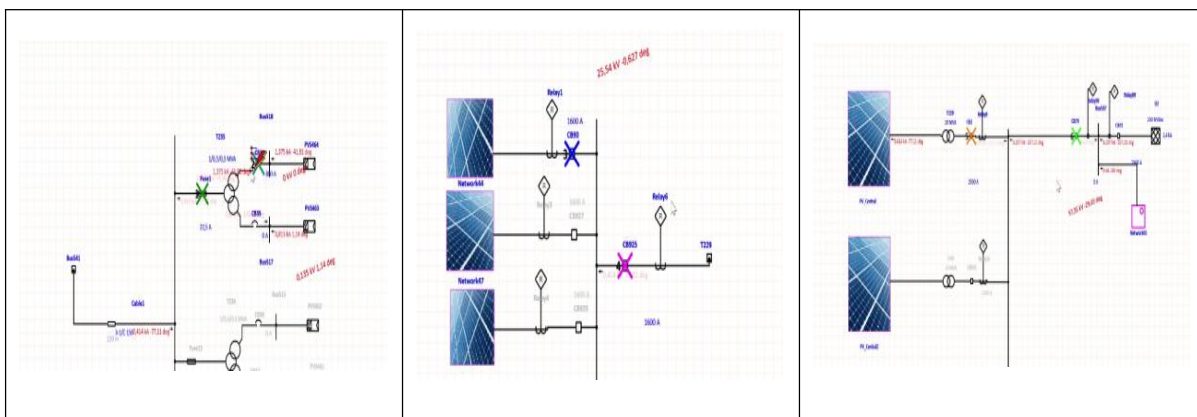


Figure 68 protection coordination of inverter

IV.5. Protection & coordination reports:

Project:	ETAP	Page:	1
Location:	19.0.1C	Date:	04-06-2024
Contract:		SN:	
Engineer:		Revision:	Base
Filename: powerplan_tamsa	Study Case: SM	Config.:	Normal

Fault at bus : **Bus504**
 Nominal kV = 60.000 Voltage c Factor = 1.10 (User-Defined)

Line-To-Line Fault

Contribution		% Voltage at From Bus						Current at From Bus (kA)						Sequence Current (kA)		
		Va		Vb		Vc		Ia		Ib		Ic				
		From Bus ID	To Bus ID	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	I1
Bus504	Total	110.10	0.2	55.05	-179.8	55.05	-179.8	0.000	0.0	2.085	-161.4	2.085	18.6	1.204	1.204	0.000
Bus541	Bus504	95.13	0.4	0.44	0.4	95.57	-179.6	0.009	3.3	0.009	-116.7	0.009	123.3	0.009	0.000	0.000
Bus555	Bus507	110.10	0.2	55.05	-179.8	55.05	-179.8	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000	0.000
U2	Bus507	110.00	0.0	110.00	-120.0	110.00	120.0	0.009	-176.7	2.079	-161.5	2.087	18.4	1.202	1.204	0.000
Bus516	Bus541	95.13	0.4	0.44	0.0	95.57	-179.6	0.017	33.3	0.017	-86.7	0.017	153.3	0.017	0.000	0.000
Bus517	Bus516	94.32	1.9	3.06	-9.2	97.32	-178.4	0.009	33.3	0.009	-86.7	0.009	153.3	0.009	0.000	0.000
Bus518	Bus516	94.32	1.9	3.06	-9.2	97.32	-178.4	0.009	33.3	0.009	-86.7	0.009	153.3	0.009	0.000	0.000
Bus518	Bus517	94.32	1.9	3.06	-9.2	97.32	-178.4	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000	0.000
PVS463	Bus517	94.32	1.9	3.06	-9.2	97.32	-178.4	0.813	33.3	0.813	-86.7	0.813	153.3	0.813	0.000	0.000
PVS464	Bus518	94.32	1.9	3.06	-9.2	97.32	-178.4	0.813	33.3	0.813	-86.7	0.813	153.3	0.813	0.000	0.000
Bus507	Bus504	110.10	0.2	55.05	-179.8	55.05	-179.8	0.009	-176.7	2.079	-161.5	2.087	18.4	1.202	1.204	0.000

Indicates fault current contribution is from three-winding transformers
 * Indicates a zero sequence fault current contribution (3I0) from a grounded Delta-Y transformer

Chapter IV : Coordination of Overcurrent Relays in Power System Networks

Project:	ETAP	Page:	1
Location:	19.0.1C	Date:	04-06-2024
Contract:		SN:	
Engineer:		Revision:	Base
Filename: powerplan_tamsa	Study Case: SM	Config.:	Normal

Fault at bus: **Bus504**
 Nominal kV = 60.000
 Voltage c Factor = 1.10 (User-Defined)

Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus ID	To Bus ID	% V From Bus	kA Symm. rms	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
				Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
Bus504	Total	0.00	2.417	0.00	110.11	110.11	2.408	2.408	1.39E+001	4.17E+001	1.39E+001	4.17E+001
Bus541	Bus504	0.63	0.012	63.79	110.11	63.36	0.009	0.000	5.37E+003	6.70E+003		
Bus555	Bus507	0.00	0.000	0.00	110.11	110.11	0.000	0.000				
U2	Bus507	110.00	2.406	110.00	110.00	110.00	2.406	2.408	1.39E+001	4.17E+001	1.39E+001	4.17E+001
Bus516	Bus541	0.63	0.025	63.80	110.12	63.36	0.017	0.000	8.00E+003	3.07E+003		
# Bus517	Bus516	4.41	0.012	65.58	110.69	62.60	0.009	0.000	1.60E+004	6.15E+003		
# Bus518	Bus516	4.41	0.012	65.58	110.69	62.60	0.009	0.000	1.60E+004	6.15E+003		
# Bus518	Bus517	4.41	0.000	65.58	110.69	62.60	0.000	0.000				
PVS463	Bus517	4.41	1.174	65.58	110.69	62.60	0.813	0.000				
PVS464	Bus518	4.41	1.174	65.58	110.69	62.60	0.813	0.000				
Bus507	Bus504	0.00	2.406	0.00	110.11	110.11	2.406	2.408				
			3-Phase	L-G	L-L	L-L-G						
Initial Symmetrical Current (kA, rms)		:	2.417	2.408	2.085	2.408						
Peak Current (kA), Method C		:	4.714	4.694	4.065	4.695						
Breaking Current (kA, rms, symm)		:		2.408	2.085	2.408						
Steady State Current (kA, rms)		:	2.428	2.408	2.085	2.408						

Indicates a fault current contribution from a three-winding transformer.

* Indicates a zero sequence fault current contribution (3I0) from a grounded Delta-Y transformer.

Chapter IV : Coordination of Overcurrent Relays in Power System Networks

Project:	ETAP	Page: 1
Location:	19.0.1C	Date: 04-06-2024
Contract:		SN:
Engineer:		Revision: Base
Filename: powerplan_tamsa	Study Case: SM	Config.: Normal

Fault at bus: **Bus541**
 Nominal kV = 30.000
 Voltage c Factor = 1.10 (User-Defined)

Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus ID	To Bus ID	% V From Bus	kA Symm. rms	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
				Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
Bus541	Total	0.00	2.312	0.00	104.75	98.14	2.718	2.718	1.64E+001	9.10E+001	2.46E+000	4.92E+001
Bus516	Bus541	0.01	0.025	0.00	104.76	98.15	0.017	0.000	5.42E+003	6.43E+003		
Bus504	Bus541	58.66	2.290	77.50	85.54	110.10	2.717	2.718 *	1.64E+001	9.10E+001	2.46E+000	4.92E+001
# Bus517	Bus516	3.87	0.013	24.09	98.70	94.36	0.009	0.000	1.08E+004	1.29E+004		
# Bus518	Bus516	3.87	0.013	24.09	98.70	94.36	0.009	0.000	1.08E+004	1.29E+004		
Bus555	Bus507	58.66	0.000	77.50	85.54	110.10	0.000	0.000				
U2	Bus507	110.00	1.145	110.00	110.00	110.00	0.780	0.000	1.39E+001	4.17E+001	1.39E+001	4.17E+001
# Bus518	Bus517	3.87	0.000	24.09	98.70	94.36	0.000	0.000				
PVS463	Bus517	3.87	1.198	24.09	98.70	94.36	0.813	0.000				
PVS464	Bus518	3.87	1.198	24.09	98.70	94.36	0.813	0.000				
Bus507	Bus504	58.66	1.145	77.50	85.54	110.10	0.780	0.000				
			3-Phase	L-G	L-L	L-L-G						
Initial Symmetrical Current (kA, rms) :			2.312	2.718	1.985	2.677						
Peak Current (kA), Method C :			5.189	6.094	4.451	6.001						
Breaking Current (kA, rms, symm) :				2.718	1.985	2.677						
Steady State Current (kA, rms) :			2.333	2.718	1.985	2.677						

Indicates a fault current contribution from a three-winding transformer.
 * Indicates a zero sequence fault current contribution (3I0) from a grounded Delta-Y transformer.

Project:	ETAP	Page: 1
Location:	19.0.1C	Date: 04-06-2024
Contract:		SN:
Engineer:		Revision: Base
Filename: powerplan_tamsa	Study Case: SM	Config.: Normal

Chapter IV : Coordination of Overcurrent Relays in Power System Networks

Fault at bus : **Bus541**
 Nominal kV = 30.000 Voltage c Factor = 1.10 (User-Defined)

Contribution		Line-To-Line Fault														
		% Voltage at From Bus						Current at From Bus (kA)						Sequence Current (kA)		
		Va		Vb		Vc		Ia		Ib		Ic				
From Bus ID	To Bus ID	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	I1	I2	I0
Bus541	Total	110.10	0.4	55.05	-179.6	55.05	-179.6	0.000	0.0	1.985	-169.4	1.985	10.6	1.146	1.146	0.000
Bus516	Bus541	110.11	0.4	55.05	-179.6	55.06	-179.6	0.017	3.1	0.017	-116.9	0.017	123.1	0.017	0.000	0.000
Bus504	Bus541	103.19	-16.2	96.21	-162.2	58.66	97.3	0.017	-176.9	1.975	-169.8	1.992	10.2	1.144	1.146	0.000
Bus517	Bus516	110.66	1.8	53.11	-177.7	57.55	-178.7	0.009	3.1	0.009	-116.9	0.009	123.1	0.009	0.000	0.000
Bus518	Bus516	110.66	1.8	53.11	-177.7	57.55	-178.7	0.009	3.1	0.009	-116.9	0.009	123.1	0.009	0.000	0.000
Bus555	Bus507	103.19	-16.2	96.21	-162.2	58.66	97.3	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000	0.000
U2	Bus507	110.00	-30.0	110.00	-150.0	110.00	90.0	0.580	-169.9	0.565	-169.7	1.145	10.2	0.572	0.573	0.000
Bus518	Bus517	110.66	1.8	53.11	-177.7	57.55	-178.7	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000	0.000
PVS463	Bus517	110.66	1.8	53.11	-177.7	57.55	-178.7	0.813	3.1	0.813	-116.9	0.813	123.1	0.813	0.000	0.000
PVS464	Bus518	110.66	1.8	53.11	-177.7	57.55	-178.7	0.813	3.1	0.813	-116.9	0.813	123.1	0.813	0.000	0.000
Bus507	Bus504	103.19	-16.2	96.21	-162.2	58.66	97.3	0.580	-169.9	0.565	-169.7	1.145	10.2	0.572	0.573	0.000

Indicates fault current contribution is from three-winding transformers

* Indicates a zero sequence fault current contribution (3I0) from a grounded Delta- Y transformer

Chapter IV : Coordination of Overcurrent Relays in Power System Networks

Project:	ETAP	Page:	1
Location:	19.0.1C	Date:	04-06-2024
Contract:		SN:	
Engineer:		Revision:	Base
Filename: powerplan_tamsa	Study Case: SM	Config.:	Normal

Fault at bus: **Bus516**
 Nominal kV = 30.000
 Voltage c Factor = 1.10 (User-Defined)

Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus ID	To Bus ID	% V From Bus	kA Symm. rms	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
				Va	Vb	Vc	Ia	3I0	R1	X1	R0	X0
Bus516	Total	0.00	2.306	0.00	104.75	98.10	2.712	2.712	1.68E+001	9.12E+001	2.62E+000	4.92E+001
Bus541	Bus516	0.54	2.284	0.50	104.68	98.24	2.711	2.712	1.68E+001	9.12E+001	2.62E+000	4.92E+001
# Bus517	Bus516	3.87	0.013	24.05	98.71	94.35	0.009	0.000	1.08E+004	1.29E+004		
# Bus518	Bus516	3.87	0.013	24.05	98.71	94.35	0.009	0.000	1.08E+004	1.29E+004		
Bus504	Bus541	58.74	2.284	77.64	85.47	110.10	2.711	2.712 *	1.64E+001	9.10E+001	2.46E+000	4.92E+001
# Bus518	Bus517	3.87	0.000	24.05	98.71	94.35	0.000	0.000				
PVS463	Bus517	3.87	1.198	24.05	98.71	94.35	0.813	0.000				
PVS464	Bus518	3.87	1.198	24.05	98.71	94.35	0.813	0.000				
Bus555	Bus507	58.74	0.000	77.64	85.47	110.10	0.000	0.000				
U2	Bus507	110.00	1.142	110.00	110.00	110.00	0.778	0.000	1.39E+001	4.17E+001	1.39E+001	4.17E+001
Bus507	Bus504	58.74	1.142	77.64	85.47	110.10	0.778	0.000				

	3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms)	2.306	2.712	1.980	2.671
Peak Current (kA), Method C	5.151	6.054	4.419	5.962
Breaking Current (kA, rms, symm)	2.712	2.712	1.980	2.671
Steady State Current (kA, rms)	2.327	2.712	1.980	2.671

Indicates a fault current contribution from a three-winding transformer.

* Indicates a zero sequence fault current contribution (3I0) from a grounded Delta-Y transformer.

Chapter IV : Coordination of Overcurrent Relays in Power System Networks

Project:	ETAP	Page:	1
Location:	19.0.1C	Date:	04-06-2024
Contract:		SN:	
Engineer:		Revision:	Base
Filename: powerplan_tamsa	Study Case: SM	Config.:	Normal

Fault at bus : **Bus516**
 Nominal kV = 30.000 Voltage c Factor = 1.10 (User-Defined)

Line-To-Line Fault

Contribution		% Voltage at From Bus						Current at From Bus (kA)						Sequence Current (kA)		
From Bus	To Bus	Va		Vb		Vc		Ia		Ib		Ic		I1	I2	I0
ID	ID	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.			
Bus516	Total	110.11	0.4	55.05	-179.6	55.05	-179.6	0.000	0.0	1.980	-169.1	1.980	10.9	1.143	1.143	0.000
Bus541	Bus516	110.10	0.4	55.44	-179.3	54.66	-179.8	0.017	-176.9	1.969	-169.5	1.986	10.4	1.141	1.143	0.000
Bus517	Bus516	110.66	1.8	53.11	-177.7	57.55	-178.7	0.009	3.1	0.009	-116.9	0.009	123.1	0.009	0.000	0.000
Bus518	Bus516	110.66	1.8	53.11	-177.7	57.55	-178.7	0.009	3.1	0.009	-116.9	0.009	123.1	0.009	0.000	0.000
Bus504	Bus541	103.09	-16.2	96.34	-162.2	58.74	97.1	0.017	-176.9	1.969	-169.5	1.986	10.4	1.141	1.143	0.000
Bus518	Bus517	110.66	1.8	53.11	-177.7	57.55	-178.7	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000	0.000
PVS463	Bus517	110.66	1.8	53.11	-177.7	57.55	-178.7	0.813	3.1	0.813	-116.9	0.813	123.1	0.813	0.000	0.000
PVS464	Bus518	110.66	1.8	53.11	-177.7	57.55	-178.7	0.813	3.1	0.813	-116.9	0.813	123.1	0.813	0.000	0.000
Bus555	Bus507	103.09	-16.2	96.34	-162.2	58.74	97.1	0.000	0.0	0.000	0.0	0.000	0.0	0.000	0.000	0.000
U2	Bus507	110.00	-30.0	110.00	-150.0	110.00	90.0	0.578	-169.7	0.564	-169.5	1.142	10.4	0.570	0.572	0.000
Bus507	Bus504	103.09	-16.2	96.34	-162.2	58.74	97.1	0.578	-169.7	0.564	-169.5	1.142	10.4	0.570	0.572	0.000

Indicates fault current contribution is from three-winding transformers

* Indicates a zero sequence fault current contribution (3I0) from a grounded Delta-Y transformer

IV.6. Conclusion

This last chapter concludes by reinforcing the importance of well-coordinated protection systems in electrical networks, especially with the increasing integration of distributed generations. By understanding the principles and devices involved in network protection, we can enhance the stability and reliability of power systems. The discussion on overcurrent relay coordination highlights the complexity and criticality of ensuring that protection systems operate effectively under various fault conditions. This chapter provides a solid foundation for exploring advanced protection strategies and technologies that will support the evolving demands of modern power systems.

Through this work and this study we can say that this station is protected from excess currents and applicable on the ground.

GENERAL CONCLUSION

General conclusion

In this project, a state of the art presented the basic principles of photovoltaic panels and solar radiation, in addition it delves into the equations and sizing necessary for installing photovoltaic power plant. The third chapter points out a detailed study of the Tamsa station, including the design and an overview of the basic equipment. At the last chapter, a design of 220MW power plant described using the ETAP software to monitor and analyze different operating scenarios, such as load flow, short circuit analysis and protection with coordination cases resulting in a comprehensive report and critical system information.

In this research, protection and coordination analysis is done on ETAP to find the primary and back up relays, after determining the pick up current by load flow analysis. This study considers distributed generation in 4 different cases.

The results indicate that modern protection devices, including overcurrent relays (OCRs), circuit breakers, and fuses, are essential for the swift detection and isolation of faults, ensuring uninterrupted electricity delivery and system safety. Proper relay settings and coordination are paramount, enhancing the overall protection scheme's effectiveness and stability, which is crucial for supporting critical infrastructure and fostering economic development in response to the dynamic demands of modern electrical networks.

The obtained results show that the implementation of PV solar generation station of Tamsa power distribution station and develops the voltage profile in term of increasing the stability of the system. Therefore, the analyses of this study declare the power station is adequate to realize and implement its parameters.

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