



RELIABILITY IMPROVEMENT

REDUCING FORCED OUTAGES

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LEARNING OUTCOMES

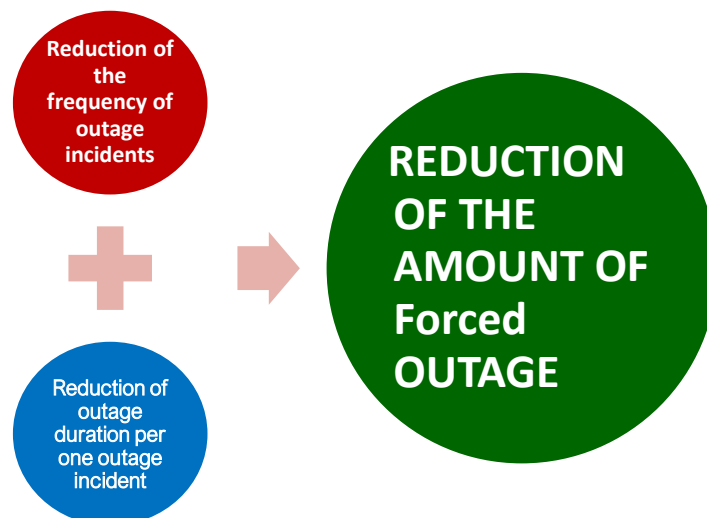
- Know the key contributors to Reducing Forced Outages
- Discuss the importance of systematic outage recording
- Discuss the importance of Analysis of relevant Accumulated Data
- Discuss the importance of correctly identifying the damaged equipment
- Describe the importance of applying appropriate countermeasures exogenous and endogenous cases .
- State some typical countermeasures for identified root causes.
- State the Key tasks/activities that reduce outage duration

REDUCING FORCED OUTAGES

INTRODUCTION

- Outage is the state of an equipment when it is not available to properly perform its intended function due to some event directly associated with the equipment.
- Outage can be Scheduled or Forced.
- An Forced outage occurs when equipment malfunctions or human errors necessitate immediate removal of the affected equipment from service. This removal can happen either automatically, through devices like reclosers and circuit breakers, or as soon as switching operations (using Sectionalizing Switches) can be carried out to swiftly isolate the cause of the outage, known as the fault point.

INTRODUCTION CONTD..



REDUCTION OF THE AMOUNT OF Forced OUTAGE

Reduction of the frequency of outage incidents

In order to reduce the frequency of outage incidents, it is necessary to:

Record the data of outage incidents properly.

Analyze the accumulated data.

Plan and undertake the appropriate countermeasures.

verify the countermeasure effectiveness

REDUCTION OF THE AMOUNT OF Forced OUTAGE: **FREQUENCY**

Data Points for Proper recording of Outage Incidents



- Date and time of outage
- Date and time of full restoration
- Relay that worked
- Number of customers affected
- Converted duration

For an efficient analysis of the given data points, it is better to use a pre-programmed system i.e., a computer application (software), than to use media like paper.

Incident ID	Date	Time	Location	Relay	Customers Affected	Duration (min)	Root Cause	Location of Fault	Weather	Equipment
001	2023-10-26	10:15	Area A	R1	150	45	Overload	Transformer	Sunny	Transformer
002	2023-10-27	14:30	Area B	R2	200	60	Weather	Line	Thunderstorm	Line
003	2023-10-28	08:00	Area C	R3	100	30	Equipment	Switch	Clear	Switch

- Root cause
- Location of the fault point and its geographical characteristic
- Weather condition
- Damaged equipment that became the fault point, and its manufacturer.

REDUCTION OF THE AMOUNT OF Forced OUTAGE: **FREQUENCY**

What are the benefits of proper recording of outage data?

- **Identifying Patterns and Trends:** helps utilities understand the underlying causes of outages, enabling them to take proactive measures to prevent or mitigate future disruptions
- **Root Cause Analysis:** making informed decisions about infrastructure upgrades, maintenance schedules, and equipment replacements.
- **Improving Reliability** through prioritizing investments, and implementing targeted maintenance
- **Optimizing Restoration Processes:** Inform planning for restoration after an outage
- **Regulatory Compliance:** Helps utilities meet regulatory requirements, report performance and avoid penalties

REDUCTION OF THE AMOUNT OF Forced OUTAGE: FREQUENCY

ANALYSIS OF THE ACCUMULATED DATA

- **Analysis from the perspective of equipment** is necessary and important to identify what the frequently-damaged (i.e. Becoming the fault point frequently) equipment is, and to plan and undertake the appropriate countermeasures.
- **Analysis from the perspective of root cause** is also necessary and important to identify what the most frequent root cause(s) is (are), and to plan and undertake the appropriate countermeasures.
- **Verification of the effectiveness of the countermeasure:** As the result of applying the countermeasure, it is necessary to verify whether the frequency of outage incidents decreased or not. If there is no decrease in outage incidents, alternative countermeasures have to be considered.

REDUCTION OF THE AMOUNT OF Forced OUTAGE: FREQUENCY

COUNTER MEASURES FOR REDUCING OUTAGE

Generally, root causes are classified roughly into exogenous and endogenous ones.

- **EXOGENOUS** causes include natural disasters and objects touching the distribution equipment, which are difficult to control. However, Discos have to make the effort to prevent exogenous causes by preplanned trimming of vegetation, or installing instruments that prevent things from touching the distribution equipment.
- **ENDOGENOUS** causes include aging of distribution equipment. The main countermeasure for that is replacement, but in order to advance the replacement in an efficient and informed manner, it is important to **analyze** the tendency of: the **manufacturer**, the **model number**, the **year of manufacture**, and so on for trends relating to aged, damaged, and deteriorated equipment.

REDUCTION OF THE FREQUENCY OF OUTAGE INCIDENTS: **ANALYSIS OF THE ACCUMULATED DATA**

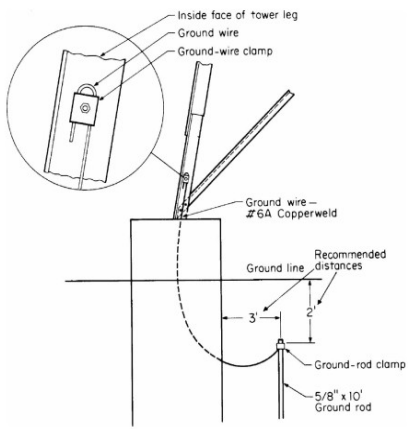
TYPICAL EXAMPLES OF THE COUNTERMEASURES

S/N	EQUIPMENT /MATERIAL	ROOT CAUSE	COUNTERMEASURE
1	CONDUCTOR	Break due to aging	Replacement
		Vegetation touching the conductor	 Installing insulated conductor

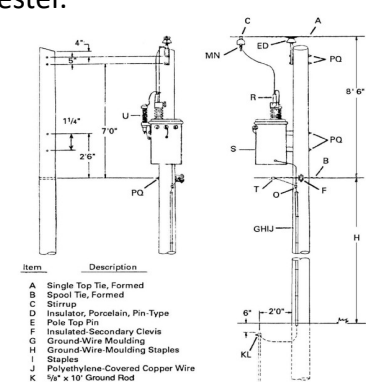
Typical examples of countermeasures contd..

S/N	EQUIPMENT /MATERIAL	ROOT CAUSE	COUNTERMEASURES
2.	CONDUCTOR	Birds and their nest touching the conductor	Patrolling to find the nests and removing them beforehand
			Instruments that preventing birds from perching on the conductor or from making nest on the distribution facility 

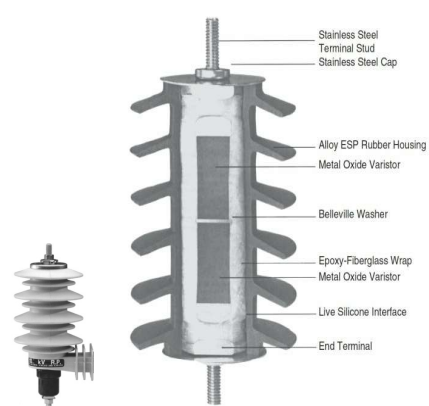
Typical examples of countermeasures contd..

S/N	EQUIPMENT /MATERIAL	ROOT CAUSE	Installing additional ground wire and lightning arrester.
3.	CONDUCTOR AND EQUIPMENT	Thunder and lightning	

Typical examples of countermeasures contd..

S/N	EQUIPMENT /MATERIAL	ROOT CAUSE	Installing additional ground wire and lightning arrester.
3.	CONDUCTOR AND EQUIPMENT	Thunder and lightning	 Item Description - A Single Top Tie, Formed - B Spool Tie, Formed - C Stirrup - D Insulator, Porcelain, Pin-Type - E Pole Top Pin - F Insulated Secondary Clevis - G Ground-Wire Moulding - H Ground-Wire-Moulding Staples - I Staples - J Polyethylene-Covered Copper Wire - K 1/2" x 10' Ground Rod - L Ground-Rod Clamp - M Hot-Line Clamp - N Stranded, Soft-Drawn, Bare Copper Wire - O Splice Bolt Connector - P Machine Bolt, 1/2" - Q Square Washer, Flat - R Current Limiting Fuse - S Distribution Transformer - T Connector, Aluminum (Neutral) - U Surge Arrester

Typical examples of countermeasures contd..

S/N	EQUIPMENT /MATERIAL	ROOT CAUSE	Installing additional ground wire and lightning arrester.
3.	CONDUCTOR AND EQUIPMENT	Thunder and lightning	

Typical examples of countermeasures contd..

S/N	EQUIPMENT /MATERIAL	ROOT CAUSE	
4.	EQUIPMENT	Aging	Observe carefully the tendency of damaged equipment. If some specific manufacturer, model number, or manufacture year tend to give the frequent malfunction on the equipment, the total amount of the equipment to be replaced should be grasped and preplanned replacement should be executed.

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LEARNING CHECK -> REDUCING FORCED OUTAGES

REDUCTION OF OUTAGE DURATION PER ONE OUTAGE INCIDENT

REDUCING FORCED OUTAGES

Reduction of outage duration per one outage incident.

- In order to reduce outage duration, it is necessary and important to “**energize the healthy section as early as possible**”, and to “**restore the faulty point as early as possible**”.
- Energizing the healthy section as early as possible: In order to energize the healthy section as early as possible, what is most important is to **identify and isolate the faulted section as early as possible**. The **course on fault detection** outlines effective methods for identifying and isolating the faulted section as early as possible
- Thus, for reduction of outage duration per one outage incident, **supply from surrounding feeders** is the major condition to be taken into account.
- In restoring the faulty point as early as possible it is important to **train those who are engaged in restoration work regularly**, maintaining and improving their restoration skills.

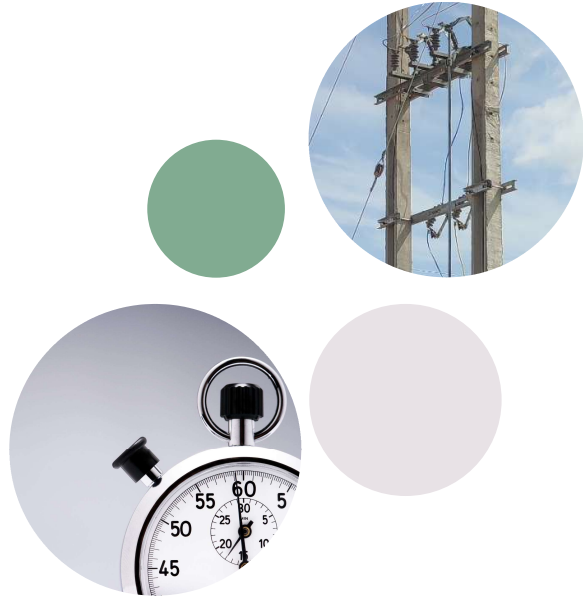
REDUCTION OF THE AMOUNT OF Forced OUTAGE: **Reduction of outage duration per one outage incident**

REDUCTION OF OUTAGE DURATION PER ONE OUTAGE INCIDENT

In order to reduce outage duration, it is necessary and important to

“energize the healthy section as early as possible”, and to

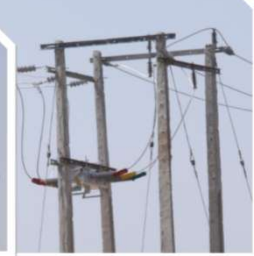
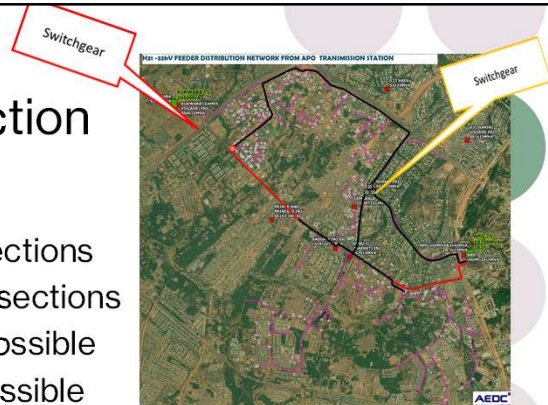
“restore the faulty point as early as possible”



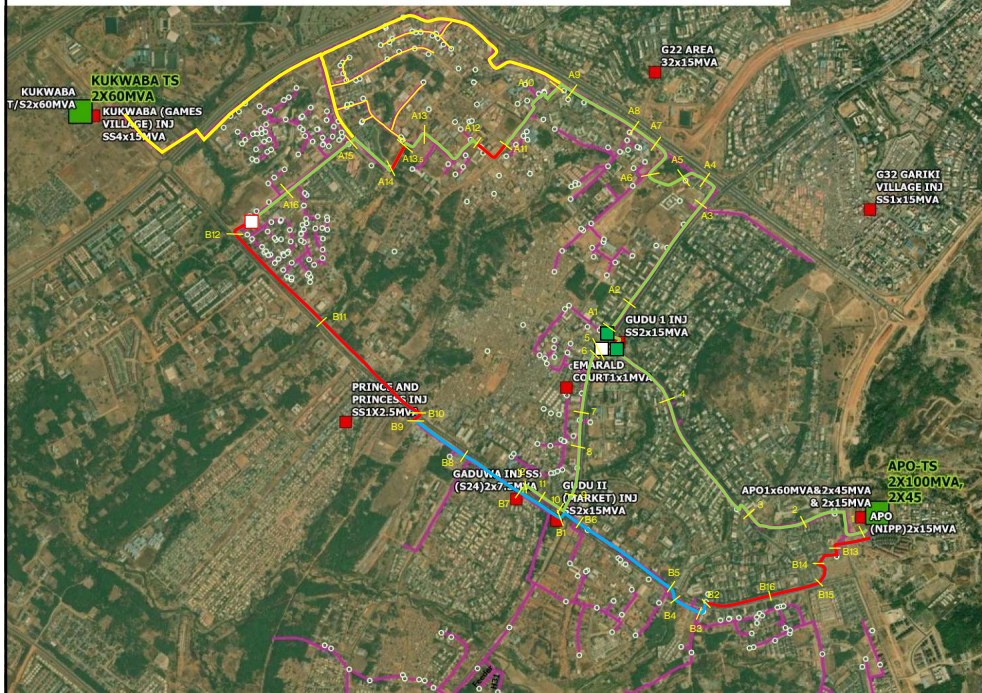
1. Energizing the healthy section as early as possible

For early/timely energization of healthy sections

- The feeder should be divided into some sections
- identify the faulted section as early as possible
- isolate the faulted section as early as possible
- It is advisable that switchgear dividing the feeder into some sections are able to cut off the load



131-33kV FEEDER DISTRIBUTION NETWORK FROM APO TRANSMISSION STATION

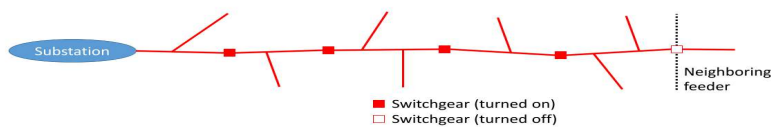


1. Energizing the healthy section as early as possible

The healthy section in "source-side" of the fault section can be supplied from the substation, however

the healthy section in "load-side" of the fault section cannot be supplied from the substation.

In such cases, the load-side section is to be supplied from the other feeders surrounding the faulted feeder



Normally Open Position



1. Energizing the healthy section as early as possible



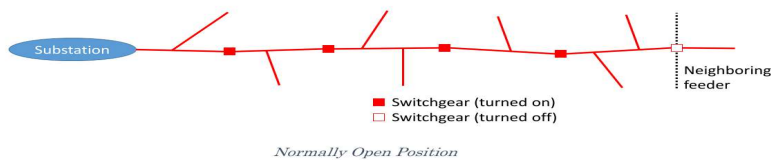
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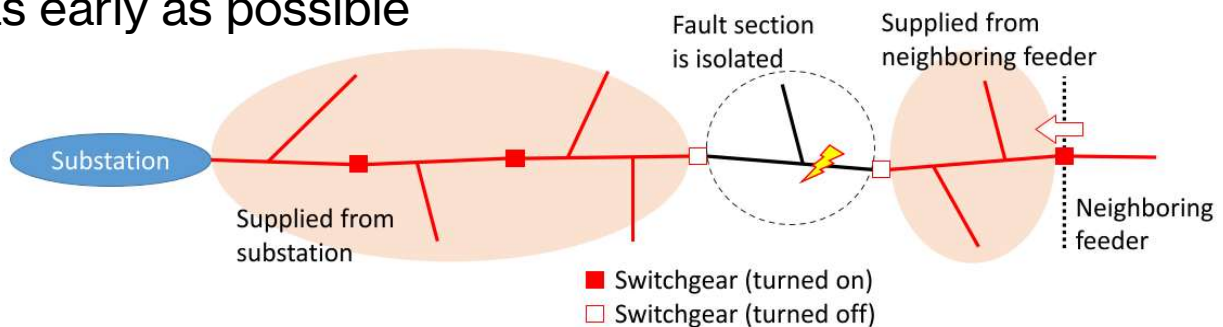
In such cases, the load-side section is to be supplied from the other feeders surrounding the fault feeder.



Thus, for reduction of outage duration per one outage incident, **supply from surrounding feeders** is the major condition to be taken into account when the distribution grids are configured, and switchgears for that purpose are also available for sectionalizing the feeder.



1. Energizing the healthy section as early as possible



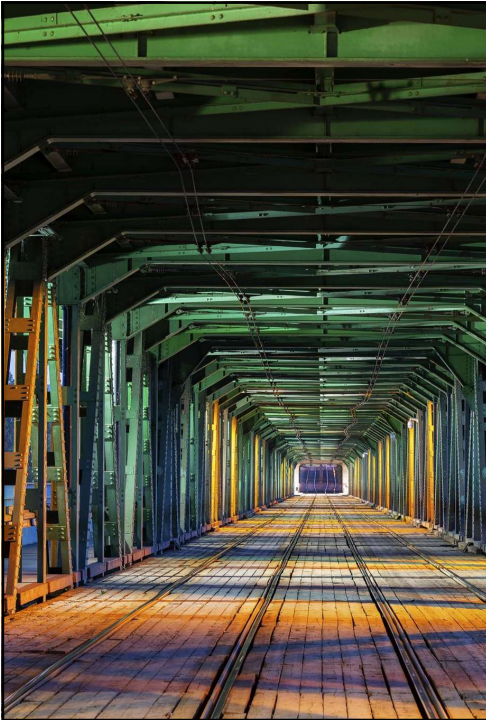
We assume the faulted section has been identified/located by the fault location methods

EXAMPLE

4th section was identified as the fault section and isolated by the 2 switchgears that are turned off.

The 1st, 2nd, and 3rd sections are in source-side of the fault section, therefore they are supplied from the substation

the 5th section is in load-side of the fault section, it will be supplied from the neighboring feeder, by turning on the switchgear between those 2 feeders which are usually turned off.



2. Restoring the faulty point as early as possible

- It is important to regularly train and upskill those who are engaged in restoration work, maintaining and improving their restoration skills.



OTHER

- - If anyone finds and establishes effective methods for the reduction of the frequency of outage incidents or the reduction of outage duration per one outage incident, such sample cases should be actively rolled out and shared by everyone involved.
- For that purpose, it is advisable that offices from many areas have chance to gather regularly, share the good examples, and propose the better method for:

1. Energizing the healthy section as early as possible
2. Restoring the faulty point as early as possible

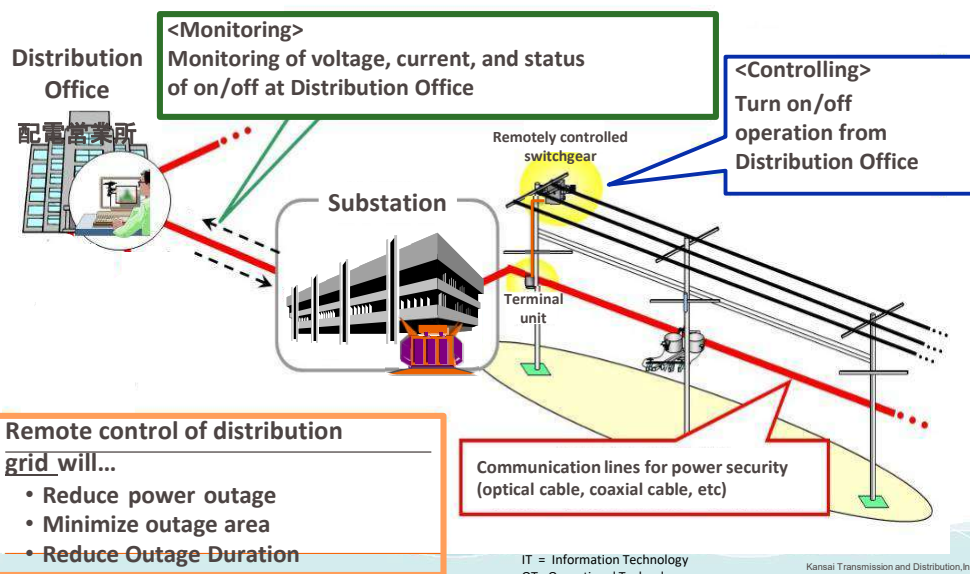


DISTRIBUTION AUTOMATION SYSTEM (DAS)

REDUCING FORCED OUTAGES

The overview of DAS (Distribution Automation System)

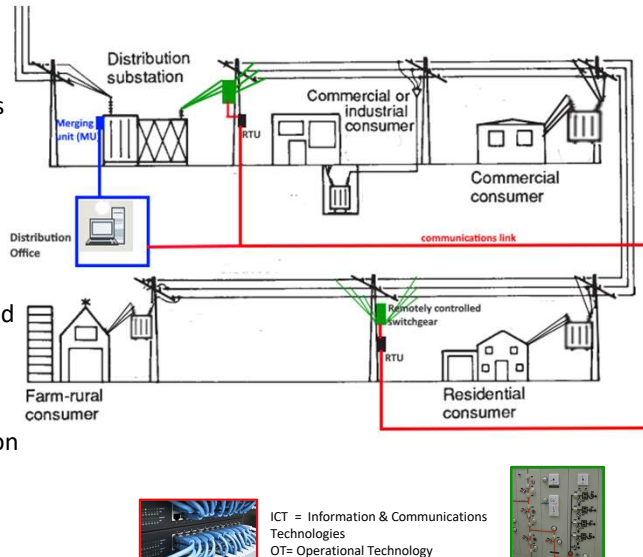
- Distribution automation is the complete automation (IT+OT) of all controllable equipment and monitoring functions in the distribution power grid



The overview of DAS (Distribution Automation System)

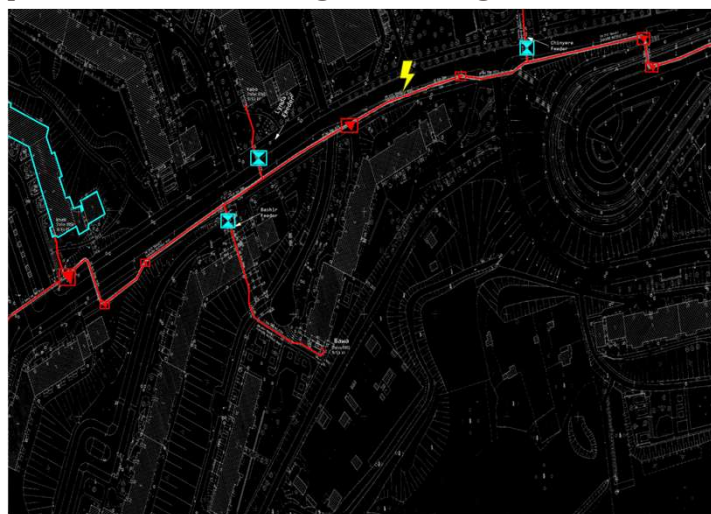
● Distribution automation is the complete automation (ICT+OT) of all controllable equipment and monitoring functions in the distribution power grid

- Monitoring (V,I, on/off status) And Controlling is done at Distribution Office (Centralized) and/or at feeders or substation level (Distributed)
- DAS helps to meet requirement of high supply reliability for the customer.
- Supply reliability is typically quantified by criteria such as SAIDI, SAIFI, Converted duration.
- DAS is realized through the integration of automation with well articulated operating procedures and training of employees



DAS for Reliability Improvement through supply of healthy feeder from neighbouring feeder

- Feeder ACTIVE HEALTHY
- Feeder OUTAGE
- Section fed from Healthy NEIGHBOR
- Feeder MAINTENANCE



Substation

Cause of OUTAGE



RC Switchgear OFF



RC Switchgear ON



RC Switchgear LOCKED

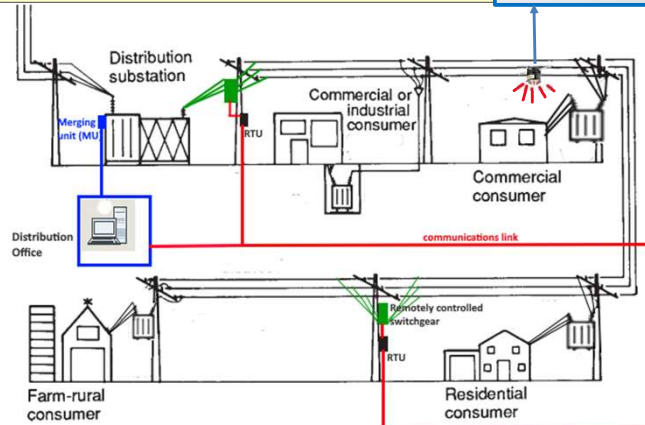
Overhead Feeder Fault Detector/Indicator

- The Overhead Feeder Fault Detector is a device that locates and signals the presence of short circuits and earth faults in overhead line networks



Two variants commonly exist:

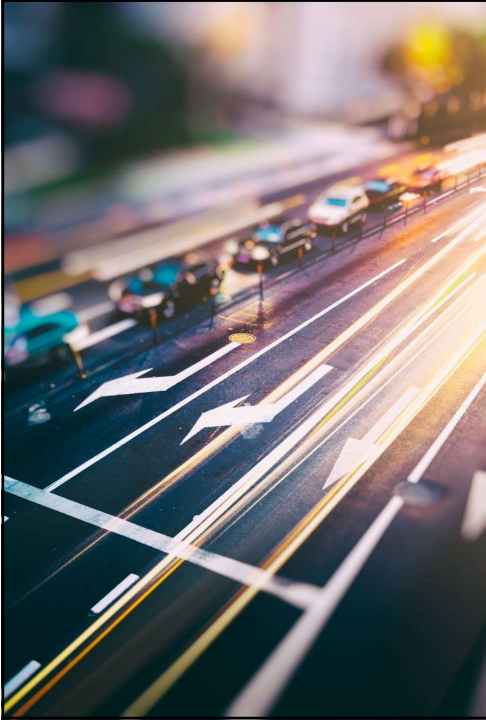
- **With communication** (The fault event is transferred to a gateway by a secured short-range radio channel for processing by the DAS) and
- **without communication** (The faults are signaled directly at the device by LEDs.)



Overhead Feeder Fault Location

- Thermovision cameras, also known as thermal imaging cameras, are used to detect temperature anomalies in distribution feeders
- They can be used to monitor feeders for unbalanced loads, insulation breakdowns, hot joints and hot spots in distribution feeders.
- For proper detailed documentation, It is good to use this before the fault detection activity has taken place and after the supply to the feeder is restored.





SUMMARY

- The driving objective of reducing forced outages is quick service restoration, and maximizing the number of customers restored
- During supply restoration activities, The overall objectives are:
 - 1. Energizing the healthy section as early as possible
 - 2. Restoring the faulty point as early as possible
- A systematic method of properly recording outage incidents is helpful for analysing accumulated outage data, planning and implementing countermeasures and verifying the effectiveness of countermeasures



1. Introduction to Power Quality Analysis

The term **power quality** refers to a wide variety of electromagnetic phenomena that characterize the voltage and current at a given time and a given location on the power system.

Power quality has become a strategic issue for electricity generating and distribution companies, the operating, maintenance, and management personnel of the service sector and industrial sites, as well as for equipment manufacturers, for several reasons. These include:

1.1. Widespread Use of Equipment Sensitive to Voltage Disturbance and/or Generate Disturbances Itself

Because of their numerous advantages (flexible operation, excellent efficiency, high-performance levels, etc), there has been tremendous development and widespread use of *automated systems* and *adjustable speed drives* in the industries, information systems, and compact fluorescent lighting (CFLs) in the service and domestic sectors. These equipment are not only sensitive to voltage disturbance but also contribute to the generation of disturbance and power quality degradation themselves.

Their multiple uses within individual processes require an electrical power supply that can provide ever-increasing performance in terms of continuity and quality. The temporary shutdown of just one element in the chain may interrupt the whole production/manufacturing facilities or delivery of services (such as data processing centres, banks, telecommunications, etc).

Consequently, stricter standards and recommendations have been set and approved by both local and international electrical standard institutions like the International Electrotechnical Committee (IEC), the Institute of Electrical and Electronic Engineers (IEEE), the Nigeria Electricity Regulatory Commission (NERC), etc.

1.2. The Economic Necessity for Businesses to Increase Their Competitiveness with Uninterrupted and Quality Power Supply

Power quality degradation comes with certain costs to businesses. Cost reduction is thus taken seriously since it is crucial to attaining the economic and competitive operations of companies.

- (1) Reducing costs from oversized installations and high energy bills. Power quality issues lead to:

- Lower energy efficiency, which results in higher energy bills
 - Overloading of the system, causing it to age faster and break down more often.
- (2) Reducing costs related to supply interruptions and quality problems. These costs include production losses, wasted raw materials, restarting production, poor product quality, and delivery delays.
- Disturbances like power interruptions, voltage dips, harmonics, and lightning surges can be very costly.
 - Malfunctions or shutdowns of essential equipment (like computers, lighting, and safety systems) can endanger lives, especially in places like hospitals, airports, and tall buildings.
 - Costs also cover high-quality, targeted maintenance to prevent potential issues.

These are some of the reasons why professional users of electricity are keen on having quality power supply and so optimize the operation of their electrical installations.

1.3. The Opening Up or Deregulation of the Electricity Market

The rules governing the electricity sector are undergoing radical change globally. Here in Nigeria, with the signing of the Electricity Act 2022, the Nigerian Electricity Supply Industry (NESI) has opened to competition, generation is being decentralized, State governments can now generate and distribute their electricity while (large) electricity consumers may have the opportunity to choose their supplier. In 1985, the Commission of the European Communities (Directive 85/374) considered electricity a product and consequently made it necessary to define its essential characteristics clearly.

In addition, in the context of liberalizing energy markets, the search for competitiveness by electricity companies now means that quality has become a differentiating factor. A ***guarantee of quality*** is a potential criterion of choice for industrial users when looking for an energy supplier.

2. Objectives of Power Quality Study and Enhancements

Power quality studies and enhancements focus on ensuring that electrical systems operate efficiently and reliably. Here are the primary objectives:

2.1. Improve System Reliability

The study aims to identify factors that impact the reliability of the distribution system. This includes analyzing issues such as voltage sags, surges, harmonics, and transient disturbances. Enhancements are then applied to mitigate these issues, ensuring that the distribution network delivers a stable and continuous supply of electricity. Improved reliability helps prevent unexpected outages and disruptions, which are critical for maintaining smooth operations in both residential and industrial settings.

2.2. Enhance System Efficiency

The goal is to optimize the overall performance of the electrical systems. This involves improving the power factor, reducing energy losses, and ensuring efficient operation of equipment. By studying power quality, inefficiencies can be pinpointed and addressed, such as correcting imbalances in the power supply or upgrading outdated equipment. Enhancements may include implementing advanced technologies, such as energy-efficient transformers or capacitor banks, which contribute to better energy management and cost savings.

2.3. Minimize Downtime and Maintenance Costs

Power quality studies help in identifying potential issues that could lead to system failures or degradation. By addressing these issues proactively, the aim is to minimize system downtime and reduce maintenance costs. Enhancements may involve installing diagnostic tools and monitoring systems to detect and address problems before they escalate. This approach not only helps avoid costly repairs but also extends the lifespan of critical equipment, leading to long-term cost savings.

2.4. Ensure Compliance with Standards

Compliance with industry standards and regulations is essential for safety and operational efficiency. Power quality studies ensure that the system meets the required standards for voltage, frequency, and other key parameters. Enhancements are made to align with these standards, which helps avoid regulatory fines and ensures that the power system operates within safe and efficient limits. Regular monitoring and adjustments are necessary to keep up with evolving standards and technological advancements.

2.5. Support Technological Upgrades

As technology evolves, new equipment and systems are introduced, which can impact power quality. Studies help in understanding how these technological upgrades will affect the existing distribution infrastructure. Enhancements are then implemented to

accommodate new technologies, ensuring compatibility and optimal performance. This may involve upgrading infrastructure to handle increased loads or integrating new power quality management tools. Supporting technological upgrades helps in maintaining a future-proof and adaptable power system.

3. Power Quality Definitions

Power quality refers to the consistency and reliability of the electrical power supplied to consumers. It encompasses various aspects such as voltage stability, frequency stability, and the absence of disturbances like transients, harmonics, and flicker. Good power quality ensures that electrical equipment operates efficiently and without interruption or damage.

Electric power anomalies or electromagnetic disturbances come in many forms and go by many forms. The electromagnetic disturbances that are likely to disturb the correct operation of industrial equipment and processes are generally ranked in various classes relating to conducted and radiated disturbance:

- low frequency (< 9 kHz) disturbances
- high frequency (≥ 9 kHz) disturbances
- electrostatic discharge (ESD).

It is worth noting that, although not mentioned as a separate category, the power system itself is a major contributor to existing power quality problems, especially continuity, and the quality of grounding connections.

Key elements of power quality include:

Voltage Stability: Maintaining a steady voltage level within specified limits to prevent over-voltage or under-voltage conditions.

Frequency Stability: Keeping the frequency of the electrical supply consistent to ensure the proper functioning of equipment designed to operate at a specific frequency.

Minimal Harmonics: Reducing distortions in the electrical waveform that can cause overheating and malfunctions in sensitive equipment.

Low Transients: Minimizing sudden surges or spikes in voltage that can damage equipment.

Continuous Supply: Ensuring an uninterrupted power supply to avoid downtime and operational disruptions.

Proper Grounding: Effective grounding to enhance safety and minimize electrical noise and disturbances.

Power quality in the distribution network ensures that electrical power is delivered in a stable, reliable, and clean manner, supporting the optimal performance and longevity of electrical devices and systems.

4. COMPONENTS OF POWER QUALITY

The categories of ***power system disturbances or anomalies*** are:

- (1) Transients
- (2) Voltage Dips and Interruptions
- (3) Voltage Sags and Swells
- (4) Overvoltage and Undervoltage
- (5) Voltage Unbalance
- (6) Electrical Noise (or Electromagnetic Interference, EMI)
- (7) Harmonic Distortion
- (8) Voltage flickers

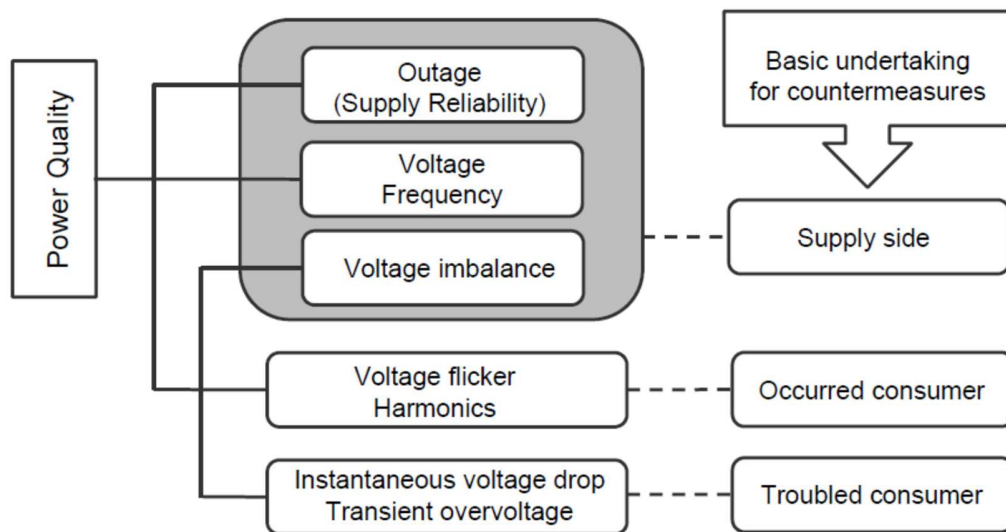
These anomalies can be placed in four categories affecting the:

- (1) Magnitude
- (2) Waveform
- (3) Frequency and
- (4) Symmetry of the voltage or current.

Disturbances can also be classified according to their permanent, semi-permanent, or random nature (lightning, short-circuit, switching operations, etc).

Of these anomalies, transients, overvoltage, and voltage harmonic distortions are the three potentially destructive disturbances passed on to customers externally.

Power quality refers to the characteristics of electrical power that affect the performance of electrical equipment and devices. It encompasses various aspects of the electrical supply, including voltage, current, frequency, waveform, and harmonics. Here are some key components of power quality as outlined in the diagram:



A. Power outages (supply reliability), which are disruptions in the electricity supply, can have a significant impact on power quality.

1. Voltage Sags and Swells: Power outages can cause voltage sags (temporary drops in voltage) or swells (temporary increases in voltage). These fluctuations can damage sensitive equipment and disrupt the normal functioning of electrical devices.
2. Transients: Power outages often lead to voltage transients or surges when power is restored. Transients are sudden and brief spikes in voltage that can damage equipment or cause data loss.
3. Voltage Frequency: Power outages can also affect the frequency of the electrical supply. The frequency should ideally remain stable at the rated value (e.g., 50 Hz or 60 Hz), but during an outage, the frequency may deviate from the normal range. This can impact the operation of time-sensitive devices or cause issues with motors and rotating machinery.
4. Voltage unbalance/imbalance: Voltage unbalance occurs when the voltages in a three-phase power system are not equal. It can be caused by imbalances in loads, faults in the distribution network, or phase-to-phase faults. Voltage unbalance can lead to overheating of motors, reduced efficiency, and increased current harmonics.

B. Voltage Harmonics: Harmonics are additional frequencies that exist alongside the fundamental frequency of the power system. They are typically caused by nonlinear loads such as computers, variable speed drives, or fluorescent lighting. High levels of

harmonics can lead to overheating, equipment malfunctions, and interference with communication systems.

C. **Voltage Flicker:** Voltage flicker refers to rapid voltage fluctuations caused by sudden changes in load or disturbances in the power system. It can cause visual disturbances in lighting and affect the performance of sensitive equipment like computers.

D. **Voltage Transients:** Voltage transients, also known as surges or spikes, are short-duration high-voltage events that can occur due to lightning strikes, switching operations, or equipment faults. They can damage or degrade electronic components.

4.1. Transients

Transients are short-duration disturbances characterized by rapid voltage changes. These disturbances typically have frequencies ranging from tens to hundreds of kilohertz, and sometimes even into the megahertz range. Voltage excursions can vary from hundreds to thousands of kilovolts. Voltage disturbances lasting less than half a cycle ($\Delta T < T/2$) are considered transients. Common causes include the energizing of capacitor banks, fault isolation by a fuse or a fast LV circuit breaker, and commutation notches from polyphase converters.

4.1.1. Sources of Transients

Transients are also known as spikes, impulses, and surges. They can be generated from various sources within a building or office, including:

- (1) **Switching of Devices:** Intentional or automatic switching operations, such as maintenance, load transfers, or fault isolation, can generate transients. Examples include switching transformers, transmission lines, and capacitor banks.
- (2) **Lightning or Electrostatic Discharge (ESD):** Lightning strikes, whether direct or indirect, can cause significant transients. ESD, a smaller-scale discharge of static electricity, can also generate harmful spikes.
- (3) **Arcing:** Poor or degraded wiring connections, such as loose phase conductors, can cause arcing, resulting in transients.

4.1.2. Types of Transients

Normal Transient: Occurs during routine operations like switching transformers or transmission lines, causing slight deviations from steady-state values. During a normal transient, the variables defining the state do not differ greatly from their values in the steady state.

Fault Transient: Caused by faults or accidental changes like asymmetrical ground faults, short circuits, or erroneous circuit breaker operations, leading to sharp discontinuities in system variables.

4.1.3. Causes of Transients

4.1.3.1. Switching-caused Transients

In power systems operations, it is often necessary to intentionally perform switching operations on different components (like transmission lines, transformers, and generators) to suit the demands for power from time to time, like maintenance. Besides such intentional switching operations, there are other unintentional or automatic switching operations during ground faults, short circuits, breaking of conductor, and lightning strokes, which are governed by the magnitude of the disturbance caused by the switching processes.

Switching operations, whether intentional or due to faults, can cause transient disturbances. For example, switching power-factor-correction capacitor banks generates transients that, while less powerful than lightning, still pose risks. Large reactive loads, like motors or HVAC systems, can also generate spikes when switched on or off.

The response of the power system under such electric disturbances resulting from switching, lightning or arcing is often termed the TRANSIENT performance of the system. Such transient phenomena are rather slow, and the transient state of the system would decay within one or two seconds.

4.1.3.2. Lightning-caused Transients

Lightning is the discharge of stored electricity in clouds. This discharge may occur between two points in the clouds, or between a cloud and the earth. Quite often, lightning strikes something projecting up from the earth such as a telephone pole or a transmission line. If this happens, the lightning's energy is dumped into the power lines. Transients generated from *direct strikes* have the greatest potential for damaging equipment – both for the utility and the customer.

Lightning is the most destructive cause of transients. It can induce direct strikes, dumping energy into power lines, or indirect strikes, inducing significant energy into nearby lines. Both can cause substantial damage to equipment.

But lightning does not have to strike the power lines to cause spikes. A strike in the vicinity of the lines can induce enough energy in them to cause a significant transient with a lot of punch. Such strikes are called *indirect strikes*.

4.1.3.3. Arcing-caused Transients

Another source of transients is *arcing*. Arcing occurs when there are poor or degraded connections in the wiring system. A loose phase conductor in a panel is a good example. When the loose wire moves, arcs result, and this creates spikes. Arcing is almost always associated with other disturbances. Momentary interruptions, higher voltage distortion, and sags are likely results of arcing.

4.1.4. Solutions to Transients

Mitigating transients involves several strategies:

- (1) **Lightning Arrestors:** Essential for protecting against lightning-induced transients. A quality system should include proper grounding and maintained conduction path clearances.
- (2) **Transient Voltage Suppressor System (TVSS):** Complementary to lightning arrestors, TVSS can reduce transient energy reaching equipment.
- (3) **Power Conditioners:** Technologies like transformer-based power conditioners can prevent the side effects of transients.
- (4) **TVSS for Switching Transients:** Large- and small-scale TVSS systems can reduce spikes from switching transients. Additional mitigation devices, such as computer-grade power line conditioners, may be necessary.
- (5) **Data Line Protectors:** To prevent "back-door hits" where transients enter through I/O ports, data line protectors are used to safeguard connected components.

4.2. Voltage Dips and Interruptions

Utilities periodically perform large grid switching to maintain system performance, which can introduce momentary voltage dips and interruptions. These disturbances range from less than a cycle to several cycles, acting as very brief outages.

4.2.1. Definitions of Voltage Dip and Interruption

- **Voltage Dip:** This is defined by IEC 61050-161 as a sudden reduction of voltage at a point in an electrical power system, followed by recovery within a few cycles to a few seconds. It's typically detected by calculating the root mean square (rms) value over one cycle every half-cycle.

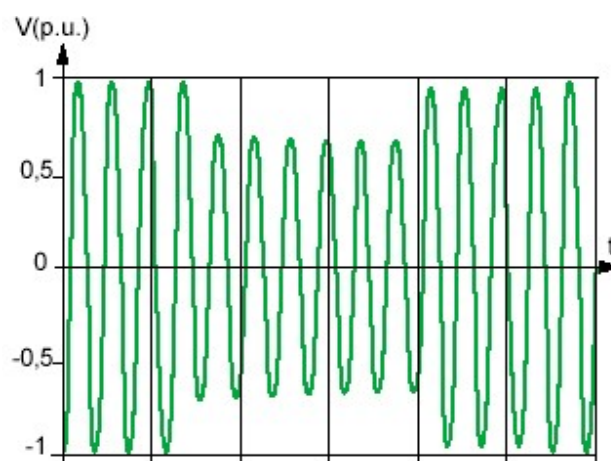


Fig 1: Characteristic Waveform of a Voltage Dip.

- **Voltage Interruption:** A special type of voltage dip where the voltage drops to a few percentages of the nominal value, typically between 1-10%. They are characterized by duration.

Most of these interruptions are overshadowed by the utility's distribution system. The interruption hardly exists by the time it gets to most customers. But for those customers close to substations, or those who have distribution switches at their service entrance, momentary interruptions are important concerns.

The electronic devices in a customer's business will probably withstand short-duration interruptions during change. However, the equipment will respond adversely to longer interruptions.

The power supplies may not be able to keep the DC voltage perfectly stable, contributing to equipment problems like **lockups** and **restarts**.

4.2.2. Characterization of Voltage Dip

A voltage dip is characterised by two parameters.

- depth: ΔU (or its magnitude U),
- duration ΔT .

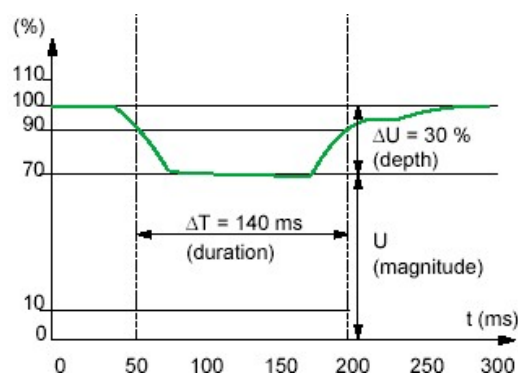


Fig 2: RMS Value of a Voltage Dip

Voltage interruptions are a special type of voltage dip to a few percentages of U_{ref} (typically, within the range of 1-10 %). They are *characterised by one parameter only: the duration*.

Short interruptions last less than one minute (extended to three minutes depending on network operating conditions) and often result from tripping and automatic reclosure of a circuit breaker designed to avoid long interruptions that have a longer duration.

Short and long interruptions differ in both their origins and the solutions required to prevent or reduce their occurrence.

Different terms are used depending on the length of the dips and interruptions:

- Instantaneous ($T/2 < \Delta T < 30 T$),
- Momentary ($30 T < \Delta T < 3 s$),
- Temporary ($3 s < \Delta T < 1 \text{ min}$),
- Sustained interruption and undervoltage ($\Delta T > 1 \text{ min}$).

Depending on the context, the measured voltages may be between live conductors (between phases or between phase and neutral), between live conductors and earth (ph/earth or neutral/earth), or between live conductors and the protective conductor.

4.2.3. Causes of Voltage Dips and Interruptions

Voltage dips and short interruptions are mainly caused by phenomena leading to high currents, which in turn cause a voltage drop across the network impedances with a magnitude that decreases in proportion to the electrical distance of the observation point from the source of the disturbance.

Voltage dips and short interruptions have various **causes**, namely:

- (1) Faults on transmission (HV) or distribution (MV or LV) networks or on the installation itself
- (2) Switching of large loads (asynchronous motors, arc furnaces, welding machines, boilers, etc)

The occurrence of **faults** causes voltage dips for all users.

The **duration of a dip** is usually *conditioned by the operating time of the protective devices*. The isolation of faults by protective devices (circuit breakers, fuses) will produce interruptions (long or short) for users supplied by the faulty section of the power system.

Short interruptions are often the result of the **operation of automated systems** on the network such as fast and/or slow automatic reclosers, or changeover of transformers or lines.

Users are subjected to a succession of voltage dips and/or short interruptions caused by intermittent arc faults, sequence of automatic reclosing (on overhead or mixed radial

networks) intended to extinguish transient and semi-permanent faults, or voltage feedback intended to locate the fault.

Long interruptions are the result of the **definitive isolation of a permanent fault** (requiring repairing or replacing any component before re-energising) through protective devices or by the intentional or unintentional opening of a device.

Overhead networks, which are exposed to bad weather, are subject to more voltage dips and interruptions than underground networks. However, an underground feeder connected to the same busbar system as overhead or mixed networks will suffer voltage dips which are due to the faults affecting overhead lines.

4.2.4. Mitigation Solutions

(1) **Enhanced Power Supplies:** Use power supplies with longer ride-through times.

(2) **Energy Storage Devices:** Install standby power systems (SPS) or uninterruptible power systems (UPS) for additional ride-through time.

4.3. Voltage Sags and Swells

4.3.1. Overview

Voltage sags and swells are short-term variations in RMS voltage, lasting from about half a cycle to several seconds. A **sag** refers to a reduction in voltage, while a **swell** refers to an increase in voltage. If these fluctuations persist for longer than a few seconds, they are termed undervoltage or overvoltage respectively.

4.3.2. Causes

Sags and swells primarily result from load changes and system impedance. According to Ohm's Law, changes in current interacting with system impedance led to changes in voltage.

- **Load Changes:** When a large load is turned on, it can cause a voltage sag. Conversely, turning off a load can result in a voltage swell.
- **System Impedance:** The magnitude of sags and swells is influenced by the system impedance, with higher impedance leading to more significant disturbances.

4.3.3. Impact

- **Swells:** Can easily damage equipment, especially power supplies that control various devices.

- **Sags:** Typically, do not cause direct damage but can disrupt operations, leading to issues like data corruption or device lock-ups. For instance, a sag may cause a device to restart, disrupting its function and potentially damaging the product it is working on.

4.3.4. Solutions

- (1) **Increase Wire Size:** Since sags and swells are closely related to wiring or system impedance, increasing the wire size can reduce impedance, thereby minimizing the magnitude of the disturbance.
- (2) **Introduce Energy Storage or Voltage Regulation:** If increasing wire size isn't feasible, using energy storage devices, tap-switching power conditioners, or voltage regulators can help maintain voltage stability and protect equipment.
- (3) **Enhanced Power Supplies:** Products that offer longer ride-through times, such as enhanced power supplies or tap-switching power conditioners, can help manage voltage sags and swells. Standby power systems (SPS) can also be used to switch to temporary backup power during disturbances.

Voltage regulators can be stand-alone devices or integrated with other technologies, such as transformers, to enhance their capabilities.

4.4. Overvoltage and Undervoltage

Overvoltage occurs when the peak value of the voltage applied to a device exceeds the limits defined in a standard or specification. There are three main types of overvoltage:

- (1) **Power-Frequency Overvoltage**
- (2) **Switching Overvoltage**
- (3) **Lightning Overvoltage**

The first two are often grouped as **internal overvoltage**, while lightning overvoltage is called **external overvoltage**.

4.4.1. Power-Frequency Overvoltage

Definition: Overvoltages with a frequency under 500 Hz, usually caused by faults or specific system conditions.

Causes:

- **Insulation Faults:** When an insulation fault occurs between phase and earth in an isolated neutral system or impedance-earthed neutral system, the voltage of the healthy phases to earth may reach the phase-to-phase voltage. Overvoltages on

low-voltage (LV) installations may propagate from high-voltage (HV) installations through the earth of the HV/LV station.

- **System Earthing:** The method of neutral earthing affects overvoltage magnitude. Solid neutral earthing reduces overvoltage in healthy phases but increases short-circuit current. Resistive or reactive earthing limits short-circuit current but leads to higher overvoltage in healthy phases.
- **Overvoltage Ratio:** The ratio of overvoltage in healthy phases to the normal operating voltage depends on the zero-sequence impedance to the positive-sequence impedance.

$$\frac{V_{over}}{V_n} \approx \sqrt{3} \left[\frac{\sqrt{n_0^2 + n_0 + 1}}{n_0 + 2} \right]$$

where V_n = nominal operating voltage

V_{over} = overvoltage

$n_0 = Z_0 / Z_1$

Z_0 = zero sequence impedance

Z_1 = positive sequence impedance

For a solidly earthed network, $n_0 < 3$. For $n_0 = 3$, $V_{over} / V_n = 1.25$.

- **Ferroresonance:** A rare, non-linear oscillatory phenomenon involving a circuit with a capacitor and a saturable inductance, such as a power transformer. It can cause severe malfunctions or destruction of devices.
- **Break of the Neutral Conductor:** Devices powered by the phase with the least load may experience a voltage increase, sometimes up to the phase-to-phase voltage.
- **Faults on Alternator Regulators or Tap-Changing Transformers:** These can lead to improper voltage regulation and overvoltage.
- **Overcompensation of Reactive Power:** Shunt capacitors can cause voltage increases, especially during low load periods.

Applications:

- For extra high voltage (EHV) systems, transformers should have reduced insulation towards the neutral side of the winding, and all neutral points should be solidly earthed to minimize overvoltage and reduce transformer costs.

4.4.2. Switching Overvoltage

Definition: Switching overvoltages are caused by rapid modifications in the network structure, such as opening or closing protective devices. These overvoltages are characterized by their oscillatory nature and can be divided into:

- **Normal Load Switching Overvoltage:** Occurs during regular switching operations, like connecting or disconnecting capacitive circuits, and can produce transient overvoltages.
- **Tripping of Long Transmission Lines:** Transitioning from a fully loaded to a no-load condition on a transmission line can result in significant overvoltage, particularly due to the Ferranti Effect, where voltage builds up along the line and can double at the open end.
- **Transient Overvoltage:** After clearing a short circuit, the transient overvoltage across circuit breaker contacts can reach up to 280% of the crest value of the system's phase-to-neutral voltage.

Examples:

- **Capacitor Bank Energization:** This can produce a transient overvoltage with the first peak reaching up to $2\sqrt{2}$ times the RMS value of the nominal voltage and a transient overcurrent with a peak value of up to 100 times the rated current of the capacitor.
- **Ferranti Effect:** Sudden switching in of a long off-load line can result in a voltage build-up, potentially doubling the magnitude at the open end of the line. In the absence of any damping, the voltage may reach double its peak or crest value of the phase. The damping and the distortion during propagation of the wave (due to I^2R losses, skin effect, and the corona effect) decrease the magnitude of the transient overvoltage and the steepness of the wave. The *overvoltage factor* is around 1.05 for a 300 km line and 1.16 for a 500 km line.
- **Short Circuit Removal:** After a short circuit is cleared, transient overvoltage across the circuit breaker contacts can reach 280% of the crest value of the system phase-to-neutral voltage. The main oscillation frequency varies from a few hundred to a thousand hertz. The frequency of the oscillation depends on the number of incoming circuits and the line lengths. The frequency decreases both when the operating voltage of the system increases and the short circuit MVA increases.

Generally, the effect of switching overvoltage is more severe for radial lines than for lines connected in ring or meshes networks. For radial lines, the *overvoltage factor*, which is

defined as the ratio of the overvoltage to the nominal voltage, can be as high as 1.90, whilst for meshed networks, it is hardly 1.28. In practice, the stationary overvoltage due to on-load tripping does not exceed 130% of the normal operating voltage for lines of about 300 km length.

4.4.3. Lightning Overvoltage

Definition: Lightning overvoltages are caused by atmospheric lightning strikes, which generate high-voltage transients that can affect electrical systems. Lightning strikes can either directly hit power lines or induce voltage spikes from nearby strikes, leading to significant overvoltage.

Types:

- **Direct Lightning Strikes:** Occur when lightning directly strikes a line or structure, causing a surge in voltage.
- **Indirect Lightning Effects:** Include induced overvoltages and increased earth potential, which can still affect equipment even if the strike is not direct.

4.4.4. Solutions to Overvoltage and Undervoltage

- **Surge Protection Devices (SPDs):** Install SPDs to protect against transient overvoltages caused by switching or lightning.
- **Proper Earthing:** Ensure proper earthing practices to mitigate the effects of power-frequency overvoltage.
- **Voltage Regulators:** Use voltage regulators to maintain stable voltage levels and protect equipment from both overvoltage and undervoltage.
- **Uninterruptible Power Supplies (UPS):** For undervoltage conditions, UPS can provide temporary power and maintain equipment operation during voltage sags.

4.4.5. Undervoltage

Definition: Occurs when the voltage falls below the specified limits, leading to inadequate operation or damage to electrical equipment.

Causes:

- Load changes, poor power distribution, and faults in the power system can lead to undervoltage conditions.

Impact:

- Undervoltage can cause equipment to malfunction, reduce performance, or sustain damage due to insufficient power supply.

Solutions:

- **Voltage Stabilizers:** Maintain steady voltage supply during undervoltage conditions.
- **Uninterruptible Power Supplies (UPS):** Provide temporary power to prevent equipment shutdowns.

Understanding and managing overvoltage and undervoltage conditions is essential for maintaining the reliability and longevity of electrical systems.

4.5. Voltage Unbalance

Voltage unbalance in a 3-phase system occurs when the RMS values of the phase voltages or their phase angles are not identical. This unbalance can lead to inefficient operation, overheating, and even damage to equipment designed to operate with balanced 3-phase power.

Understanding and managing voltage unbalance is crucial for ensuring the reliable operation of electrical systems, especially in industrial and commercial environments where 3-phase equipment is common.

4.5.1. Degree of Unbalance

The degree of unbalance is quantified using Fortescue's symmetrical components, which decompose an unbalanced system into three sets of balanced components:

- (1) **Positive Sequence Component (U_{1d}):** Represents the balanced portion of the system.
- (2) **Negative Sequence Component (U_{1i}):** This represents the unbalanced portion that rotates in the opposite direction to the positive sequence.
- (3) **Zero Sequence Component (U_{1o}):** Represents any imbalance in the system that is the same in all phases.

The degree of unbalance is typically defined by comparing the negative sequence component to the positive sequence component. This comparison can be done using the following approximate formula:

$$\text{Percentage Unbalance} = \frac{(U_{1i} \text{ or } U_{1o})}{U_{1d}} \times 100$$

Where:

- U_{1i} = Negative sequence component of the voltage

- U_{1o} = Zero sequence component of the voltage
- U_{1d} = Positive sequence component of the voltage

4.5.2. Causes of Voltage Unbalance

Voltage unbalance arises primarily from:

- **Unbalanced Loads:** Loads that draw different amounts of current from each phase can cause voltage unbalance. Examples include:
 - **Single-phase loads** (e.g., household appliances connected between one phase and neutral)
 - **Two-phase loads** (e.g., certain industrial equipment like welding machines or induction furnaces)
- **Network Impedances:** The unbalanced current drawn by unbalanced loads causes different voltage drops across the network impedances, leading to unbalance.
- **Faults:** Single-phase or two-phase faults in the system can create unbalance until protective devices trip and isolate the fault.

4.5.3. Effects of Voltage Unbalance

- **Equipment Overheating:** Motors and other 3-phase equipment may overheat, leading to reduced efficiency and potential failure.
- **Reduced Performance:** The efficiency of motors and other equipment may drop significantly in the presence of unbalance.
- **Increased Losses:** Additional losses occur in the power system due to the unbalanced currents.

4.5.4. Mitigation of Voltage Unbalance

- **Balancing Loads:** Distribute single-phase loads evenly across all three phases to minimize unbalance.
- **Using Unbalance Correction Devices:** Devices such as phase balancers can be employed to mitigate the effects of unbalance in critical applications.

- **Regular Monitoring:** Continuously monitor the system to detect and correct imbalances as early as possible.

4.6. Electrical Noise (or Electromagnetic Interference, EMI)

Electrical noise, sometimes called electromagnetic interference, EMI, consists of high frequency, low voltage signals coupled onto the power lines. Frequencies may vary from the kilohertz to the megahertz range, and magnitudes may be up to 10 or 20 volts.

The source of EMI may be:

- *conducted*, meaning it started out on the power lines, or
- *radiated*, meaning it started out in the air and was coupled into the power lines

If EMI is radiated, it could also couple into data cables. This is one reason most data cables are shielded. Shielding protects the high frequency noise from entering the cable and disrupting data flow. High frequencies found in things like electrical noise, travel through power lines and couple onto the DC voltage and signal lines in devices. And so, data may be corrupted from the source, or while travelling to another device.

Just about all electronic devices have EMI filters built into their power supplies. And so the question arises as to how EMI gets into a device if it has a filter. The answer, quite often, is through the ground. We think of ground as some vast sink for unwanted electrical garbage. Yet, *at high frequencies, ground is one more conduction path for noise.* The ground is the digital reference for the device.

Noise can travel along the ground and affect the circuits and components inside or, if data cable shields are not properly terminated, noise can enter through them.

EMI is seldom damaging in and of itself, But, like voltage sags, EMI indirectly causes damage and loss of product. EMI can cause disruption in sensitive devices. An example would be in a process control computer regulating gasoline dispensing. EMI may confuse the computer, causing it to pump more gasoline than requested.

Solutions to EMI or Noise

Should EMI be a problem, there are a few typical solutions

- The first solution is to *locate where the interference* is coming from and remove or relocate the victim or culprit.
- The second is to isolate the victim or culprit by using an *EMI filter*.
- To reduce EMI data flow problems, ensure that all system components and devices are *properly grounded*. This includes all data cables. If necessary, isolated ground systems should be installed.

- The final solution is very complicated. It is possible that the interference in the power lines began as interference in air, or what is called radiated EMI. If this is the case, then steps must be taken to identify and locate the source, identify its frequency, and then provide protection to the victim. This protection often takes the form of placing a *conductive shield* around the device to isolate it from the EMI. Obviously, this is complex and costly.
- If problems still exist with distributed systems, consider using fibre-optic data transmission. Since fibre-optic cables are non-conductive, no EMI coupling will occur.

4.7. Harmonics

The fundamental waveform is altered by harmonics, which are undesirable higher frequencies overlaid on it. A harmonic is a wave or signal whose frequency is an integral (whole number) multiple of the frequency of the same reference signal or wave. As part of the harmonic series, the term can also refer to the ratio of the frequency of such a signal or wave to the frequency of the reference signal or wave.

4.7.1. Causes of Harmonics

In recent years, due to the rapid progress of power electronics technology using semiconductors and thyristors, semiconductor application equipment has become widely used in home appliances, general-purpose inverters, and industrial equipment. As a result, harmonic currents generated from an unspecified number of home appliances, general-purpose products, and large-capacity industrial equipment flow out to the distribution network, distorting the voltage of the distribution network. The harmonic distortion, which shows the difference between the actual network voltage or load current and the ideal sinusoidal waveform, is the primary indicator of power quality.

The following are some consequences the harmonics may have on the installation, the machinery, or both:

- Increased efficiency losses in the electrical installation and equipment-based system.
- Unexpected reverberations
- "Logical" errors in digital circuits are brought on by disturbances in electronic equipment.
- Unwanted overload for transformers and wires, or requirement for oversizing
- Problems with generators and motors
- Unwanted tripping of circuit breakers or blowing of fuses.

Harmonics mitigation can provide industry-critical processes, IT systems, data centers, etc. with demonstrable advantages in terms of installation costs overall, energy bill savings, and protection from equipment breakdowns and process interruptions.

4.7.2. Influence by harmonics

Harmonics cause damage to the high-voltage phase lead capacitors (abnormal noise of the capacitor body, abnormal sound of the series reactor, overheating, burnout). In addition, many existing capacitors are operated without series reactors, and the voltage distortion is further expanded by harmonic resonance between these capacitors and the impedance of the distribution network.

Here are a few instances of problems that harmonics may be involved with.

Lighting that flicker is frequently a sign of a power quality problem. Machinery that experiences sudden changes in load current or voltage is a potential cause of flickering lights. Large motors that are starting up are among these machines, as are devices that use cyclo-converters, such as mine winders and rolling mill drives, as well as equipment that use static frequency converters, like AC motors and electric arc furnaces.

Harmonic problems, which happen when non-linear loads draw current in sharp pulses rather than smoothly sinusoidally, can cause harmonic currents to flow back into other components of the power system, leading to overheated transformers and tripped breakers.

Table: Limits of Harmonic Current Distortion

Harmonic Order (n)	Low Voltage	Low Voltage	Medium Voltage
	Contracted Power less than 10 kW	Contracted Power greater than 10 kW	
	A	%	%
(odds no multiples of 3)			
5	2,28	12	12
7	1,54	8.5	8.5
11	0,66	4.3	4.3
13	0,42	3,0	3,0
17	0,26	2.7	2.7
19	0,24	1.9	1.9
23	0,20	1.6	1.6
25	0,18	1.6	1.6
> 25	4,5/n	$0.8 + 0.8 \cdot 25/n$	$0.8 + 0.8 \cdot 25/n$

(odds multiples or 3)			
3	4,6	16.6	16.6
9	0,8	2.2	2.2
15	0,3	0.6	0.6
21	0,21	0.4	0.4
> 21	4,5/n	0.3	0.3
(even)			
2	2,16	10.0	10.0
4	0,86	2.5	2.5
6	0,60	1.0	1.0
8	0,46	0.8	0.8
10	0,37	0.8	0.8
12	0,31	0.4	0.4
> 12	3,68/n	0.3	0.3
Total	240 V Users: 5 A 400 V Users: 14 A	20.0%	20.0%

Source: The Distribution Code for the Nigeria Electricity Distribution System (NERC)

4.7.3. Countermeasures of harmonics

Most of the harmonic disturbances occur in high-voltage phase lead capacitors, but the cause is that capacitors without series reactors expand the harmonics of the distribution network and the harmonic withstand capability of the series reactor is insufficient. It is required to operate in combination with a series reactor with an appropriate harmonic withstand capability not only for large capacitors but also for small capacitors.

There are two options for dealing with this.

- (1) By adding filters, the harmonics can be reduced.
- (2) Replace the transformer with one that can handle the distortion and has a high K factor.

Both two systems have advantages and drawbacks in terms of price.

Depending on the cause of the harmonic distortion, installing filters may prove to be both

economically and technically highly beneficial. Harmonic analyses of the system's associated equipment are necessary to determine the precise source(s). Consider which equipment uses the most current, such as huge drives or high-power UPS systems, to determine which ones have the highest THD present. A good place to start is with the largest electronic drives. Over a few days, gather as much harmonic data as you can to observe how the THD varies and describe the worst-case possibilities. A filter supplier can then be informed of this information and offer suggestions for the best options for each load. The issue may only be caused by one or two pieces of equipment. The worst-case scenario is that you require a larger system, but a supplier can once again provide advice on an appropriate solution.

Transformer replacement is more challenging. The K-factor—the harmonic heating effect—cannot yet be discovered without harmonic surveys. A proper instrument can calculate the K factor for you, but an IEEE-recommended approach is used to deduce it from the harmonics. The installation of a new transformer can be disruptive and result in significant downtime. K-factor-rated transformers are more expensive than normal transformers. But occasionally, this can be the only workable option.

4.8. Voltage flickers

4.8.1. Causes and Influence of Voltage Flicker

Voltage flicker is a phenomenon in which the distribution voltage continuously repeats periodic fluctuations for a short time due to load fluctuations and may cause adverse effects such as flickering of lighting and malfunction of equipment. Typical loads that cause electric melters, arc furnaces, tunnel excavators, etc. are known, but recently it has been reported that they are generated from devices using power electronics.

According to the NERC D-Code, the Flicker Severity at the Connection Point of any User, shall not be above the maximum values stated in IEC 61000-3 Standard for more than 3 % of the measured period. Likewise, the maximum emission limits produced by any User shall be below the maximum values stated in IEC 61000-3 Standard.



4.8.2. Countermeasures of voltage flicker

Countermeasures of voltage flicker for high-voltage users include methods to reduce grid

impedance and reactive power other than installing dedicated distribution lines.

a. Reduce grid impedance

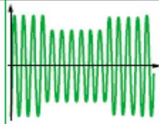
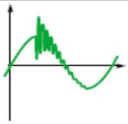
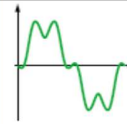
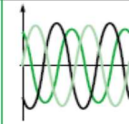
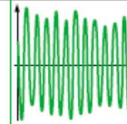
To reduce the impedance of the system (1) Increases the capacity of the injection transformer. (2) Shorten the length of distribution lines. (3) Increase the conductor size of distribution lines. However, it is especially important to reduce the reactance.

b. Reduce reactive power

There are various ways to reduce reactive power, but the current mainstream is the installation of a static VAR compensator (SVC). SVC adjusts reactive power by turning capacitors and reactors on and off.

4.9. Summary of Origin and Characteristic Waveforms of Electrical Power System Disturbances

Table 1: Summary of Origin and Characteristic Waveforms of Power System Disturbances on Various Equipment and Processes

Disturbances	Voltage dips	Overvoltages	Harmonics	Unbalance	Voltage fluctuations
Characteristic waveforms					
Origin of disturbance					
■ Power system					
□ Insulation fault, break of the neutral conductor...					
□ Switching, ferroresonance					
□ Lightning					
■ Equipment					
□ Asynchronous motor					
□ Synchronous motor					
□ Welding machine					
□ Arc furnace					
□ Converter					
□ Data processing loads					
□ Lighting					
□ Inverter					
□ Capacitor bank					

: Occasional phenomenon
 : Frequent phenomenon

The table above illustrates the types of power quality disturbances, their characteristic waveforms, and the origins of these disturbances. The disturbances are broadly divided

into two categories in terms of their origin: power system causes and equipment-related causes. A characteristic waveform represents each disturbance type to indicate its unique behaviour in the power system. The table also shows the frequency of occurrences of each disturbance in the power system which are occasional and frequent phenomena.

5. VOLTAGE DROPS AND FERRANTI EFFECTS

5.1. VOLTAGE DROPS

Voltage drop is also a quantity associated with voltage, but it is not the same as voltage. Voltage drop is the potential difference caused in the presence of any obstacle in the circuit such as a resistor, an inductor, or a capacitor. It is the lost voltage. It occurs when the supplied energy of a voltage source is reduced as electric current moves through the passive elements (elements that do not supply voltage) of an electrical circuit. In an AC (Alternating Current) system, the voltage drops are due to the combined effects of resistance, inductance, and capacitance.

5.1.1. IEC Standard Voltages (IEC 60038)

IEC 60038 is an International Electrotechnical Commission (IEC) standard that defines standard voltage levels for electrical power systems. This standard ensures compatibility and interoperability of electrical equipment and systems across different countries and regions. Here's an overview of the standard voltages as outlined in IEC 60038:

(1) Nominal Voltage

The standard defines nominal voltages as the specified values at which electrical systems are designed to operate. These values represent the intended voltage levels for reliable and consistent operation.

(2) AC Voltages

IEC 60038 specifies standard nominal voltages for AC power systems, which are typically used for the transmission and distribution of electrical power. These are categorized into three main voltage classes:

- **Low Voltage (LV):**
 - Covers voltages up to and including 1,000 volts.
 - Commonly used in residential, commercial, and small industrial applications.
- **Medium Voltage (MV):**

- Ranges from above 1,000 volts up to and including 35,000 volts.
- Typically used in larger industrial and commercial applications, as well as distribution networks.
- **High Voltage (HV):**
 - Encompasses voltages above 35,000 volts.
 - Primarily used for long-distance transmission of electrical power and large-scale industrial applications.

(3) DC Voltages

IEC 60038 also standardizes nominal voltages for DC (Direct Current) power systems, with the following categories:

- **Low Voltage (LV):**
 - Covers voltages up to and including 1,500 volts.
 - Used in applications such as automotive, marine, and telecommunications.
- **High Voltage (HV):**
 - Encompasses voltages above 1,500 volts.
 - Used primarily in specialized industrial applications and high-voltage DC transmission systems.

(4) Regional Variations

While IEC 60038 provides a global standard for voltage levels, individual countries and regions may have specific variations or deviations based on local requirements and regulations.

(5) Voltage Range Compliance

Adhering to the specified voltage range is crucial for maintaining the stability and safety of electrical systems. IEC 60038 plays a vital role in setting these parameters, ensuring that electricity is supplied within the appropriate voltage range for consistent performance.

This standard is integral to the design, operation, and regulation of electrical systems, providing a framework that supports global electrical infrastructure.

Electricity should be supplied within the voltage range. It is very important to recognize the supply voltage range. IEC Standard Voltages (IEC 60038) is one of the international standards specifying the voltage range.

This publication applies to:

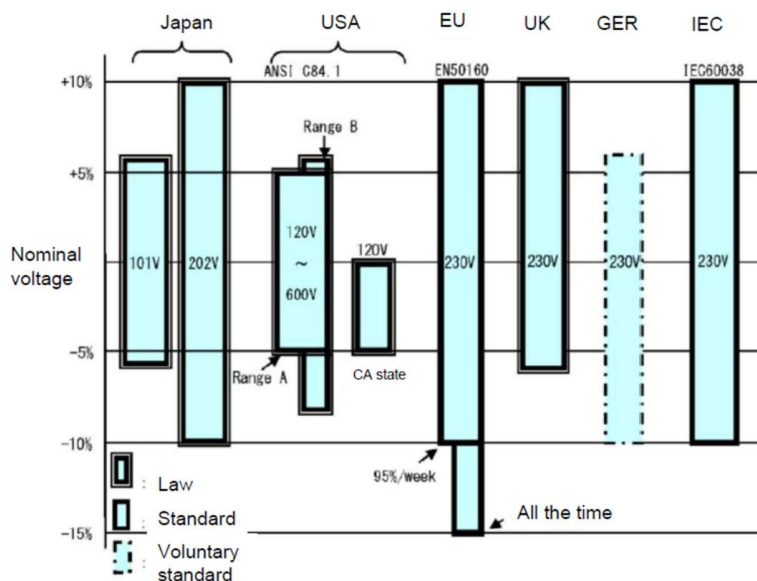
- AC transmission, distribution and utilization systems and equipment for use in such systems with standard frequencies 50 Hz and 60 Hz having a nominal voltage above 100 V;
- AC and DC traction systems.
- AC and DC equipment having nominal voltages below 120 V AC or below 750 V DC, the AC voltages being intended (but not exclusively) for 50 Hz and 60 Hz applications; such equipment covers batteries (from primary or secondary cells), other power supply devices (AC or DC), electrical equipment (including industrial and communication), and appliances.

a. The nominal voltage of AC system in the range from 100V to 1000V

Concerning supply voltage range, under normal operating conditions, the supply voltage should not differ from the nominal voltage of the system by more than $\pm 10\%$.

b. The nominal voltage of AC system in the range from 1kV to 35kV

In a nominal system of series, (except North America), the highest and the lowest voltage do not differ by more than approximately $\pm 10\%$ from the nominal voltage of the system.



Comparison of Supply voltage range

From the diagram above, the supply voltage standards vary between countries and regions. Here's a comparison of supply voltages for Japan, USA, EU, UK, and Nigeria using the following standards: ANSI C84.1, EN50160, and IEC60038.

1. Japan:

- Supply Voltage Standard: 100 V, 200V.
- Frequency: 50 Hz, 60Hz
- Standards: Japan's supply voltage standard is not directly based on ANSI C84.1, EN50160, or IEC60038. The Japanese Electricity Business Law specify the supply voltage as 100/200 V with a frequency of 50 Hz and 60Hz. The standard used in Japan differs from those used in North America and Europe.

2. USA:

- Supply Voltage Standard: 120 V (residential) and 277/480 V (commercial/industrial)
- Frequency: 60 Hz
- Standards: The supply voltage standards in the USA are defined by ANSI C84.1 (American National Standard for Electric Power Systems and Equipment - Voltage Ratings) and IEEE Std 100 (Recommended Practice for Electric Power Systems in Commercial Buildings). ANSI C84.1 specifies voltage ranges, and in residential areas, a nominal voltage of 120 V with a frequency of 60 Hz is common. Commercial and industrial areas often use a three-phase system with a nominal voltage of 277/480 V.

3. European Union (EU):

Supply Voltage Standard: 230 V

Frequency: 50 Hz

Standards: The European Union follows the supply voltage standard specified by EN50160 (Voltage Characteristics of Electricity Supplied by Public Distribution Systems). The standard voltage in most EU countries is 230 V with a frequency of 50 Hz.

4. United Kingdom (UK):

Supply Voltage Standard: 230 V (single-phase), 400 V (three-phase)

Frequency: 50 Hz

Standards: The UK follows the same supply voltage standard as the EU,

which is 230 V with a frequency of 50 Hz for single-phase systems. Three-phase systems in the UK use a standard voltage of 400 V.

5. Nigeria:

Supply Voltage Standard: 230 V (Single-Phase), 400 V (three-phase)

Frequency: 50 Hz

Standards: The Nigeria follows the same supply voltage standard as the UK, which is 230 V with a frequency of 50 Hz for single-phase systems. Three-phase systems in the UK use a standard voltage of 400 V.

5.1.2. Standard Voltage Levels in the Nigerian Electricity Supply Industry (NESI) According to NERC D-Code

The Nigerian Electricity Regulatory Commission (NERC) Distribution Code (D-Code) establishes the standard voltage levels for electrical power systems in Nigeria. These standards ensure uniformity, compatibility, and reliability in the generation, transmission, distribution, and utilization of electricity across the country.

(1) Nominal Voltage Levels:

The D-Code defines nominal voltages as the designated values at which electrical systems are designed to operate under normal conditions. These nominal voltages are critical for the stable operation of electrical equipment and the efficient distribution of electricity.

(2) AC Voltages:

The D-Code specifies standard nominal voltages for AC (Alternating Current) power systems in Nigeria, categorized into three voltage classes:

- **Low Voltage (LV):**

- **Nominal Voltage:** 230/400V (for single-phase/three-phase systems)
- **Application:** This voltage level is typically used in residential, commercial, and light industrial settings.
- **Voltage Tolerance:** $\pm 6\%$ of the nominal voltage, meaning the supply voltage should be within the range of **216.2V to 243.8V** for single-phase systems and **376V to 424V** for three-phase systems.

- **Medium Voltage (MV):**

- **Nominal Voltage:** 11kV, 33kV
- **Application:** Medium voltage is used in larger industrial facilities, commercial centers, and for the distribution of electricity to smaller substations.
- **Voltage Tolerance:** $\pm 5\%$ for 11kV and 6% for 33kV, implying a range of **10.45kV to 11.55kV** for 11kV systems and **31kV to 34.98kV** for 33kV systems.
- **High Voltage (HV):**
 - **Nominal Voltage:** 132kV, 330kV
 - **Application:** High voltage is used for long-distance transmission of electricity and interconnections between major substations and power generation stations.
 - **Voltage Tolerance:** $\pm 10\%$ for both 132kV and 330kV, meaning the voltage should be within **118.8kV to 145.2kV** for 132kV systems and **297kV to 363kV** for 330kV systems.

The summary of the nominal voltages

Nominal Voltage	Operational Voltages	
	Minimum (pu)	Maximum (pu)
330 kV	297 kV (0.90)	363 kV (1.10)
132 kV	118.8 kV (0.90)	145.2 kV (1.10)
33 kV	31 kV (0.94)	34.98 kV (1.06)
16 kV	15.2 kV (0.95)	16.8 kV (1.05)
11 kV	10.45 kV (0.95)	11.55 kV (1.05)

400 V	376 V (0.94)	424 V (1.06)
230 V	216.2 V (0.94)	243.8 V (1.06)

(3) DC Voltage Classifications

While the NERC D-Code primarily addresses AC systems, it acknowledges the presence of DC (Direct Current) systems in specialized applications. However, specific standard voltage levels for DC systems are typically governed by other standards and may vary depending on the application.

- **Low Voltage (LV):**
 - Range: Up to 1,500 volts (V).
 - Application: Used in specialized systems such as telecommunications, automotive, and marine applications.
- **High Voltage (HV):**
 - Range: Above 1,500V.
 - Application: Primarily used in high-voltage DC transmission systems (HVDC), which are not yet widespread in Nigeria but are considered for future high-capacity transmission projects.

(4) Voltage Quality and Compliance:

The D-Code emphasizes the importance of maintaining voltage levels within the specified tolerances to ensure the safe and efficient operation of electrical equipment and to minimize power quality issues such as flicker, harmonics, and voltage unbalance.

Utilities and distribution companies are mandated to ensure that the electricity supplied to end-users remains within the specified voltage range. This is critical for minimizing the risk of damage to electrical equipment, reducing energy losses, and ensuring customer satisfaction.

5.2. Calculation method of voltage drops (33kV, 11kV)

The calculation method for voltage drops in power systems depends on various factors such as the length of the circuit, the current flowing through the circuit, and the resistance and reactance of the conductors.

Here is a general overview of the calculation method for voltage drops in a 33 kV and 11 kV power system:

1. Determine the length of the circuit: Measure or determine the length of the circuit for which you want to calculate the voltage drop. This can be the length of a distribution line, a feeder, or any other part of the power system.
2. Obtain the resistance and reactance values: Determine the resistance and reactance values for the conductors used in the circuit. These values can be obtained from the manufacturer's specifications or through testing.
3. Calculate the impedance: The impedance of the circuit is the combination of the resistance and reactance. Impedance is typically represented as a complex number, where the resistance is the real part, and the reactance is the imaginary part. The impedance can be calculated using the formula: $Z = R + jX$, where Z is the impedance, R is the resistance, and X is the reactance.
4. Determine the current: Determine the current flowing through the circuit. This can be done by measuring the load current or calculating it based on the power consumed by the connected devices.
5. Calculate the voltage drop: The voltage drop can be calculated using Ohm's Law and the impedance of the circuit. The formula to calculate the voltage drop is:

$$V_d = I \cdot Z$$

where V_d is the voltage drop, I is the current, and Z is the impedance.

6. Convert voltage drop to percentage: To express the voltage drop as a percentage, divide the voltage drop by the source voltage and multiply by 100. This gives you the voltage drop as a percentage of the source voltage.

It's important to note that the above method provides a general approach for calculating voltage drops. In practice, power system engineers may consider additional factors such as temperature, power factor, and voltage regulation requirements when performing detailed voltage drop calculations.

$$e = k \cdot L \cdot (R \cos \theta + X \sin \theta) \cdot I = k \cdot L \cdot Z \cdot I$$

e : Voltage drop (V)

k : Constant (for single phase, $k = 2$, and for 3 phase, $k = \sqrt{3}$)

L : Length of the line (km)

R : Resistance of conductor (Ω/km)

X : Reactance of conductor (Ω/km)

Z : Impedance of conductor (Ω/km)

I : Current of the sending end (A)

Cables (example)

33kV Cables	R (Ω/km)	X (Ω/km)	Z (Ω/km) $\cos\theta=0.9$
XLPE 120mm ²	0.199	0.124	0.2332
XLPE 150mm ²	0.164	0.120	0.1999
XLPE 185mm ²	0.132	0.116	0.1694
XLPE 240mm ²	0.102	0.111	0.1402
11kV Cables	R (Ω/km)	X (Ω/km)	Z (Ω/km) $\cos\theta=0.9$
XLPE 120mm ²	0.199	0.103	0.2240
XLPE 150mm ²	0.164	0.100	0.1912
XLPE 185mm ²	0.132	0.097	0.1611
XLPE 240mm ²	0.102	0.093	0.1323

Overhead Conductors (example)

33kV Overhead conductors	R (Ω/km)	X (Ω/km)	Z (Ω/km) $\cos\theta=0.9$
ACSR 100mm ²	0.279	0.276	0.3714
ACSR 150mm ²	0.205	0.365	0.3433
11kV Overhead conductors	R (Ω/km)	X (Ω/km)	Z (Ω/km) $\cos\theta=0.9$
ACSR 100mm ²	0.279	0.276	0.3714
ACSR 150mm ²	0.205	0.365	0.3433

5.3. Calculation method of voltage drops (LV)

$$e = k \cdot L \cdot (R \cos\theta + X \sin\theta) \cdot I = k \cdot L \cdot Z \cdot I$$

e : Voltage drop (V)

k : Constant (for single phase, $k = 2$, and for 3 phase, $k = \sqrt{3}$)

L : Length of the line (km)

R : Resistance of conductor (Ω/km)

X : Reactance of conductor (Ω/km)

Z : Impedance of conductor (Ω/km)

I : Current of the sending end (A)

Overhead Conductors (example)

3 phase 400V	R (Ω/km)	X (Ω/km)	Z (Ω/km) $\cos\theta=0.9$
AAC 50mm ²	0.550	0.397	0.6681
AAC 100mm ²	0.280	0.276	0.3723
AAC 150mm ²	0.190	0.257	0.2831
Single phase 400V	R (Ω/km)	X (Ω/km)	Z (Ω/km) $\cos\theta=0.9$
AAC 50mm ²	0.550	0.397	0.6681
AAC 100mm ²	0.280	0.276	0.3723
AAC 150mm ²	0.190	0.257	0.2831

5.4. Ferranti Effects

5.4.1. Definition

The Ferranti effect, also known as Ferranti's phenomenon, is a phenomenon that occurs in long power transmission or distribution lines carrying alternating current (AC). It refers to the increase in voltage observed at the receiving end of a transmission or distribution line compared to the voltage at the sending end, particularly when the line is lightly loaded or unloaded. It is named after Sebastian Ziani de Ferranti, an electrical engineer who first observed and explained this effect.

The Ferranti effect is primarily caused by the inductive reactance of the transmission or distribution line. When AC current flows through a transmission or distribution line, it creates a magnetic field around the conductor. This magnetic field causes a voltage drop along the length of the line due to the inductance of the line. As a result, the voltage at the receiving end is typically lower than the voltage at the sending end.

However, when the line is lightly loaded or unloaded, the current flowing through it decreases, reducing the magnetic field and the associated voltage drop. This reduction

in voltage drop causes the voltage at the receiving end to increase, resulting in a higher voltage than the voltage at the sending end. This effect is more pronounced in long transmission lines with high inductive reactance.

The Ferranti effect can lead to voltage regulation issues and can potentially cause overvoltage conditions at the receiving end of the transmission line. To mitigate this effect, various compensation techniques such as series capacitors or voltage regulators are employed to maintain the voltage within acceptable limits.

5.4.2. Why Ferranti effect occurs?

Capacitance and inductance are the main parameters of the transmission/distribution lines having a long length. On such transmission or distribution lines, the capacitance is not concentrated at some definite points. It is distributed uniformly along the whole length of the line. When the voltage is applied at the sending end, the current drawn by the capacitance of the line is more than current associated with the load. Thus, at no load or light load, the voltage at the receiving end is quite large as compared to the constant voltage at the sending end.

5.4.3. How to reduce Ferranti effect

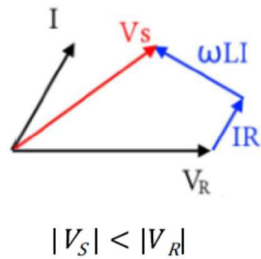
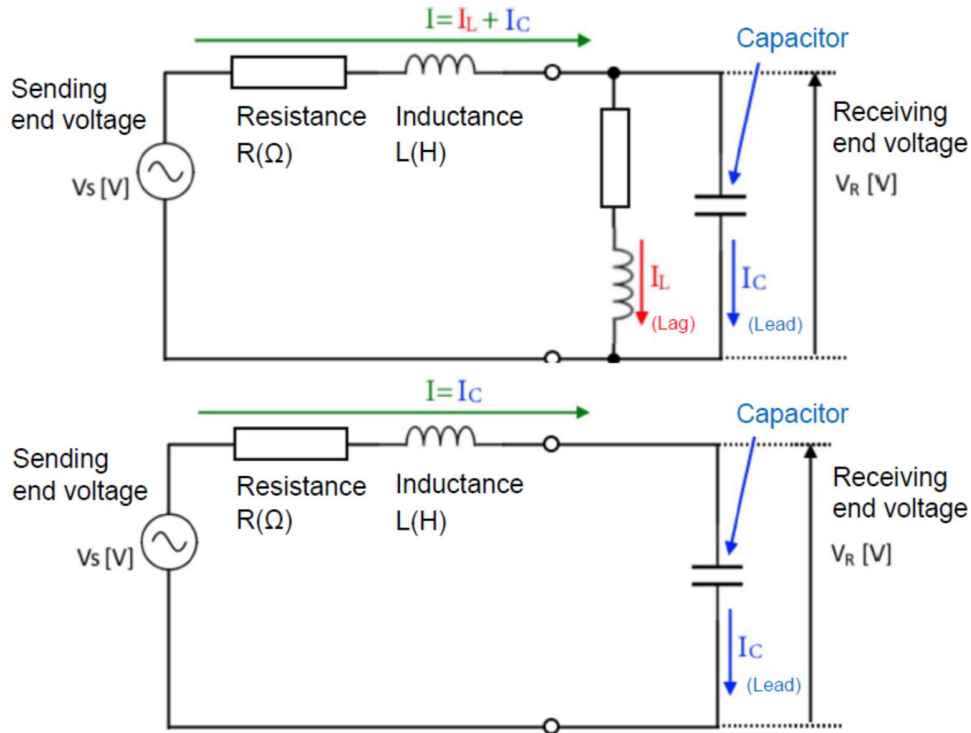
Electrical devices are designed to work at some voltage. If the voltages are high at the user ends their equipment get damaged, and their windings burn because of high voltage. Ferranti effect on long transmission/distribution lines at low load or no load increases the receiving end voltage. This voltage can be controlled by placing the shunt reactors at the receiving end of the lines.

Shunt reactor is an inductive current element connected between line and neutral to compensate the capacitive current from transmission/distribution lines. When this effect occurs in long transmission/distribution lines, shunt reactors compensate the capacitive VAR of the lines and therefore the voltage is regulated within the prescribed limits.

5.5. Calculation method of voltage drops including Ferranti effects

Ferranti effect mainly occurs because of light load or open circuit at the receiving end. The capacitive loads cause a leading power factor as shown in the figure below. In this case, the receiving end voltage V_R is higher than the sending end voltage V_S .

$$V_S = IR + j\omega LI + V_R$$

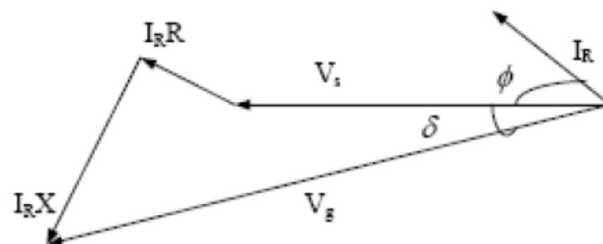
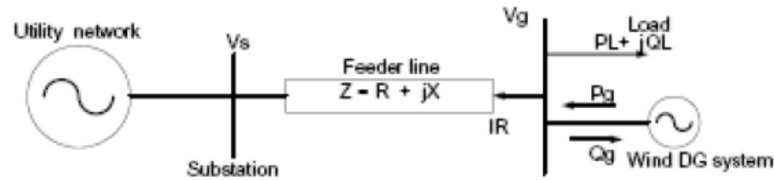


5.5.1. Voltage rise principle by distributed generators.

When generator is connected to a radial feeder, its active power export reduces the power flow from the primary substation and so reduces the voltage drop along the feeder. If the generator power export is larger than the feeder load, power flows from the generator to the primary substation and this causes a voltage rise along the feeder.

The figure below shows a connection of typical wind power generator consisting of the induction machine and wind turbine to the distribution network. The active and reactive powers of the wind generator are P_g and Q_g respectively; P_L and Q_L represent the active and reactive power of the load connected to the distribution system. IR is the net current through the line impedance $Z = R + jX$. The substation voltage and connection point voltage are V_s and V_g , respectively.

In this case, the connection point voltage V_g is higher than the substation voltage V_s .



5.6. Simple calculation method of voltage drops using Excel

To calculate voltage drops using Excel, you need to understand the basic formula for voltage drop and how to apply it using the given parameters. The voltage drop formula is as follows:

$$e = k \cdot L \cdot (R \cos \theta + X \sin \theta) \cdot I = k \cdot L \cdot Z \cdot I$$

Here's a step-by-step explanation of how to perform voltage drop calculations in Excel:

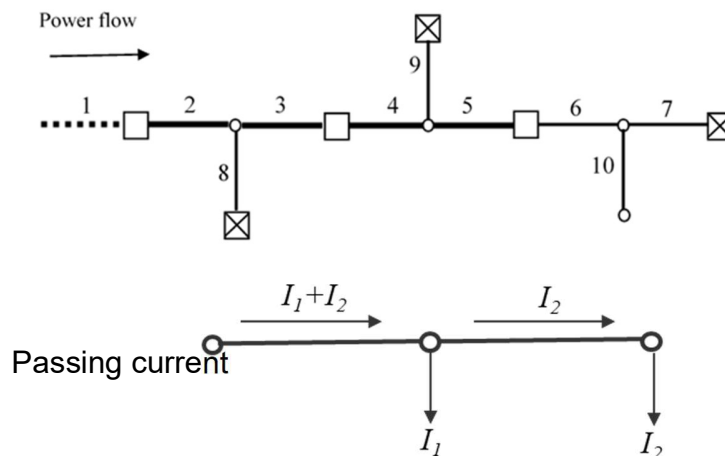
1. Open Microsoft Excel and create a new spreadsheet.
2. Label the columns as follows: Section, Resistance (R), Impedance (Z), Length (L), Conductor (C), Current (I), and Voltage Drop (V).
3. Enter the values for each parameter in their respective columns. For example, you might have section, resistance values in ohms per kilometer (Ω/km), impedance values in ohms per kilometer (Ω/km), length values in kilometers (km), conductor types (such as copper or aluminum), current values in amperes (A), and leave the voltage drop column empty for now. These values can be obtained from the specifications of the electrical system you are working with or cable/conductor manufacturer datasheet use in the system.
4. In the Voltage Drop (V) column, enter the following formula: " $=K * L * Z * I$ ". This formula calculates the voltage drop based on the length (L), impedance (Z), and current (I), multiplied by a constant factor (k). Choose the constant factor (k) based on the circuit to ensure the correct calculation.

- Repeat the formula for each row in the Voltage Drop (V) column, adjusting the cell references as needed to match the respective values in the other columns. For example, if the length is in cell B2, the impedance is in cell C2, and the current is in cell F2, the formula in cell G2 would be " $=K * B2 * C2 * F2$ ".
- Apply the formula to the remaining rows by dragging the bottom right corner of the cell with the formula down to the desired range.
- Once the formula is applied to all rows, the Voltage Drop (V) column will display the calculated voltage drop for each section.

This method assumes that you have the necessary data for section, resistance, impedance, length, conductor, and current. It also assumes that you have determined the appropriate constant factor (k) based on the units used in your calculations.

NOTE:

Remember to double-check your formulae and ensure that you are using consistent units throughout the calculation



Distributed current.

$$e_1 = \sqrt{3} \cdot L_1 \cdot Z_1 \cdot (I_1 + I_2)$$

$$e_2 = \sqrt{3} \cdot L_2 \cdot Z_2 \cdot I_2$$

Section	R (Ω/km)	Z (Ω/km)	Length (km)	R (Ω)	Z (Ω)	Cable, Conductor
1	0.10	0.14	1.00	0.10	0.14	XLPE 240mm ²
2	0.20	0.34	1.00	0.20	0.34	ACSR 150mm ²
3	0.20	0.34	1.00	0.20	0.34	ACSR 150mm ²
4	0.20	0.34	1.00	0.20	0.34	ACSR 150mm ²
5	0.20	0.34	1.00	0.20	0.34	ACSR 150mm ²
6	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
7	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
8	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
9	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
10	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
Total			10.00			

Distributed current(A)				
Section	Current (A)			
1	0			
2	100			
3	100			
4	100			
5	100			
6	100			
7	100			
8	100			
9	100			
10	100			
Total	900			
Passing current(A)				
Section	Current (A)			
1	900			
2	800			
3	600			
4	500			
5	300			
6	200			
7	0			
8	0			
9	0			
10	0			
Total				
Voltage drop(V)				
Section	Voltage drop (V)			
1	218.5			
2	535.2			
3	416.2			
4	356.8			
5	237.9			
6	193.0			
7	64.3			
8	64.3			
9	64.3			
10	64.3			
Max. Voltage drop	2,021.9	at the end of section 7		

5.7. Simple calculation method of voltage drops for the network planning

When formulating of the facilities plan that considers the increase in load for each year, calculate the voltage drop for each year and check that it is within the supply voltage range.

To calculate the voltage drop in a network planning scenario where load increases each year, you can use the formula:

$$e = k \cdot L \cdot (R \cos \theta + X \sin \theta) \cdot I = k \cdot L \cdot Z \cdot I$$

Let's break down the variables in this formula:

e: Voltage drop

k: Constant factor (specific to the unit of measurement being used)

L: Length of the line

R: Resistance per unit length of the line

X: Reactance per unit length of the line

Z: Impedance per unit length of the line

θ : Power factor angle

I: Current flowing through line

Here's how you can calculate the voltage drop for each year:

1. Determine the initial values:

- L: Length of the transmission line
- R: Resistance per unit length of the line
- X: Reactance per unit length of the line
- Or Z: Impedance per unit length of the line
- θ : Power factor angle
- I: Initial current flowing through the line

2. Calculate the voltage drop for the first year:

- Substitute the initial values into the formula: $e = k * L * (R \cos \theta + X \sin \theta) * I$
- This will give you the voltage drop for the first year.

3. Calculate the load increase for the next year:

- Determine the increase in load for the next year, considering the network planning.
- Let's denote this increase as ΔI , $I' = I + \Delta I$

4. Calculate the voltage drop for the next year:

- Multiply the increased load (I') with the length of the line (L) and the impedance (Z) of the line: $V' = k * L * Z * I'$

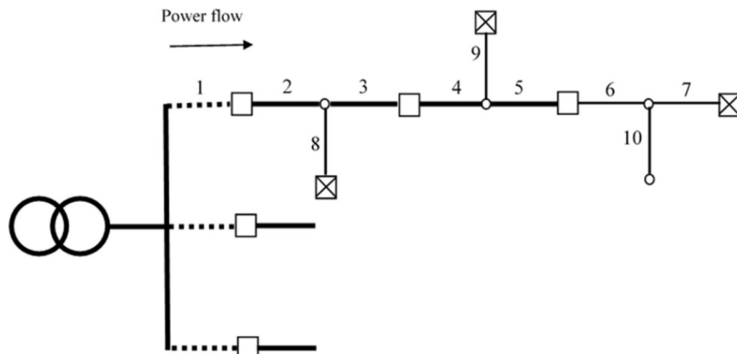
5. Repeat steps 3 and 4 for subsequent years:

- For each subsequent year, calculate the increased load (I') and use it to calculate the voltage drop (V') using the formula from step 4.

6. Accumulate the voltage drops for each year:

- Add up the voltage drops for each year to obtain the total voltage drop over the planning period.

It's important to note that the constant factor (k) should be chosen based on the circuit. Additionally, the values of R, X, and θ can be determined based on the characteristics of the line and the electrical system under consideration.



	Section	R (Ω/km)	Z (Ω/km)	Length (km)	R (Ω)	Z (Ω)	Cable, Conductor
	1	0.10	0.14	1.00	0.10	0.14	XLPE 240mm ²
	2	0.20	0.34	1.00	0.20	0.34	ACSR 150mm ²
	3	0.20	0.34	1.00	0.20	0.34	ACSR 150mm ²
	4	0.20	0.34	1.00	0.20	0.34	ACSR 150mm ²
	5	0.20	0.34	1.00	0.20	0.34	ACSR 150mm ²
	6	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
	7	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
	8	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
	9	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
	10	0.28	0.37	1.00	0.28	0.37	ACSR 100mm ²
	Total			10.00			

Distributed current(A)		Increasing rate of load=3%/year											
Section	Current (A)	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	
1	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
2	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
3	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
4	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
5	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
6	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
7	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
8	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
9	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
10	100	100.0	103.0	106.1	109.3	112.6	115.9	119.4	123.0	126.7	130.5	134.4	
Total	900	900.0	927.0	954.8	983.5	1,013.0	1,043.3	1,074.6	1,106.9	1,140.1	1,174.3	1,209.5	

Passing current(A)													
	Section	Current (A)	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	1	900	900.0	927.0	954.8	983.5	1,013.0	1,043.3	1,074.6	1,106.9	1,140.1	1,174.3	1,209.5
	2	800	800.0	824.0	848.7	874.2	900.4	927.4	955.2	983.9	1,013.4	1,043.8	1,075.1
	3	600	600.0	618.0	636.5	655.6	675.3	695.6	716.4	737.9	760.1	782.9	806.3
	4	500	500.0	515.0	530.5	546.4	562.8	579.6	597.0	614.9	633.4	652.4	672.0
	5	300	300.0	309.0	318.3	327.8	337.7	347.8	358.2	369.0	380.0	391.4	403.2
	6	200	200.0	206.0	212.2	218.5	225.1	231.9	238.8	246.0	253.4	261.0	268.8
	7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	9	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	10	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total												

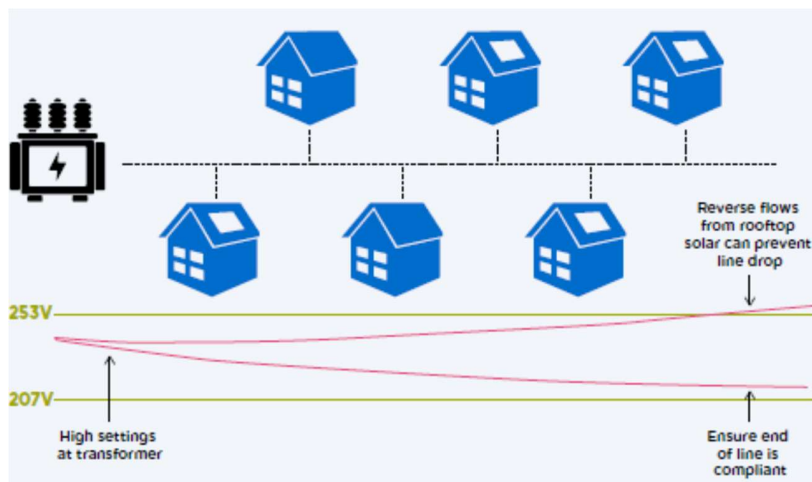
Voltage drop(V)													
	Section	Voltage Drop (V)	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
	1	218.5	218.5	225.1	231.8	238.8	246.0	253.3	260.9	268.8	276.8	285.1	293.7
	2	535.2	535.2	551.2	567.8	584.8	602.3	620.4	639.0	658.2	677.9	698.3	719.2
	3	416.2	416.2	428.7	441.6	454.8	468.5	482.5	497.0	511.9	527.3	543.1	559.4
	4	356.8	356.8	367.5	378.5	389.9	401.6	413.6	426.0	438.8	452.0	465.5	479.5
	5	237.9	237.9	245.0	252.3	259.9	267.7	275.7	284.0	292.5	301.3	310.3	319.7
	6	193.0	193.0	198.8	204.8	210.9	217.2	223.7	230.4	237.4	244.5	251.8	259.4
	7	64.3	64.3	66.3	68.3	70.3	72.4	74.6	76.8	79.1	81.5	83.9	86.5
	8	64.3	64.3	66.3	68.3	70.3	72.4	74.6	76.8	79.1	81.5	83.9	86.5
	9	64.3	64.3	66.3	68.3	70.3	72.4	74.6	76.8	79.1	81.5	83.9	86.5
	10	64.3	64.3	66.3	68.3	70.3	72.4	74.6	76.8	79.1	81.5	83.9	86.5
	Max. Voltage drop	2,021.9	2,021.9	2,082.6	2,145.0	2,209.4	2,275.7	2,343.9	2,414.3	2,486.7	2,561.3	2,638.1	2,717.3
	Max. Voltage drop: at the end of section 7												

5.8. Voltage management for distribution network

Voltage management has considerable impacts on the distribution network. Higher voltages can be desirable from a network planning perspective as they typically result in reduced line losses, which means less energy is lost in transportation. Higher network voltages also result in better utilization of assets, which can reduce the network reinforcement needed to accommodate peak demand.

Traditionally, setting voltages high in the allowable range has been common practice to allow for voltages to drop as electricity flows along the power line, so that customers at the end of the power line are still supplied electricity within the compliant range, as shown below.

Often the voltage rise caused by solar exports can be managed through low-cost solutions like lowering transformer tap settings to increase solar hosting capacity. However, opportunities to tap down distribution transformers can have limitations, including where there are no lower tap settings or fixed tap settings, therefore requiring replacement. Additionally, the increasing range of voltages being experienced in distribution networks is requiring implementation new tools such as dynamic voltage management systems.



5.9. Countermeasures for voltage drop and rise

5.9.1. Tap changers

Adjusting tap positions at distribution transformers is a low-cost, traditional method for managing voltage. Similarly, adjustments can be made to the fixed voltage target at injection substations.

5.9.2. Phase balancing

Phase imbalance arises when load and/or generation is unevenly spread across a three-phase system, resulting in a mismatch of the voltage between phases. Phase balancing aims to reallocate single phase connections to resolve the imbalance.

5.9.3. Dynamic voltage management

Dynamic voltage management is a sophisticated option which, once implemented, allows networks to dynamically adjust voltage to respond to changing network conditions.

- SVR: Step Voltage Regulator
- SVC: Static Var Compensator
- TVR: Thyristor Voltage Regulator

5.9.4. Reinforcement

Network reinforcement involves the replacement of conductors and transformers which can help reduce the effects of congestion and voltage drop/rise.

5.9.5. Load management.

Changing the timing of customer loads, such as controlled load hot water, can be used to manage voltage.

6. Effects of Electrical Power Disturbances on Equipment and Processes

The effects of all disturbances can be classified in two ways:

- (1) **Instantaneous effects:** unwanted operation of contactors or protective devices, incorrect operation or shutdown of a machine.

The financial impact of the disturbance can be estimated directly.

- (2) **Deferred effects:** energy losses, accelerated ageing of equipment due to overheating and additional electro-dynamic stress caused by the disturbance.

The financial impact (e.g. on productivity) is more difficult to quantify.

6.1. Effect of Voltage Dips and Interruptions

Voltage dips and interruptions disturb many types of devices connected to the network. They are the **most frequent cause of power quality problems**. A voltage dip or interruption of a few hundred milliseconds may have damaging consequences for several hours.

The most sensitive areas or applications where voltage dips and interruptions cannot be tolerated are:

- (1) complete continuous *production lines* where the process cannot tolerate any temporary shutdown of any element in the chain (printing, steelworks, paper mills, petrochemicals, etc.)
- (2) *lighting and safety systems* (hospitals, airport lighting systems, public and high-rise buildings, etc.)
- (3) *computer equipment* (data processing centres, banks, telecommunications, etc.)
- (4) *essential auxiliary plant* for power stations.

The paragraphs below cover the main consequences of voltage dips and interruptions on equipment used in the industrial, service and domestic sectors.

6.1.1. Effect of Voltage Dip and Interruptions on Asynchronous Motors

When a voltage dip occurs, the torque of an asynchronous motor (proportional to the square of the voltage) drops suddenly which slows down the motor. This slowdown depends on the

- magnitude and duration of the dip
- inertia of the rotating masses and
- torque speed characteristics of the driven load.

If the mechanical torque developed by the motor drops below the resistant electromagnetic torque, the motor stops (stalls).

Following an interruption, at the time of voltage recovery, the motor tends to re-accelerate and absorb current whose value is nearly its starting current, the duration of which depends on the duration of the interruption. Where there are several motors in an installation, the *simultaneous restarting may produce a voltage drop in the upstream impedances on the network which will increase the duration of the dip and may make*

restarting difficult (long restarts with overheating) or even impossible (mechanical motor torque lower than the resistive electromagnetic torque).

Rapidly reconnecting (~ 150 ms) the power to an asynchronous motor which is slowing down without precautionary measures may lead to reclosing in opposition to the phase between the source and the residual voltage in asynchronous motors. In this case the first current peak may reach three times the startup current (15 to 20 rated current)

The **overcurrents** and consequent **voltage drops** have consequences for the asynchronous motor. These include

- (1) *excessive overheating* which may cause insulation failures and eventual breakdown
- (2) *electro-dynamic force* in the coils, which may cause torque shocks with abnormal mechanical stress on the couplings and reducers, leading to premature wear or even breakage as well as other equipment such as contactors (wear or even fusion of the contacts).
- (3) *tripping* of the main general protective devices of the installation causing the process to shutdown.

6.1.2. Effect of Voltage Dips and Interruptions on Synchronous Motors

The effects are almost identical to those for asynchronous motors. Synchronous motors can, however, withstand deeper voltage dips (around 50 %) without stalling, owing to the

- generally greater inertia
- possibilities of overexcitation and the
- fact that their torque is proportional to the voltage.

In the event of stalling, the motor stops and the entire complex start-up process must be repeated.

6.1.3. Effect of Voltage Dips and Interruptions on Actuators

The control devices (contactors, circuit breakers with voltage loss coils) powered directly from the network are sensitive to voltage dips whose depth exceeds 25 % of rated voltage.

Indeed, for a standard contactor, there is a **minimum voltage value** which must be observed (known as the **drop-out voltage**), otherwise the poles will separate and transform a voltage dip (lasting a few tens of milliseconds) or a short interruption into a long interruption until the contactor is reenergized.

6.1.4. Effect of Voltage Dips and Interruptions on Computer Equipment

Computer equipment (computers, measurement apparatus) today occupy a dominant position in the monitoring and control-command of installations, management and production. All of this equipment is sensitive to voltage dips with depth greater than 10 % the rated voltage.

The ITIC (Information Technology Industry Council) curve – formerly CBEMA curve – shows on a duration-amplitude scale, the typical withstand of computer equipment to voltage dips, interruptions and overvoltages. See the Fig below.

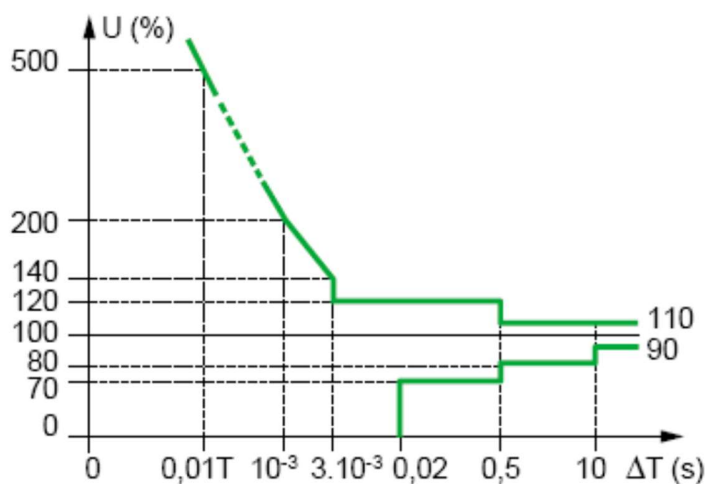


Fig: Typical Withstand as Defined by the ITIC curve.

Operation outside these limits leads to:

- loss of data,
- incorrect commands, and
- shutdown or malfunction of equipment.

The consequences of the loss of equipment functions depend in particular on the restart conditions when voltage is restored. Certain equipment, for example, have their own voltage dip detection devices which enable data to be backed up and ensure safety by interrupting calculation processes and any incorrect commands.

6.1.5. Effect of Voltage Dips and Interruptions on Adjustable Speed Machines

The problems variable speed drives are subjected to by voltage dips and interruptions are:

- (1) It is not possible to supply sufficient voltage to the motor (loss of torque, slowdown).
- (2) The control circuits supplied directly by the network cannot function.
- (3) There is overcurrent when voltage recovers (the drive filter capacitor is recharged).
- (4) There is overcurrent and unbalanced current in the event of voltage dips on a single phase.
- (5) There is loss of control of DC drives functioning as inverters (regenerative braking).

Adjustable speed drives usually trip out when a voltage dip deeper than 15 % occurs.

6.1.6. Effect of Voltage Dips and Interruptions on Lighting Equipment

- (1) Voltage dips cause premature ageing of incandescent lamps and fluorescent tubes.
- (2) Voltage dips deeper than or equal to 50 % with duration of around 50 ms will extinguish discharge lamps. The lamp must then be left off for several minutes to cool the bulb before it is turned on again.

6.2. Effect of Overvoltages

The consequences of overvoltages are varied according to the period of application, repetitivity, magnitude, mode and frequency. Some of these include

- (1) *Dielectric breakdown* – causing significant permanent damage to equipment (electronic components, etc).
- (2) *Degradation of equipment through ageing* – repetitive rather than destructive overvoltages
- (3) *Long interruptions* – caused by the destruction of equipment (loss of sales for distribution company, loss of production for industrial companies)
- (4) *Disturbances* – in control systems and low current communication circuits
- (5) *Electrodynamic and thermal stress*

Overhead networks are most vulnerable to lightning, but installations supplied by underground networks may also be affected by stress due to high voltage if lightning strikes close to the site.

Switching overvoltages are repetitive and their probability of occurrence is considerably higher than that of lightning, with a longer duration. They can lead to degradation as serious as that caused by lightning.

6.3. Effects of Voltage Unbalance

The main effect of voltage unbalance is the **overheating of 3-phase asynchronous machines**. In fact, the zero-sequence reactance of an asynchronous machine is equivalent to its reactance during the start-up phase. The current unbalance factor will thus be several times that of the supply voltage. Phase currents can thus differ considerably. This increases the overheating of the phase(s) which the highest current flows through and reduces the operating life of the machine.

In practice, a voltage unbalance factor of 1 % over a long period, and 1.5 % over a few minutes is acceptable.

6.4. Summary of Effects of Electrical Power System Disturbances on Equipment and Processes

Table 2: Summary of Effects of Power System Disturbances on Various Equipment and Processes

Equipment	Sensitivity to disturbance					
	Voltage dips < 0.5 s	> 0.5 s	Overvoltages	Harmonics	Unbalance	Voltage fluctuation
■ Asynchronous motor						
■ Synchronous motor						
■ Actuator						
■ Speed drive						
■ Data processing load, numerical control						
■ Induction furnace						
■ Lighting						
■ Capacitor bank						
■ Transformer						
■ Inverter						
■ Circuit breaker						
■ Cable						

Table 2 above outlines the sensitivity of different types of equipment to various power quality disturbances. Each equipment has different sensitivities to specific disturbances. This helps engineers and designers

- Identify the power quality needs of specific equipment.
- Implement mitigation measures
- Prioritize protection for equipment most sensitive to each disturbance type.

7. Measurement and Evaluation of Power Quality

7.1. Power Quality Measurements and its Objectives

The measurement parameters and the accuracy may differ depending upon application. The following are some of the objectives of power quality measurement.

7.1.1. Contractual Purposes

In a deregulated market, contracts exist not only between the electricity supplier and end user but also between power generation companies, transmission companies, and distribution companies, similar to the Supply Level Agreement (SLA) between Distribution Companies (DisCos) and the Transmission Company of Nigeria (TCN). These contracts require agreed-upon terms and predefined power quality parameters, involving significant data processing.

A contractual arrangement requires that terms are defined jointly and mutually agreed upon by all parties. The parameters for measuring power quality must therefore be defined and the values compared with predefined. This arrangement may frequently require the processing of significant quantities of data.

7.1.2. Corrective Maintenance

Despite best practices (use of good protective devices and proper neutral point connections), system malfunctions can occur due to overlooked disturbances or changes in the installation (like new loads or modifications). Troubleshooting aims to resolve these issues quickly, often requiring portable measurement systems for temporary checks or fixed systems for continuous monitoring.

Portable measurement systems (for **limited periods**) or **fixed** apparatus (for **continuous monitoring**) make it easier to carry out installation diagnostics (detection and archiving of disturbances and triggering of alarms).

7.1.3. Optimising the Operations of Electrical Installations

To enhance productivity and reduce costs, proper process operation and energy management procedures are necessary, both of which depend on power quality. Operating, maintenance and management personnel of service sector and industrial sites all aim for a power quality which matches their requirements. Service sector and industrial site personnel strive for power quality that meets their needs. Complementary software tools are essential for control, command, and continuous monitoring of installations.

7.1.4. Statistical Surveys or Research

Statistical approaches based on wide-ranging results from surveys from power system operators are usually used in research. Thus, benchmarks are needed to:

- (1) Assess the general performance of a power system.
- (2) Evaluate performance at specific points in a power system.

7.2. Contractual Purpose

The contract must state the following:

- (1) Duration
- (2) The parameters to be measured.
- (3) The contractual values.
- (4) The measurement point(s).
- (5) The voltages measured: these voltages (between phases and/or between phase and neutral) must be the equipment supply voltages.
- (6) For each parameter measured the choice of *measurement method*, the *time interval*, the *measurement period* (e.g. 10 minutes and 1 year for the voltage amplitude) and the *reference values*; for voltage dips and interruptions, for example, the reference voltage, detection thresholds and the distinction between long and short interruptions must be defined.
- (7) The measurement accuracy.
- (8) The method of determining penalties in the event of one party failing to honour the terms of the contract.
- (9) Clauses in the event of disagreement concerning the interpretation of the measurements (intervention of third parties, etc.).
- (10) Data access and confidentiality.

7.3. Corrective Maintenance

This is generally the consequence of incidents or malfunctions during operation requiring troubleshooting in order to apply corrective measures. The usual steps are:

- (1) *Data collection* - This involves the collection of information such as the type of load, the age of the network components and the single-line diagram.

- (2) *Search for symptoms* - This involves identifying and locating the equipment subject to disturbance, determining the time and date (fixed or random) when the problem occurred, any correlation with particular meteorological conditions (strong winds, rain, storm) or recent modification of the installation (installation of new machines, modification of the power system).
- (3) *Examination of the installation* - This phase is sometimes sufficient for quickly determining the origin of the malfunction. Environmental conditions such as humidity, dust and temperature must not be overlooked. The installation, especially the wiring, circuit breakers and fuses, have to be checked.
- (4) *Monitoring of the installation* - This step consists in equipping the site with measurement apparatus to detect and record the event where the problem originated.

It may be necessary to place instruments at several points in the installation, especially (where possible) close to the equipment subject to disturbance. The apparatus detects events when the thresholds of the parameters used to measure the power quality are exceeded, and records the data characterizing the event (for example date, time, depth of voltage dip, THD).

Fixed apparatus can be used for continuous monitoring of the installation. If the apparatus settings are correct, it will carry out prevention and detection by recording each occurrence of disturbance.

The data can be displayed locally or remotely via an Intranet or Internet connection. This can be used to diagnose events as well as to anticipate problems (preventive maintenance). This is the case with apparatus in the Power Logic System range (Circuit Monitor – Power Meter), Digipact and the latest generation of Masterpact circuit breakers fitted with Micrologic P trip release (see Fig below).

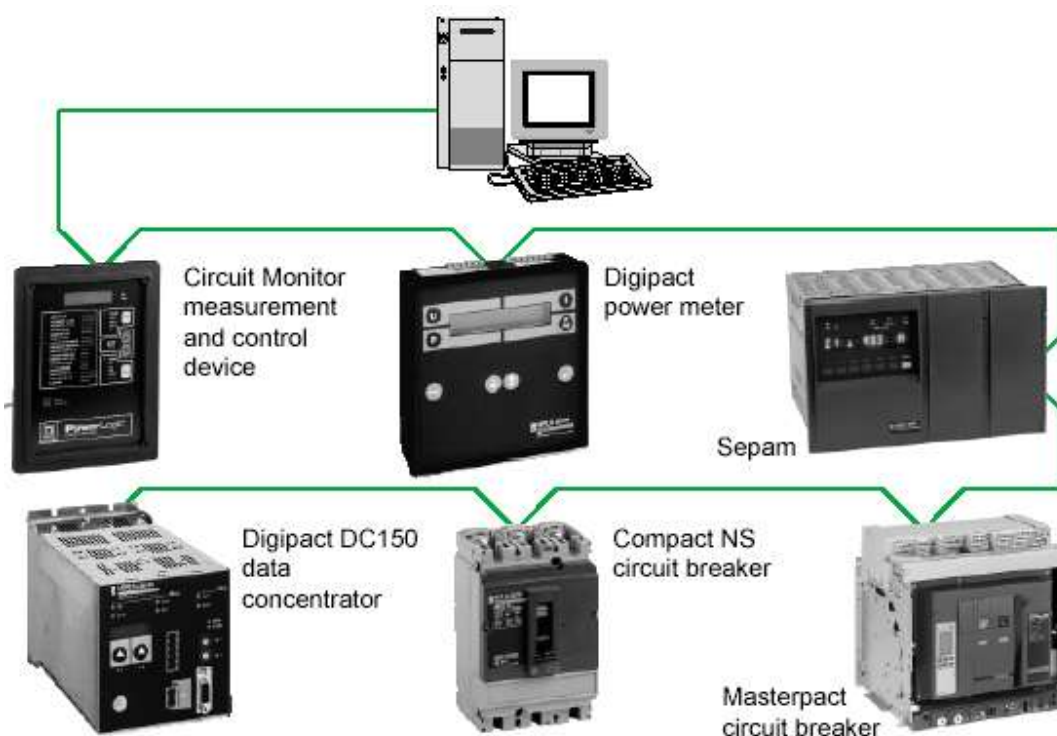


Fig: Some Communicating Products (Merlin Gerin Brand)

Records of disturbance from the distributor's power system which have caused damage (destruction of equipment, production losses, etc.) may also prove useful when negotiating compensation claims.

- (5) *Identification of Origin* - The signature (waveform, profile of rms value) of the disturbance can in general be used by experts to locate and identify the source of the problem (fault, motor starting, capacitor bank energization, etc.). The simultaneous recognition of the signature for the voltage and the current can be used to determine if the disturbance is sourced upstream or downstream of the measurement point. The disturbance may come from either the installation or the distribution power system.
- (6) *Definition and Choice of Mitigating solutions* - A list of solutions and costings is prepared. The choice of solution is often made by comparing the cost with the potential lost earnings in the event of disturbance. After implementing a solution, it is important to verify, via measurement, that it is effective.

The operation of electrical installations can be optimised through three complementary actions:

- (1) **Saving Energy and Reducing Energy Bills:**
 - making users aware of costs

- assigning costs internally (by site, department or product line)
 - locating potential economies
 - managing peaks in consumption (load shedding, stand alone sources)
 - optimizing the power contract (through reduction in subscribed power demand)
 - improving the power factor (reduction in reactive power)
- (2) Ensuring the Power Quality
- displaying and monitoring the measurement parameters for power quality
 - detecting problems in advance (monitoring of harmonics and neutral current, etc.) for preventive maintenance purposes.
- (3) Ensuring Continuity of Service:
- optimising maintenance and operation
 - becoming acquainted with the network in real time
 - monitoring the protection plan
 - diagnosing faults
 - reconfiguring a network following a fault
 - ensuring an automatic source transfer.

Software tools are used for the control-command and monitoring of the installation. They can be used for example to detect and archive events, monitor circuit breakers and protection relays in real time, control circuit breakers remotely, and generally make use of the possibilities of communicating devices (see Fig. above).

8. Solutions for Improving Power Quality

A degradation of quality may lead to a change in behaviour, performance or even the destruction of equipment and dependent processes with possible consequences for the safety of personnel and additional economic costs. This assumes three elements:

- (1) one or more generators of disturbance,
- (2) one or more loads sensitive to the disturbance,

(3) a channel for the disturbance to be propagated between them.

The solutions consist in taking action with regard to all or part of the three elements, either globally (the installation) or locally (one or more loads).

The solutions can be implemented to:

- (1) correct a malfunction in an installation,
- (2) take preventive action when polluting loads are to be connected,
- (3) ensure the installation conforms to a standard or to the power distributor's recommendations,
- (4) reduce energy bills (reduction of subscribed power in kVA, reduction in consumption).

Loads are not sensitive to the same disturbance and have different levels of sensitivity. The solution adopted, as well as being the best from a technical and economic point of view, must ensure an appropriate level of power quality which meets actual requirements.

It is vital that specialists carry out a prior diagnosis to determine the nature of the disturbance to be prevented (e.g. remedies may differ depending on the duration of an interruption). This determines the effectiveness of the chosen solution. The definition, choice, implementation and maintenance (to ensure long-term effectiveness) of solutions must also be carried out by specialists.

The value of the choice and implementation of a solution depends on:

- (1) The **required level of performance**: Malfunction is not permitted if it would put lives at risk (e.g. in hospitals, airport lighting systems, lighting and safety systems in public buildings, auxiliary plant for power stations, etc.).
- (2) The **financial consequences of malfunction**: Any unprogrammed stop, even when very short, of certain processes (manufacture of semiconductors, steelworks, petrochemicals, etc.) results in loss or non-quality of production or even restarting of production facilities.
- (3) The **time required for a return on the investment**: This is the ratio of financial losses (raw materials, production losses, etc.) caused by the non-quality of electrical power and the cost (research, implementation, operation, maintenance) of the solution.

Other criteria such as practices, regulation and the limits on disturbance imposed by the distributor must also be taken into account.

8.1. Solutions to Voltage Dips and Interruptions

The network architecture, automated power restart systems, the reliability of equipment, the presence of a control-command system and maintenance policy all play an important role in the reduction and elimination of interruptions.

Correct diagnosis is vital before choosing an effective solution. For example, at the point of common coupling (the customer's electricity input), it is important to determine whether the voltage dip is coming from the customer's installation (with a corresponding increase in current) or from the distribution power system (no increase in current).

Different types of solutions exist.

8.1.1. Reducing the Number of Voltage Dips and Interruptions

Distributors can take certain measures such as making their infrastructure more reliable (targeted preventive maintenance, modernization, underground installation) or restructuring power systems (shortening feeders). For impedance earthed neutral power systems, they can also replace auto-reclosing circuit breakers with shunt circuit breakers which present the major advantage of not causing interruptions on a damaged feeder in the event of a transient earth fault (reducing the number of short interruptions).

These circuit breakers allow the extinction of transient earth faults by cancelling the voltage to the fault terminals for at least 300 ms by earthing the single faulty phase at the substation busbars. This does not alter the voltage between phases supplying the customer.

8.1.2. Reducing the Duration and Depth of Voltage Dips

(1) At power system level

- Increasing the possibilities of ring connections (new substations, ring closing switch)
- Improving the performance of electrical protective devices (selectivity, automatic power restart, remote control devices on the network, remote management, replacement of spark gaps with surge arresters, etc.)
- Increasing the network short-circuit power

(2) At equipment level

- Decrease the power consumed by the switched large loads with real time reactive compensators and soft starters which limit current peaks (and mechanical stress).

8.1.3. Increasing Immunity of Industrial and Service Installations

The general principle for ensuring that equipment is immune to voltage dips and interruptions is to compensate for a lack of power with an energy storage device between the distribution power system and the installation. The availability of the storage device has to be greater than the duration of the disturbances to which the system has to be immune to.

The information required when choosing mitigation solutions is:

- the quality of the source (maximum level of existing disturbances),
- the load requirements (voltage sag ride-through capability in the duration-depth scale).

Only by careful analysis of the process and of the technical and financial consequences of disturbances can these two elements be reconciled. There are various possible solutions to provide immunity depending on the power required by the installation and the duration of the voltage dip or interruption. It may well be helpful to study solutions by making a distinction between power supplies for control systems and regulation systems and those for motors and large power consumers. Indeed, a voltage dip or interruption (even of short duration) may be sufficient to open all of the contactors whose coils are supplied by the power circuit. Loads controlled by the contactors are thus no longer supplied when the voltage is restored.

8.1.4. Increasing Immunity of the Control System

The increase of immunity of a process is in general based on providing immunity to the control system. In general, the control system is not of high power and is thus extremely sensitive to disturbances. It is therefore often more economical to immunise only the control system rather than the equipment power supply.

Maintaining control of machines assumes:

- (1) There will be no risk to the safety of personnel or equipment when the voltage is restored.
- (2) The loads and processes tolerate a short interruption in the power circuit (high inertia or slowdown is tolerated) and can be restarted on the fly when the voltage is restored.
- (3) The source can ensure that all of the equipment can be supplied simultaneously (in the case of a replacement source) and provide the inrush current caused by the simultaneous restart of several motors.

The solutions consist in powering all of the contactor coils from a reliable auxiliary source (battery or rotating set with flywheel), or in using an off-delay relay, or in using a rectifier and a capacitor connected in parallel with the coil.

8.1.5. Increasing Immunity of the Equipment Power Supply

Certain loads cannot withstand the expected disturbance levels, i.e. neither voltage dips nor interruptions. This is the case for "priority" loads such as computers, lighting and safety systems (hospitals, airport lighting systems, public buildings) and continuous production lines (manufacture of semi-conductors, data processing centres, cement works, water treatment, materials handling, paper industry, steelworks, petrochemicals, etc.).

The following different technical solutions are possible depending on the power required by the installation and the duration of the voltage dip or interruption.

8.1.5.1. Solid-state Uninterruptible Power Supply (UPS), consisting of three main elements:

- a rectifier-charger, powered from the main supply, to convert AC voltage to DC,
- a flywheel and/or battery (kept charged) which on interruption provide the necessary power for the load via the inverter,
- a DC-AC inverter.

Two technologies are currently in use: on-line and off-line.

(a). On-line UPS Technology

During normal operation, power is supplied continuously via the inverter without drawing on the battery. They ensure continuity (no changeover delays) and quality (voltage and frequency regulation) of the power supply for sensitive loads ranging from a few hundred to several thousand kVA. Several UPS can be connected in parallel to obtain more power or to provide redundancy.

In the event of overload, power is provided by the static contactor (see Fig below) from network 2 (which may be combined with network 1). Power is maintained without interruption via a maintenance by-pass.

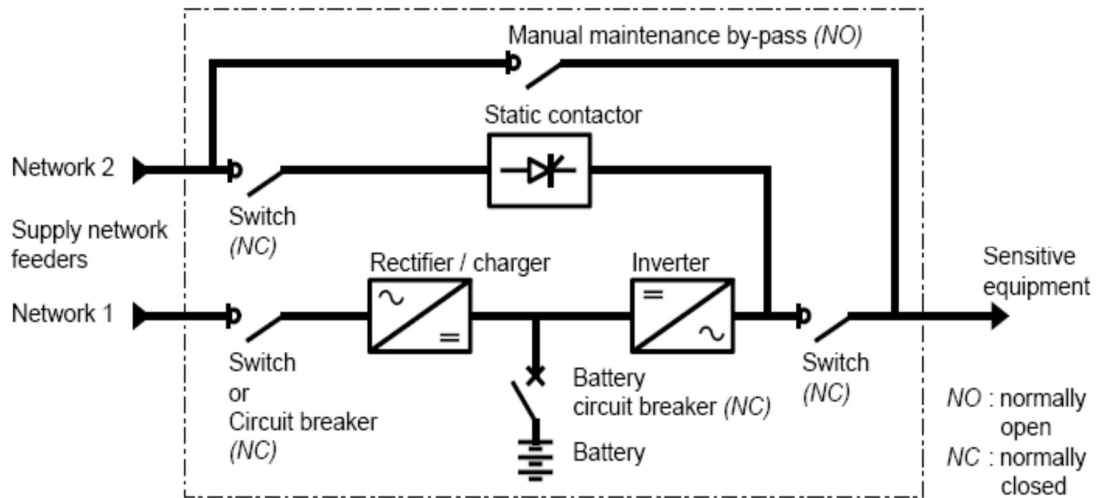


Fig: Schematic diagram of an on-line uninterruptible power supply (UPS).

(b). Off-line (or Stand-by) UPS Technology

This is used for applications of no more than a few kVA. During normal operation, power is supplied from the network. In the event of loss of network power or if the voltage exceeds the prescribed tolerances, use is transferred to the UPS. The changeover causes an interruption of 2 to 10 ms.

8.1.5.2. Sources Transfer

A device is used to control transfer between the main source and a replacement source (and vice versa) for supply to priority loads and if necessary orders the shedding of non-priority loads. There are three types of transfer depending on the duration of transfer (Δt):

- I. synchronous ($\Delta t = 0$),
- II. delayed ($\Delta t = 0.2$ to 30 s),
- III. pseudo-synchronous (0.1 s $< \Delta t < 0.3$ s).

The devices require special precautions. For example, if there are several motors in the installation, simultaneous restart may produce a voltage drop which could prevent restart or lead to excessively long restarts (with the risk of overheating). It is therefore prudent to install a PLC which will restart the priority motors at intervals, especially with a replacement (backup) source with a low short-circuit power. This solution is selected where the installation cannot withstand a long interruption of more than a few minutes, and/or requires a large amount of power. It can also be used in conjunction with a UPS.

8.1.5.3. Zero-time Set

In certain installations, the autonomy required in the event of interruption makes it necessary to install a generating set (large batteries would be too expensive, or cause technical or installation problems). Here, in the event of any loss of power supply, the battery or flywheel is used to provide sufficient time for starting and running up the stand-by engine generator, load shedding (if necessary) and interruption-free coupling by means of an automatic source changeover.

8.1.5.4. Electronic Conditioners

These are modern electronic devices to compensate voltage dips and interruptions to a certain extent with a short response time: for example the real time reactive compensator compensates the reactive power in real time and is especially well suited to loads with rapid, large variations (welding machines, lifts, presses, crushers, motor starting, etc.).

8.1.5.5. Clean Stop

If a stoppage is acceptable, it is especially advisable to prevent uncontrolled restarting if an unwanted restart would present a risk for the machine operator (circular saws, rotating electrical machines) or for the equipment (compression chambers while still under pressure, staggered restarts of air-conditioning compressors, heating pumps or refrigeration units) or for the application (necessity of controlling production restart). The process may be automatically restarted by a PLC using a predetermined restart sequence when conditions return to normal.

8.2. Solutions to Overvoltages

Correct *insulation co-ordination* involves ensuring the protection of personnel and equipment against overvoltages, with the best balance between technical and economic considerations. This requires

- (1) knowledge of the level and energy of the overvoltages which may occur on the network,
- (2) selection of the level of overvoltage withstand of the power system components to meet constraints,
- (3) use of protective devices where necessary, in fact, the appropriate solutions depend on the type of overvoltage encountered.

8.2.1. Solutions to Temporary Overvoltages

- Switch off all or some of the capacitors during periods of low load.

- Avoid configurations susceptible to ferroresonance or introduce losses (reducing resistors) to damp the phenomenon.

8.2.2. Solutions to Switching Overvoltages

- (1) Limit the capacitors energization transients by *installing a fixed reactor and pre-insertion resistors*. Static automatic reactive compensators which control closing instant are especially suitable for LV applications which cannot withstand transient overvoltages (PLCs, computer systems).
- (2) Connect *line chokes* upstream of the frequency inverters to limit the effects of transient overvoltages.
- (3) Use main *residual current circuit breakers (RCCBs)* for LV installations. Their use avoids unwanted tripping due to transient leakage currents: lightning and switching overvoltages, energisation of circuits with a high capacitance to earth (capacitive filters connected to earth, extended cable networks, etc.) which flow through the network downstream of the RCD (residual current device) via the network capacitance to earth.

8.2.3. Solutions to Lightning Overvoltages

(a) **Primary Protection**

This protects the building and its structure from direct lightning strikes (*lightning conductors, overhead earth wire/earthing wire*).

(b) **Secondary Protection**

This protects equipment against the overvoltages which follow lightning. *Surge arresters* (spark gaps are now used less and less) are installed on the particularly exposed points of HV and MV networks and at the input to MV/LV installations.

On LV installations, they are installed as far upstream as possible (to offer maximum protection) and as close as possible to the load. It is sometimes necessary to cascade surge arresters: one at the head of the installation, and one close to the load. An LV surge arrester is always connected to a disconnection device. In addition, the use of main *residual current circuit breakers* of discriminatory type on LV installations avoids any current flow to earth via the surge arrester tripping the circuit breaker at the head of the installation, which would be incompatible with some equipment (freezers, controllers, etc.).

Note that overvoltages can be propagated to the equipment by other routes than the electrical power supply:

- telephone lines (telephone, fax),

- coaxial cables (computer links, TV aerials).

Suitable protective devices are commercially available.

8.3. Solutions to Voltage Fluctuations

Fluctuations produced by industrial loads may affect a large number of consumers supplied from the same source. The fluctuation magnitude depends on the ratio between the impedance of the device generating the disturbance and the impedance of the power supply. The solutions are:

- (1) Changing the *type of lighting* - Fluorescent lamps are less sensitive to voltage fluctuations than incandescent lamps.
- (2) Installing an *uninterruptible power supply (UPS)* - This may be a cost-effective solution if users subjected to disturbance are identified and grouped together.
- (3) *Modify the device generating the disturbance* - Changing the starting mode of motors which have to start frequently, for example, can reduce overcurrents.
- (4) Use a *reactive compensator* - This device provides real time reactive compensation for each phase. Flicker can be reduced considerably.
- (5) *Connect a reactance in series* - By reducing the inrush current, a reactance downstream from the connection point of an arc furnace can reduce flicker by 30 %.

8.4. Solutions to Voltage Unbalance

The solutions to voltage unbalance are:

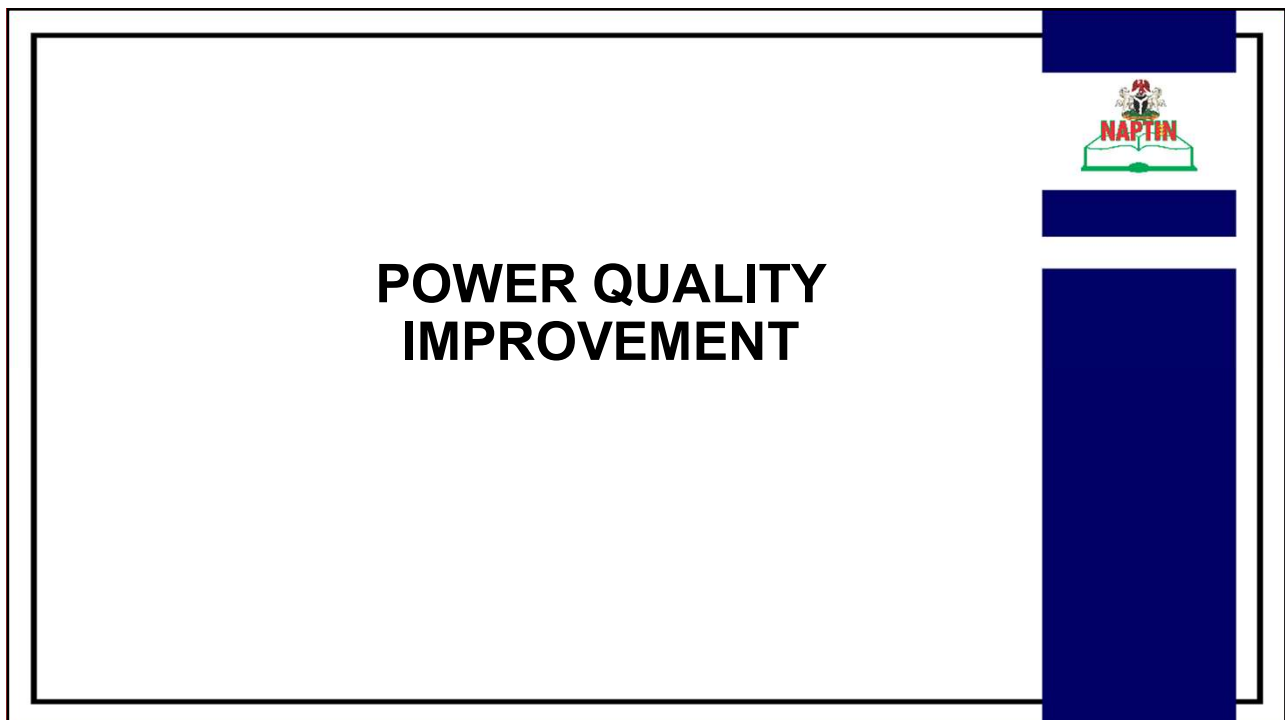
- (1) balancing single phase loads on all three phases,
- (2) reducing the power system impedance upstream of the devices causing the unbalance by increasing the transformer rated power and the cable cross-section,
- (3) fitting the appropriate protective device for the machines,

8.5. Summary

Type of disturbance	Origins	Consequences	Examples of mitigation solutions (special equipment and modifications)
Voltage variations and fluctuations	Large load variations (welding machines, arc furnaces, etc.).	Fluctuation in the luminance of lamps (flicker).	Electromechanical reactive power compensator, real time reactive compensator, series electronic conditioner, tap changer.
Voltage dips	Short-circuit, switching of large loads (motor starting, etc.).	Disturbance or shutdown of process: loss of data, incorrect data, opening of contactors, locking of drives, slowdown or stalling of motors, extinguishing of discharge lamps.	UPS, real time reactive compensator, dynamic electronic voltage regulator, soft starter, series electronic conditioner. Increase the short-circuit power (Scc). Modify the discrimination of protective devices.
Interruptions	Short-circuit, overloads, maintenance, unwanted tripping.		UPS, mechanical source transfer, static transfer switch, zero-time set, shunt circuit breaker, remote management.
Harmonics	Non-linear loads (adjustable speed drives, arc furnaces, welding machines, discharge lamps, fluorescent tubes, etc.).	Overloads (of neutral conductor, sources, etc.), unwanted tripping, accelerated ageing, degradation of energy efficiency, loss of productivity.	Anti-harmonic choke, passive or active filter, hybrid filter, line choke. Increase the Scc. Contain polluting loads. Derate the equipment.
Inter-harmonics	Fluctuating loads (arc furnaces, welding machines, etc.), frequency inverters.	Interruption of metering signals, flicker.	Series reactance.
Transient overvoltages	Operation of switchgear and capacitors, lightning.	Locking of drives, unwanted tripping, destruction of switchgear, fire, operating losses.	Surge arrester, surge diverter, controlled switching, pre-insertion resistor, line chokes, static automatic compensator.
Voltage unbalance	Unbalanced loads (large single-phase loads, etc.).	Inverse motor torque (vibration) and overheating of asynchronous machines.	Balance the loads. Shunt electronic compensator, dynamic electronic voltage regulator. Increase the Scc.

The table above summarizes various power quality disturbances, their origins, consequences, and corresponding mitigation solutions. It can be used to:

- Diagnose power quality issues based on their origins and consequences,
- Implement tailored mitigation strategies to maintain system reliability and equipment safety, and
- Optimize the performance of sensitive equipment in industrial and commercial environments.



TRAINING OBJECTIVES



- ✓ Recognize the **significance** of power quality in the systems used to distribute electricity.
- ✓ Determine typical power quality **problems** and how they **affect** electrical systems and equipment.
- ✓ Explore methods for **measuring and monitoring** power quality **parameters**.
- ✓ Learn about the **causes** of power quality anomalies.

TRAINING OBJECTIVES



- ✓ Acquire knowledge of **mitigation techniques** for various power quality problems.
- ✓ Develop skills in designing and implementing **solutions** to improve power quality.

COURSE CONTENTS

- Introduction
- Components of Power Quality and their Effects
 - Transients
 - Voltage Dips and Interruptions
 - Voltage Sag and Swell
 - Voltage Unbalance
 - Harmonics Distortions
 - Voltage Flickers
 - Electromagnetic Interference (EMI)
 - Voltage Drop
 - Ferranti Effects
- Voltage Management for Distribution Network
- Mitigation Techniques to Power Quality Problems



1. INTRODUCTION



INTRODUCTION TO POWER QUALITY ANALYSIS



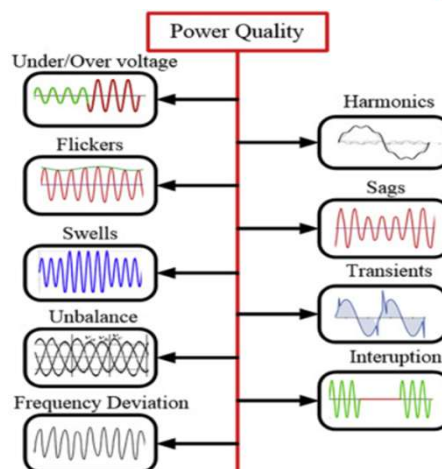
• LEARNING OUTCOMES:

- Understand the concept of power quality
- Appreciate the necessity for power quality
- The need for power quality analysis
- The standards that govern the power quality study

INTRODUCTION TO POWER QUALITY ANALYSIS



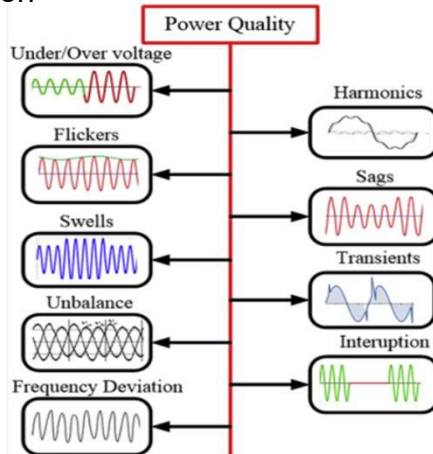
- **Power quality** is defined as the degree to which the power supply approaches the ideal case of **stable, uninterrupted, zero distortion** and **disturbance free** supply.
- The power system itself is a major contributor to existing power quality problems, especially continuity, and the quality of grounding connections.



INTRODUCTION TO POWER QUALITY ANALYSIS



- The disturbances may be broken down into the several categories.



NECESSITY FOR POWER QUALITY ANALYSIS



- Power quality has become a **strategic** issue for stakeholders of the power industry, for many reasons:
 1. The widespread use of equipment that are sensitive to voltage disturbance and/or generates disturbance itself
 2. The economic necessity for businesses to increase their competitiveness with quality power supply
 3. The opening up or deregulation of the electricity market (requirement of the regulator)
- *Section PART1: 1.5.1-j of the NERC D-Code said: Subject to and in accordance with the Conditions of License, the roles of the Distribution Companies are:*
- *...test and monitor Users Equipment/Apparatus connected to the network to ensure their compliance with the Distribution Code and other relevant regulations;*

INDICATORS OF POOR POWER QUALITY



- Some of the indicators for Power Quality (PQ) problems include:
 - ✓ Abnormal failure of electronic systems
 - ✓ Transformer overheating
 - ✓ Motor failure
 - ✓ Power factor capacitors failing
 - ✓ Electronic-controlled system that stops unexpectedly

POWER QUALITY STANDARDS



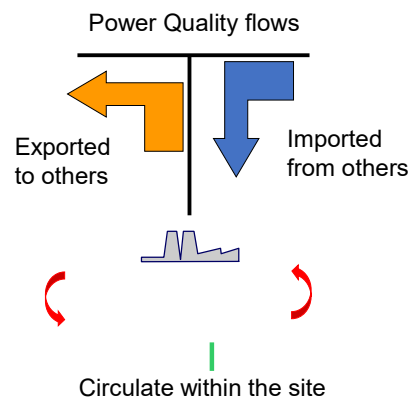
- Some existing Power Quality standards
 - EN 50160 (Europe)/NERC D-Code (: The **standard defining the voltage's main characteristics at a network user's supply terminals** in public low-voltage and medium-voltage electricity distribution systems under normal operating conditions.
 - IEEE 1159 **is a recommended practice for monitoring electric power quality**. It provides the user with a consistent set of terms, definitions, and practices for describing power quality phenomena. It describes nominal conditions and deviations from these nominal conditions that may originate within the source of supply or load equipment or may originate from interactions between the source and the load.

SOURCES OF POOR POWER QUALITY

- **Power Quality as a polluter**

- Sources:

- Industrial sites
- Domestic rural sites
- Utility network



• **HOW DOES THESE CONTRIBUTE TO POOR PQ???**



WHY MONITOR POWER QUALITY?

- **SUPPLIERS (UTILITIES)**

- **Network Planning**

- Accurate forecast of demand
- Load profiling
- Optimise transformer load
- Optimise PQ remedy location

- **Legislation (de-regulated energy markets)**

- Monitor Consumers
- Proactively respond to complaints



WHY MONITOR POWER QUALITY?

• SUPPLIERS (UTILITIES)

- According to D-Code: PART2: 2.1.1. The **Disco** shall be responsible for Distribution Planning, including:
 - (a) Forecasting the future **Demand** on its distribution area
 - ... (d) Identifying and correcting problems on Quality of Supply, Power Quality and **System Losses** in the **Distribution System**
- D-Code: PART2: 2.3.2. The **Disco** shall forecast **Demand** using **Prudent Industry Practice**. In conducting this **Load Forecast** the **Disco** shall consider:
 - (b) the effects if any, due to Demand side management and loss reduction.



WHY MONITOR POWER QUALITY?

• SUPPLIERS (UTILITIES)

- D-Code: PART2: 2.5.1. The following **System** studies are expected to be carried out by the **Disco** in order to develop the [5 Year] Distribution Plan:
 - (a) Voltage Drop Studies: Voltage drop studies shall be performed to determine that the expected voltages at the **User's connection Points** comply with the requirements stated on the Technical Requirements section and in the **Performance Standards Code...**
 - (c) *Three phase short-circuit studies and single line to ground fault studies shall be performed for most demanding scenario. These studies shall identify the most severe conditions that the **Distribution System Equipment** may be exposed to, and to determine possible constraints in fulfilling the **Power Quality** standards set out in the **Performance Standards Code**.*



WHY MONITOR POWER QUALITY?

• CONSUMERS

- Identify source of PQ problems
- Reduce Financial Costs
 - Lost production
 - Replacement of equipment
- Reduce Operational Costs
 - Interruption of services
 - Working environment (Flicker)
- Compliance
 - With supply agreements



WHY MONITOR POWER QUALITY?

• CONSUMERS

- D-Code: PART2: 3.2.3. Based on the data supplied by the **User**, the **Disco** shall conduct all the required Distribution Impact Studies it considers appropriate, to evaluate the impact of the proposed connection or modification to an existing connection on the **Distribution System**. The evaluation should include: ...
 - (b) impact of **User** Development on **Power Quality**.

• SUPPLY QUALITY STANDARDS

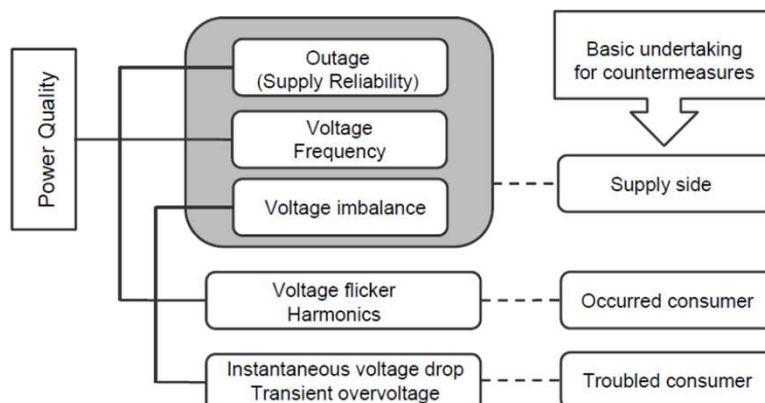
- D-Code: PART2: 4.1.1. The **Disco** shall plan and operate its **System** to ensure that at any **User's Connection Point**, the Supply Quality standards specified in the Standards of **Performance Code** are complied with.





2. COMPONENTS OF POWER QUALITY

COMPONENTS OF POWER QUALITY



Components of Power Anomalies

Transients

Voltage Sags/Dips

Voltage Swells

Voltage Variations or Fluctuations

Voltage Unbalance

Harmonic Distortion

Voltage Flickers

Electromagnetic Interference (EMI)

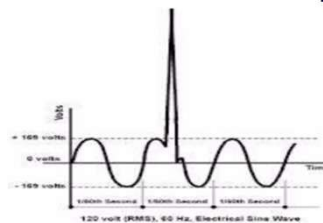
Voltage Drop



TRANSIENTS

a. **Transients:** Transients are sudden and brief spikes in voltage that can damage equipment or cause data loss. Power outages often lead to voltage transients or surges when power is restored.

- Transients (**surges, spikes, impulses**) are **disturbances** with a very fast voltage change.
- They last *less than* a half-cycle period
- The voltage excursions range from **hundreds to thousands of kilovolts**



TRANSIENTS – CAUSE & EFFECTS

- **Causes:**

- Lightning Strikes
- Switching Operations
- Faults
- Electromagnetic Interference (EMI)

- **Effects:**

- Equipment Damage
- Downtime
- Productivity Impact
- Quality Issues



TRANSIENTS – CAUSE & EFFECTS

- D-Code: PART2: 4.3.3. The **Distribution System** and the **User System** shall be designed and operated to include devices that will mitigate the effects of transient over voltages on the **Distribution System** and the **User System**. The **Disco** and the **User** shall take into account the effect of electrical transients when specifying the insulation of their electrical Equipment.



TRANSIENTS – SOME SOLUTIONS



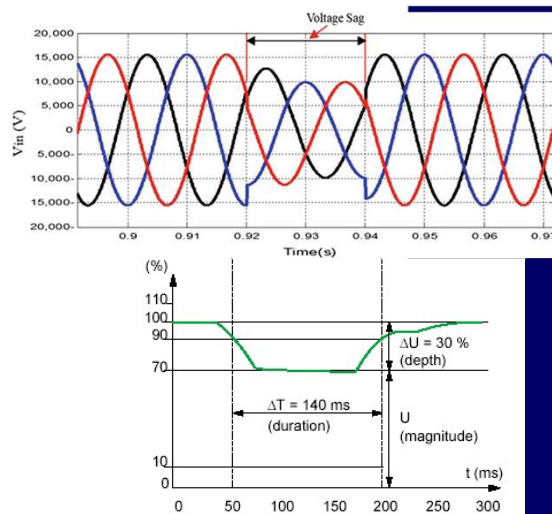
- Lightning Arresters
- Transient Voltage Suppressor System (TVSS)
- Power Line conditioners
- Data line protectors to prevent so-called “back-door hits” - *the issue when a transient enters an electronic device through the I/O ports rather than from the power lines*



VOLTAGE SAG/DIPS



- A voltage Sag/Dip is defined as a **sudden reduction of the voltage** at a point in an electrical power system **followed by voltage recovery** after a **short period** ranging from **a few cycles to a few seconds** (IEC 60050-161).
- A voltage sag is the most common supply disturbance causing interruption of production in an industrial plant.



VOLTAGE SAGS/DIPS – CAUSES & EFFECTS



- **Causes:**

- Remote fault
- load switching
- Supplying Large Inductive Loads

- **Effects:**

- Trips
- process control restarting
- motors stalling
- Voltage sags do not directly cause damage but usually initiate problems indirectly.
- For example, a sag may cause a laser machine to restart, thus damaging the product it is making

VOLTAGE SAGS/DIPS – CAUSES & EFFECTS



- *The lost energy from the sag may not be enough to shut down the device, but only enough to **confuse** the digital components.*
- *If this happens, then a **lock-up** may result.*
- Since the device switch is still on, as soon as the sag is over and the voltage has returned to nominal, the system turns back on, or **restarts**.

VOLTAGE SAGS/DIPS – SOME SOLUTIONS

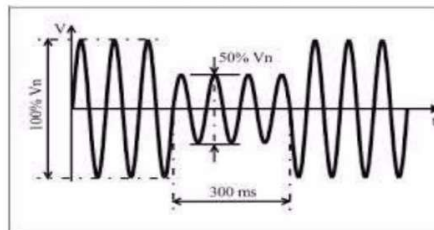


- Since sags are closely dependent on the wiring or system impedance, a possible solution to remedy these types of disturbances is to **increase the wire size of the distribution path**. Increasing the size decreases the impedance, ultimately reducing the magnitude of the disturbance.
- Use of an energy storage device or a form of **voltage regulator** to maintain voltage stability and protect equipment.
- Products that provide longer ride-through times such as enhanced power supplies, that regulate the voltage such as tap-switching power conditioners, or that switch to temporary back-up power like an **SPS**, will suffice.

VOLTAGE SAGS/DIPS – SOME SOLUTIONS



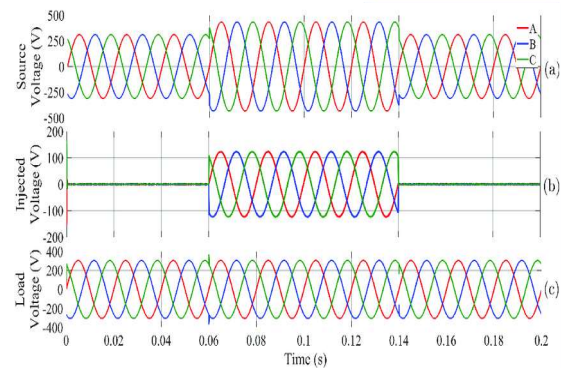
- Install an energy storage device such as a stand-by power system, called an **SPS**, or an uninterruptible power system, called a **UPS**
- Replacing the user's power supplies with ones that have longer **ride-through times**
- **NB: If a sag lasts for longer than several seconds, it is referred to as an Undervoltage**



VOLTAGE SWELLS/SURGES



- A **voltage swell** is the opposite of a dip. It describes a surge in voltage, typically exceeding 10% above the normal or recommended usage level for a few power cycles.
- IEEE 1159 defines voltage swell as the increase in the RMS voltage level to 110% - 180% of nominal, at the power frequency for durations of $\frac{1}{2}$ cycle to one (1) minute



VOLTAGE SWELLS – CAUSES & EFFECTS



- **Causes:**
 - Lightning strikes
 - Arcing
 - Switching
 - Improper Transformer Taps
- **Effects:**
 - Trips
 - damage to insulation and winding,
 - destruction of sensitive devices
- Power supplies controlling all manner of devices are the most common victims of a swell.
- Swell can cause problems with machinery and overall power quality in industrial settings.

VOLTAGE SWELLS – SOME SOLUTIONS

- Add new power system components.
- Increase the capacity of power lines (uprating).
- Utilize fixed compensation and install variable compensation systems.
- Deploy Flexible AC Transmission System (FACTS) devices



OVERVOLTAGE & UNDERVOLTAGE

- **Overvoltage** occurs when the **peak** value of the voltage applied to a device exceeds the limits defined in a standard or specification. There are three main types of overvoltage:
 - **Power-Frequency Overvoltage**
 - **Switching Overvoltage**
 - **Lightning Overvoltage**



OVERVOLTAGE & UNDERVOLTAGE



- **Power-Frequency Overvoltage**

- Overvoltages with a frequency under 500 Hz, usually caused by faults or specific system conditions.

- **Causes:**

- ❖ Insulation Faults
- ❖ Ferroresonance
- ❖ Break of the Neutral Conductor:
- ❖ Faults on Alternator Regulators or Tap-Changing Transformers
- Overcompensation of Reactive Power

OVERVOLTAGE & UNDERVOLTAGE



- **Switching Overvoltage**

- Switching overvoltages are caused by rapid modifications in the network structure, such as opening or closing protective devices. These overvoltages are characterized by their oscillatory nature and can be divided into:

- ❖ **Normal Load Switching Overvoltage**
- ❖ **Tripping of Long Transmission Lines**
- ❖ **Transient Overvoltage**
 - Capacitor Bank Energization
 - Ferranti Effect
 - Short Circuit Removal

OVERVOLTAGE & UNDERVOLTAGE



- **Lightning Overvoltage**

- Lightning overvoltages are caused by atmospheric lightning strikes, which generate high-voltage transients that can affect electrical systems. Lightning strikes can either directly hit power lines or induce voltage spikes from nearby strikes, leading to significant overvoltage.

- **Types:**

- ✦ Direct Lightning Strikes
- ✦ Indirect Lightning Effects

OVERVOLTAGE & UNDERVOLTAGE



- **Undervoltage**

- **Undervoltage** Occurs when the voltage falls below the specified limits, leading to inadequate operation or damage to electrical equipment.

- **Causes:**

- Load changes, poor power distribution, and faults in the power system can lead to undervoltage conditions.

- **Impact:**

- Undervoltage can cause equipment to malfunction, reduce performance, or sustain damage due to insufficient power supply.

OVERVOLTAGE & UNDERVOLTAGE



• Solutions to Overvoltage and Undervoltage

- ❖ **Surge Protection Devices (SPDs):** Install SPDs to protect against transient overvoltages caused by switching or lightning.
- ❖ **Proper Earthing:** Ensure proper earthing practices to mitigate the effects of power-frequency overvoltage.
- ❖ **Voltage Regulators:** Use voltage regulators to maintain stable voltage levels and protect equipment from both overvoltage and undervoltage.
- ❖ **Uninterruptible Power Supplies (UPS):** For undervoltage conditions, UPS can provide temporary power and maintain equipment operation during voltage sags.
- ❖ **Voltage Stabilizers:** Maintain steady voltage supply during undervoltage conditions.

VOLTAGE VARIATIONS/FLUCTUATIONS

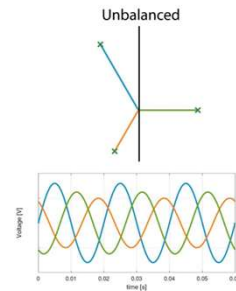
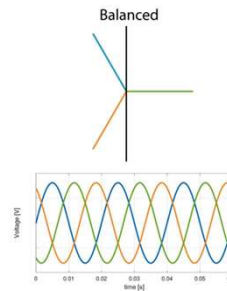


- Voltage **fluctuations** are a series of voltage changes or cyclical or random variations in the voltage envelope which are **characterized by the frequency of variation and the magnitude**.
- A broader term that encompasses **any deviation** from nominal voltage. This includes:
 - **Short-term variations:** Sags, swells, flicker, or interruptions (milliseconds to seconds).
 - **Long-term variations:** Sustained overvoltages or undervoltages (minutes to hours).
- **Slow voltage variations** are caused by the **slow variation of loads** connected to the network.

VOLTAGE UNBALANCE

NERC D-Code Voltage Unbalance Tolerance:
Maximum permissible unbalance: $\leq 2\%$.

- Voltage is **unbalanced** if the **rms value of the phase voltages or the phase angles between consecutive phases are not equal**.
- The degree of unbalance is defined using **Fortescue's** symmetrical components, comparing the **negative** sequence component or **zero** sequence component of the fundamental frequency to the **positive** sequence component.



VOLTAGE UNBALANCE

- As per IEEE 1159
- **Voltage Unbalance Rate (VUR)**: IEEE 1159 defines voltage unbalance as the maximum deviation from the average of the three-phase voltage, divided by the average voltage, expressed as a percentage.
- Voltage Unbalance (%) = $\frac{\text{Maximum Voltage Deviation from Average}}{\text{Average Voltage}} \times 100\%$
- The acceptable limit for voltage unbalance is generally **2%**.



VOLTAGE UNBALANCE



- **D-Code: PART2: 4.4. VOLTAGE UNBALANCE**

- 4.4.1. The maximum Voltage Unbalance at the **Connection Point** of any **User**, excluding the Voltage Unbalance passed on from the Transmission System shall not exceed the limits set by the affected **Disco**.
- 4.4.2. The **User** shall ensure that its **System** shall not cause the Voltage Unbalance in the **Distribution System** to exceed the limits specified in this Section.

VOLTAGE UNBALANCE – CAUSES & EFFECTS



- **Causes:**

- Unbalanced Load variation
- faults in the distribution network
- phase-to-phase faults.

- **Effects:**

- Overheating in motors and generators
- reduced efficiency,
- increased current harmonics.

VOLTAGE UNBALANCE – SOME SOLUTIONS

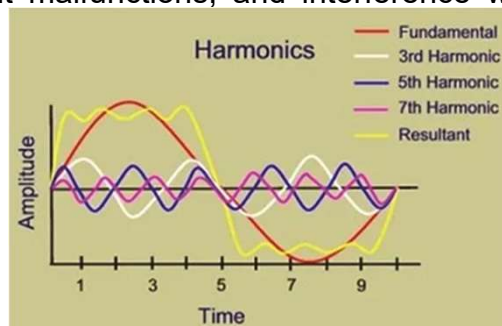


- **Regular Monitoring:** Continuously monitor the system to detect and correct imbalances as early as possible.
- **Balancing Loads:** Distribute single-phase loads evenly across all three phases to minimize unbalance.
- **Using Unbalance Correction Devices:** Devices such as phase balancers can be employed to mitigate the effects of unbalance in critical applications.

HARMONICS



- Harmonics are additional frequencies that exist alongside the fundamental frequency of the power system. They are typically caused by nonlinear loads such as computers, variable speed drives, or fluorescent lighting. High levels of harmonics can lead to overheating, equipment malfunctions, and interference with communication systems.



HARMONICS



- **D-Code:** PART2: 4.5.2. Distortion of the System voltage waveform, caused by certain types of Equipment, may result in annoyance to Users or damage to connected Apparatus. In order to limit these effects Users' Equipment connected to the Distribution System shall comply with the emission limits indicated in IEC 61000-3 Standards.

- IEC 61000-3-2: Limits for Harmonic Current Emissions
- IEC 61000-3-12: Limits for Equipment with Input Current between 16 A and 75 A

HARMONICS



- **D-Code:** PART2: 4.5.3. The level of harmonics generated by total **User's** connected Equipment at the **Connection Point**, shall not exceed the limits prescribed in the following table:

- [..¥Desktop¥JICA WG¥Power Quality¥Limits of Harmonics Currents Distortion as per NERC Distribution Code.xlsx](#)

- **D-Code:** PART2: 4.5.4. Measurements may be taken by the **Disco** at the **User's Connection Point**. Measurements shall be taken in accordance with methodologies of IEC 61000-4-7 lasting for at least 24 hours taken at 10 minute intervals.

HARMONICS – CAUSES AND EFFECTS

- **Causes**

- Power electronics,
- non-linear loads;
- signaling voltages

- **Effects:**

- Equipment mal-operation
- Unexpected reverberations
- "Logical" errors in digital equipment
- Unwanted overload for transformers and wires, or requirement for oversizing
- Unwanted tripping of circuit breakers or blowing of fuses.



HARMONIC – SOME SOLUTIONS

- Most of the harmonic disturbances occur in high-voltage phase lead capacitors, but the cause is that capacitors without series reactors expands the harmonics of the distribution network and the harmonic withstand capability of the series reactor is insufficient.
- There are two options for dealing with this.
 1. By adding filters, the harmonics can be reduced.
 2. Replace the transformer with one that can handle the distortion and has a high K factor.



VOLTAGE FLICKERS



- Voltage flicker refers to rapid voltage fluctuations caused by sudden changes in load or disturbances in the power system. It can cause visual disturbances in lighting and affect the performance of sensitive equipment like computers.
- It is a phenomenon in which the distribution voltage continuously repeats periodic fluctuations for a short time due to load fluctuations.



VOLTAGE FLICKERS



- **NERC D-Code Flicker Severity Limits:**
- PART2: 4.5.5. The Flicker Severity at the Connection Point of any User, shall not be above the maximum values stated in IEC 61000-3 Standard for more than 3 % of the measured period.
 - **3% Rule:** *Flicker Severity Should Not Exceed the Limits for More than 3% of the Period.*

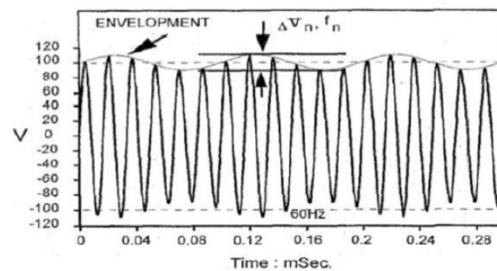
VOLTAGE FLICKERS – CAUSES AND EFFECTS

- **Causes:**

- Load variations at a particular frequency (e.g. arc furnaces..)

- **Effects:**

- Noticeable effects in the lighting

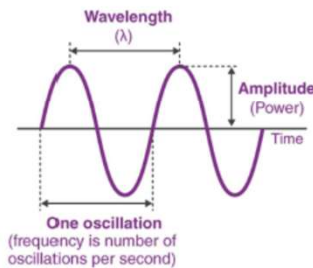


VOLTAGE FLICKERS – SOME SOLUTIONS

- Increases the capacity of the injection transformer.
- Shorten the length of distribution lines.
- Increase the conductor size of distribution lines.
- Reduce reactive power
 - There are various ways to reduce reactive power, but the current mainstream is the installation of a Static VAR compensator (SVC). SVC adjusts reactive power by turning capacitors and reactors on and off.

ELECTRICAL NOISE OR EMI

- *Electrical noise, sometimes called electromagnetic interference, EMI, consists of **high frequency**, **low voltage** signals coupled onto the power lines.*
- Frequencies may vary from the kilohertz to the megahertz range, and
- Magnitudes may be up to 10 or 20 volts.



ELECTRICAL NOISE OR EMI

- The ground is the digital reference for the device
- *At high frequencies, ground is one more conduction path for noise.*
- Noise can travel along the ground and affect the circuits and components inside or, if data cable shields are not properly terminated, noise can enter through them



ELECTRICAL NOISE – CAUSES & EFFECTS



• Causes:

- The source of EMI may be:
- *Conducted*, meaning it started out on the power lines, or
- *Radiated*, meaning it started out in the air and was coupled into the power lines

• Effects:

- EMI is seldom damaging in and of itself
- But, like voltage sags, EMI indirectly causes damage and loss of product.
- EMI can cause disruption in sensitive devices.
 - An example would be in a process control computer regulating petrol dispensing. EMI may confuse the computer, causing it to pump more petrol than requested.

ELECTRICAL NOISE - SOME SOLUTIONS



- First step: *Locate where the interference* is coming from and remove or relocate the victim or culprit.
- Second step: Isolate culprit or victim by using an **EMI filter**.
- To reduce EMI data flow problems, ensure that all system components and devices are **properly grounded**. This includes all data cables. If necessary, isolated ground systems should be installed.

ELECTRICAL NOISE - SOME SOLUTIONS

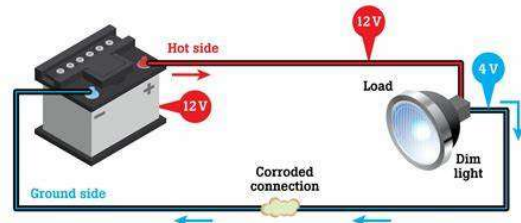


- For radiated EMI, steps must be taken to identify and locate the source, identify its frequency, and then provide protection to the victim.
 - This protection often takes the form of placing a **conductive shield** around the device to isolate it from the EMI. Obviously, this is complex and costly.
- If problems still exist with distributed systems, consider using **fibre-optic** data transmission.
 - Since fibre-optic cables are non-conductive, no EMI coupling will occur.

VOLTAGE DROP



- Voltage drop is the potential difference caused by presence of any obstacle in the circuit such as a resistor, inductor, or capacitor. ***It is the lost voltage.***
- It is when the supplied energy of a voltage source is reduced as electric current moves through the passive elements.
- In an AC system, the voltage drops are due to the combined effects of the resistance, inductance, and capacitance



IEC STANDARD VOLTAGES (IEC 60038)



- IEC 60038 is an International Electrotechnical Commission (IEC) standard that defines the standard voltages for electrical power systems.
- It provides guidelines for the nominal voltage levels used in various countries and regions around the world
- These standard voltages are crucial for ensuring compatibility and interoperability of electrical equipment and systems

IEC STANDARD VOLTAGES (IEC 60038)



- The description of the IEC standard voltages outlined in IEC 60038:
- **Nominal Voltages for AC Voltage:**
 - Low Voltage (LV) - up to and including 1000 V
 - Medium Voltage (MV) - 1kV to 35 kV
 - High Voltage (HV) - above 35 kV
 - Tolerance: $\pm 10\%$
- **Nominal Voltages for DC Voltage**
 - Low Voltage (LV) - up to and including 1,500V,
 - High Voltage (HV) - above 1,500V
 - Tolerance: $\pm 10\%$

STANDARD VOLTAGES (NERC D-CODE)

• 4.3. VOLTAGE LEVELS

- 4.3.1. Nominal and Operational Voltages on the **Transmission/Distribution System** are shown in the following Table.

Nominal Voltage	Operational Voltages	
	Minimum (pu)	Maximum (pu)
330 kV	297 kV (0.90)	363 kV (1.10)
132 kV	118.8 kV (0.90)	145.2 kV (1.10)
33 kV	31 kV (0.94)	34.98 kV (1.06)
16 kV	15.2 kV (0.95)	16.8 kV (1.05)
11 kV	10.45 kV (0.95)	11.55 kV (1.05)
400 V	376 V (0.94)	424 V (1.06)
230 V	216.2 V (0.94)	243.8 V (1.06)



VOLTAGE DROP CALCULATION

$$e = k \cdot L \cdot (R \cos \theta + X \sin \theta) \cdot I$$

$$= k \cdot L \cdot Z \cdot I$$

- e : Voltage drop (V)
- k : Constant ($k = 2$ for single phase and $= \sqrt{3}$ for 3 phase)
- L : Length of the line (km)
- Z : Impedance of the conductor (Ω/km)
- R : Resistance of the conductor (Ω/km)
- X : Reactance of the conductor (Ω/km)
- I : Current of the sending end (A) and
- θ : Power factor angle (degrees)



VOLTAGE DROP CALCULATION USING MS EXCEL



The step-by-step explanation of how to perform voltage drop calculations in MS Excel:

1. Open Microsoft Excel and create a new spreadsheet.
2. Label the columns as follows: Section, Resistance (R), Impedance (Z), Length (L), Conductor (C), Current (I), and Voltage Drop (V).

[Calculation sheet
of voltage
drop_rev1.xlsx](#)

VOLTAGE DROP CALCULATION USING MS EXCEL



3. Enter the values for each parameter in their respective columns. For example, you might have section, resistance values in ohms per kilometer (Ω/km), impedance values in ohms per kilometer (Ω/km), length values in kilometers (km), conductor types (such as copper or aluminum), current values in amperes (A), and leave the voltage drop column empty for now.

NB: These values can be obtained from the specifications of the electrical system you are working with, or the cable/conductor manufacturer datasheet used in the system.

VOLTAGE DROP CALCULATION USING MS EXCEL



4. In the Voltage Drop (V) column, enter the following formula: $=K*L*Z*I$. This formula calculates the voltage drop based on the length (L), impedance (Z), and current (I), multiplied by a constant factor (K). Choose the constant factor (K) based on the circuit to ensure the correct calculation.
5. Repeat the formula for each row in the Voltage Drop (V) column, adjusting the cell references as needed to match the respective values in the other columns. For example, if the length is in cell B2, the impedance is in cell C2, and the current is in cell F2, the formula in cell G2 would be $=K*B2*C2*F2$.

VOLTAGE DROP CALCULATION USING MS EXCEL



6. Apply the formula to the remaining rows by dragging the bottom right corner of the cell with the formula down to the desired range.
7. Once the formula is applied to all rows, the Voltage Drop (V) column will display the calculated voltage drop for each section.

VOLTAGE DROP CALCULATION USING MS EXCEL



- NB: This method assumes that you have the necessary data for section, resistance, impedance, length, conductor, and current. It also assumes that you have determined the appropriate constant factor (K) based on the units used in your calculations.
- Also: Remember to double-check your formulae and ensure that you are using consistent units throughout the calculation

VOLTAGE DROP CALCULATION FOR NETWORK PLANNING



- When formulating the facilities plan that considers the increase in load for each year, calculate the voltage drop for each year and check that it is within the supply voltage range.
- To calculate the voltage drop in a network planning scenario where load increases each year, you can use the same formula:

$$e = k \cdot L \cdot (R \cos \theta + X \sin \theta) \cdot I = k \cdot L \cdot Z \cdot I$$

VOLTAGE DROP CALCULATION FOR NETWORK PLANNING



• Here's how you can calculate the voltage drop for each year:

1. Determine the initial values:

- . L: Length of the line
- . R: Resistance per unit length of the line
- . X: Reactance per unit length of the line
- . θ : Power factor angle
- Or Z: Impedance per unit length of the line
- . I: Initial current flowing through the line

VOLTAGE DROP CALCULATION FOR NETWORK PLANNING



2. Calculate the voltage drop for the first year:

- . Substitute the initial values into the formula:

$$e = k * L * (R \cos \theta + X \sin \theta) * I$$

- . This will give you the voltage drop for the first year.

3. Calculate the load increase for the next year:

- . Determine the increase in load for the next year, considering the network planning.
- . Let's denote this increase as ΔI ,
- . The load for the next year will then be $I' = I + \Delta I$

VOLTAGE DROP CALCULATION FOR NETWORK PLANNING



4. Calculate the voltage drop for the next year:
 - . Multiply the increased load (I') with the length of the transmission line (L) and the impedance (Z) of the line:
 - . $V' = k * L * Z * I'$
5. Repeat steps 3 and 4 for subsequent years:
 - . For each subsequent year, calculate the increased load (I') and use it to calculate the voltage drop (V') using the formula from step 4.

VOLTAGE DROP CALCULATION FOR NETWORK PLANNING



6. Accumulate the voltage drops for each year:
 - . Add up the voltage drops for each year to obtain the total voltage drop over the planning period.
- It's important to note that the constant factor (k) should be chosen based on the circuit. Additionally, the values of R , X , and θ can be determined based on the characteristics of the line and the electrical system under consideration.

FERRANTI EFFECT



The Ferranti effect is a phenomenon that occurs in a **long** power transmission or distribution lines carrying alternating current (AC).

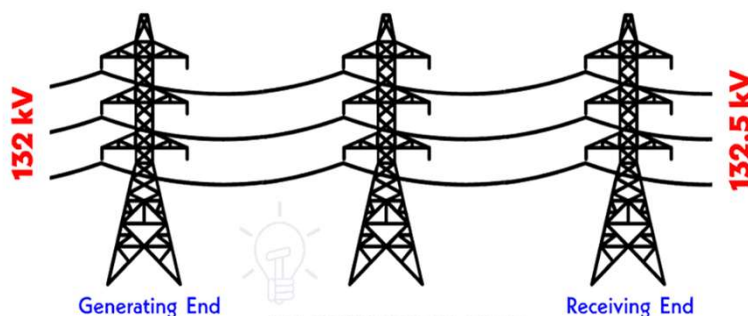
It refers to the **increase in voltage** observed at the **receiving end** of a the line **compared** to the **voltage at the sending end**, particularly when the **line is lightly loaded or unloaded**.

Ferranti effect is primarily **caused** by the **inductive reactance** of the line

FERRANTI EFFECT



The "Receiving End" Voltage is Greater Than the "Sending End" Voltage.



FERRANTI EFFECT



When the line is *lightly loaded* or *unloaded*, the *current flowing* through it *decreases, reducing the magnetic field* and the associated voltage drop.

This *reduction in voltage drop* causes the *voltage at the receiving end to increase*, resulting in a *higher voltage than the voltage at the sending end*.

This *effect* is more pronounced in long transmission or distribution lines with *high inductive reactance*

FERRANTI EFFECT

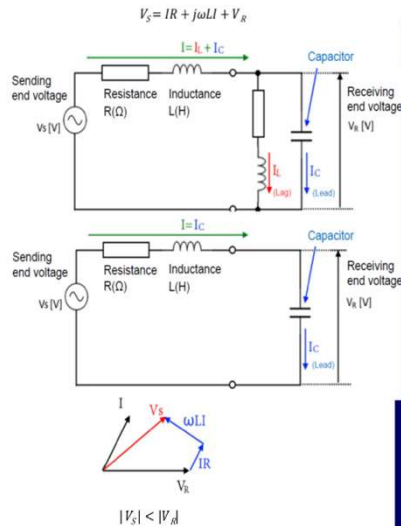


The *Ferranti effect* can lead to *voltage regulation issues* and can potentially cause *overvoltage conditions* at the *receiving end* of the line.

To *mitigate this effect*, various *compensation techniques* such as *series capacitors* or *voltage regulators* are employed to maintain the voltage within acceptable limits.

WHY FERRANTI EFFECT OCCURS?

- Ferranti effect mainly occurs because of light load or open circuit at the receiving end. The capacitive loads cause a leading power factor as shown in the figure below. In this case, the receiving end voltage V_R is higher than the sending end voltage V_S .



HOW TO ADDRESS FERRANTI EFFECT

- This voltage can be controlled by placing **shunt reactors** at the receiving end of the lines.
- Shunt reactor is an inductive current element connected between line and neutral to compensate the capacitive current from transmission/distribution lines
- Shunt reactors compensate the capacitive VAR of the lines and therefore the voltage is regulated within the prescribed limits

VOLTAGE DROP – SOME SOLUTIONS



- Tap Changers
- Phase Balancing
- Load Management
- Reinforcement
- Dynamic Voltage Management
 - SVR: Step Voltage Regulator
 - SVC: Static Var Compensator
 - TVR: Thyristor Voltage Regulator

VOLTAGE DROP – SOME SOLUTIONS



- **Tap Changers**
 - Adjusting tap positions at distribution transformers is a low-cost, traditional method for managing voltage. Similarly, adjustments can be made to the fixed voltage target at injection substations.
- **Phase Balancing**
 - Phase imbalance arises when load and/or generation is unevenly spread across a three-phase system, resulting in a mismatch of the voltage between phases. Phase balancing aims to reallocate single phase connections to resolve the imbalance.

VOLTAGE DROP – SOME SOLUTIONS



- **Load Management**

- Changing the timing of customer loads, such as controlled load hot water, can be used to manage voltage.

- **Reinforcement**

- Network reinforcement involves the replacement of conductors and transformers which can help reduce the effects of congestion and voltage drop/rise.

VOLTAGE DROP – SOME SOLUTIONS



- **Dynamic Voltage Management**

- Dynamic voltage management is a sophisticated option which, once implemented, allows networks to dynamically adjust voltage to respond to changing network conditions.

VOLTAGE DROP – SOME SOLUTIONS



➤ **SVR: Step Voltage Regulator**

The step type voltage regulator takes an incoming voltage that will change with load settings and maintains a constant output voltage. The voltage will drop as the loading rises along the distribution feeder. This voltage drop decreases the amount of power used by the lighting portion of the load. By increasing the voltage to this lighting load, more power is used up.



VOLTAGE DROP – SOME SOLUTIONS



➤ **SVC: Static Var Compensator**

The Static Var Compensator (SVC) is a device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow on power grids. The SVC regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the SVC generates reactive power (capacitive). When system voltage is high, it absorbs reactive power (inductive).



VOLTAGE DROP – SOME SOLUTIONS



➤ TVR: Thyristor Voltage Regulator (aka Silicon Controlled Rectifier – SCR)

Thyristors are semiconductor devices that act as switches, allowing current to flow in one direction only when triggered.

They are used to control the flow of electricity in order to maintain a desired output voltage

The TVR purpose is to control power flows and regulate voltage in distribution electrical networks.



3. VOLTAGE MANAGEMENT OF DISTRIBUTION NETWORK



VOLTAGE MANAGEMENT OF DISTRIBUTION NETWORK



- Voltage management considerably impacts maintaining the quality and stability of electrical distribution networks.
- It involves controlling voltage levels to ensure optimal performance, minimize losses, and prevent voltage violations.
- Higher voltages can be desirable from a network planning perspective as they typically result in reduced line losses, which means less energy is lost in transportation.
- Higher network voltages also result in better utilization of assets, which can reduce the network reinforcement needed to accommodate peak demand.

VOLTAGE MANAGEMENT OF DISTRIBUTION NETWORK



Voltage Optimization in Active Distribution Networks (ADNs):

- With the increasing integration of renewable energy sources (RESs), ADNs face new challenges.
- RESs, such as photovoltaics (PVs), wind turbines (WT), and Energy storage systems (ESS) impact voltage profiles due to their intermittent nature.
- Researchers have been working on innovative techniques to regulate voltage in ADNs, particularly in contexts with high RES penetration (such as photovoltaics).
- These strategies aim to mitigate voltage fluctuations, optimize network performance, and integrate smart technologies like smart inverters and energy storage systems (ESSs).

VOLTAGE MANAGEMENT OF DISTRIBUTION NETWORK



Key developments include decentralized control algorithms, multi-objective optimization techniques, and the use of soft open points (SOPs) to enhance grid stability and efficiency.

Voltage Control Methodologies:

1. Coordinated Control (for networks with basic development):

- a) Balances voltage across the network by adjusting tap changers, capacitor banks, and reactive power sources.
- b) Improves loss minimization and mitigates voltage violations.

[Researchers propose innovative approaches for voltage control in ADNs¹:](#)

VOLTAGE MANAGEMENT OF DISTRIBUTION NETWORK



2. Centralized Control (for fully supervised networks):

- a) Optimizes voltage regulation by harmonizing generator capability curves with regulations.
- b) Models discrete control of On-Load Tap Changer transformers.

Specific Techniques:

1. Day-Ahead and Intraday Control:

- 1. [Utilized for voltage regulation in distribution networks with PVs and electric vehicles \(EVs\)².](#)
- 2. Combines predictive and real-time control to exploit PV and EV voltage support capabilities.

VOLTAGE MANAGEMENT OF DISTRIBUTION NETWORK



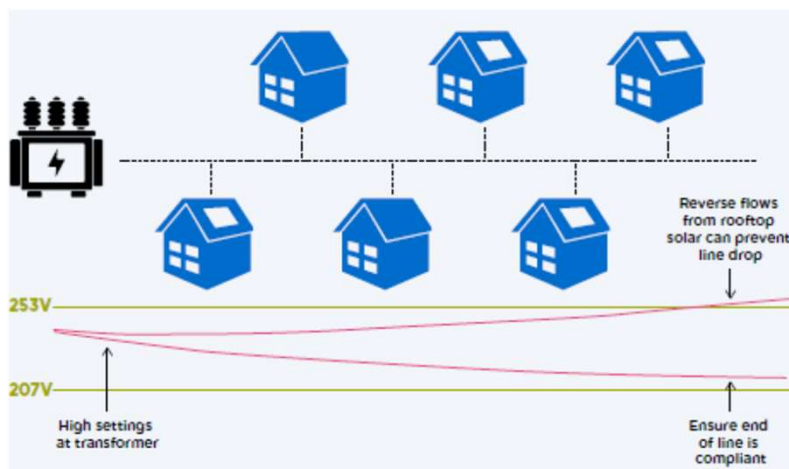
Conclusion:

Voltage management is a dynamic field, adapting to changing energy landscapes.

Coordinated and centralized control strategies play pivotal roles in maintaining network stability.

- Remember that specific network designs and regulatory frameworks influence the choice of voltage control methods.

VOLTAGE MANAGEMENT OF DISTRIBUTION NETWORK





4. MITIGATION TECHNIQUES FOR POWER QUALITY PROBLEMS

POWER QUALITY IMPROVEMENT

- Power quality improvement refers to the enhancement of the electrical power supply to ensure it meets specific standards and requirements.
- Poor power quality can result in various issues, including voltage fluctuations, harmonics, sags, surges, transients, and interruptions, which can affect the performance and reliability of electrical equipment and systems.



POWER QUALITY IMPROVEMENT



- Mitigating PQ issues involves a combination of techniques targeting specific components. Here's a **summary of techniques** for mitigating power quality problems:

- ✓ **Transients:**

- a) **Surge Protectors:** Use surge protectors to suppress voltage transients and protect sensitive equipment.
- b) **Isolation Devices:** Employ isolation devices to shield equipment from transient disturbances.

- ✓ **Voltage Sags and Swells:**

- a) **Voltage Regulators and Conditioners:** Use automatic voltage regulators (AVRs) and voltage conditioners to maintain a stable voltage level.
- b) **Energy Storage Systems (ESS):** Employ ESS like batteries to provide immediate power during voltage sags.

POWER QUALITY IMPROVEMENT



- ✓ **Interruptions:**

- a) **Uninterruptible Power Supply (UPS):** Implement UPS systems to provide backup power during interruptions.
- b) **Distributed Generation:** Integrate distributed generation sources to enhance system reliability

- ✓ **Voltage Unbalance:**

- a) **Balancing Loads:** Distribute loads evenly among phases to minimize voltage unbalance.
- b) **Phase Balancing Transformers:** Use transformers designed to balance voltages between phases

POWER QUALITY IMPROVEMENT



✓ Harmonics:

- a) **Filters:** Install harmonic filters to eliminate or reduce harmonic distortions in the power system.
- b) **Isolation Transformers:** Use isolation transformers to limit the propagation of harmonics.

✓ Flicker:

- a) **Dynamic Voltage Restorers (DVR):** Employ DVR systems to compensate for voltage fluctuations and mitigate flicker.
- b) **Optimizing System Configuration:** Adjust the configuration of loads and power factor correction to reduce flicker.

POWER QUALITY IMPROVEMENT



✓ Frequency Variations:

- a) **Frequency Converters:** Install frequency converters to regulate and stabilize the frequency in critical applications.
- b) **Load Shedding:** Implement load shedding strategies to maintain system stability during frequency variations.

✓ Power Factor Issues:

- a) **Power Factor Correction Devices:** Use power factor correction capacitors to improve power factor and reduce reactive power.
- b) **Variable Speed Drives:** Employ variable speed drives to control motor speed and improve power factor.

POWER QUALITY IMPROVEMENT



✓ **Grounding Issues:**

- a) **Proper Grounding Practices:** Ensure proper grounding of equipment and systems to prevent ground-related problems.
- b) **Ground Fault Interrupters (GFIs):** Use GFIs to detect and isolate ground faults quickly.

✓ **Voltage Flicker:**

- a) **Load Management:** Implement load management strategies to reduce voltage flicker caused by sudden load changes.
- b) **Dynamic Compensation Systems:** Use dynamic compensation systems to mitigate voltage flicker in real-time.

IMPROVING POWER QUALITY – SUMMARY



• **DIPS, SURGES, SPIKES AND INTERRUPTIONS**

- Un-interruptible Power Supplies (UPS)
- Static Var Compensation (SVC)
- Ferro-resonance Transformers

• **HARMONICS**

- Earthing Practices
- Filters (Passive and Active)

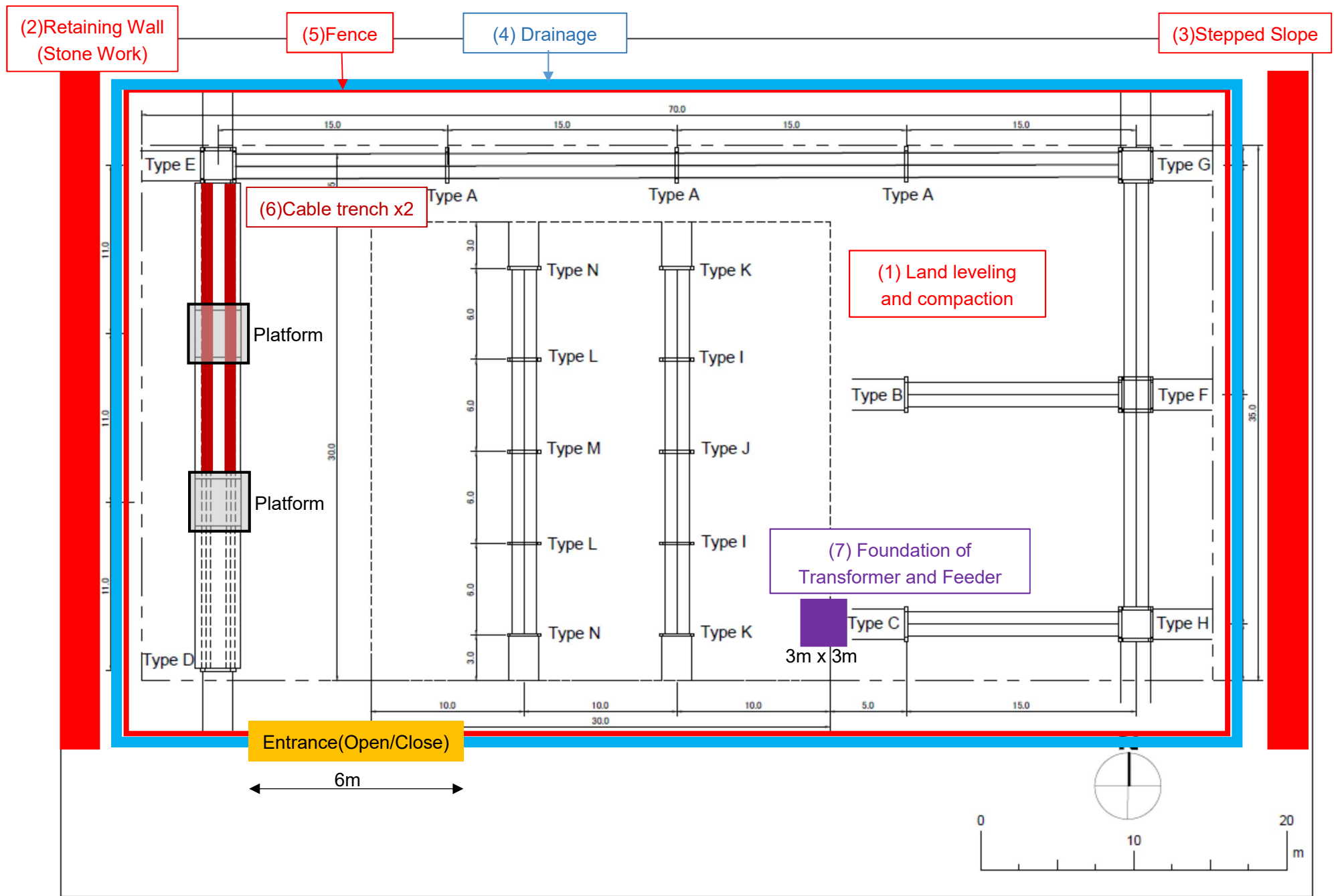
Solutions for Improving Power Quality



Type of disturbance	Origins	Consequences	Examples of mitigation solutions (special equipment and modifications)
Voltage variations and fluctuations	Large load variations (welding machines, arc furnaces, etc.).	Fluctuation in the luminance of lamps (flicker).	Electromechanical reactive power compensator, real time reactive compensator, series electronic conditioner, tap changer.
Voltage dips	Short-circuit, switching of large loads (motor starting, etc.).	Disturbance or shutdown of process: loss of data, incorrect data, opening of contactors, locking of drives, slowdown or stalling of motors, extinguishing of discharge lamps.	UPS, real time reactive compensator, dynamic electronic voltage regulator, soft starter, series electronic conditioner. Increase the short-circuit power (Scc). Modify the discrimination of protective devices.
Interruptions	Short-circuit, overloads, maintenance, unwanted tripping.		UPS, mechanical source transfer, static transfer switch, zero-time set, shunt circuit breaker, remote management.
Harmonics	Non-linear loads (adjustable speed drives, arc furnaces, welding machines, discharge lamps, fluorescent tubes, etc.).	Overloads (of neutral conductor, sources, etc.), unwanted tripping, accelerated ageing, degradation of energy efficiency, loss of productivity.	Anti-harmonic choke, passive or active filter, hybrid filter, line choke. Increase the Scc. Contain polluting loads. Derate the equipment.
Inter-harmonics	Fluctuating loads (arc furnaces, welding machines, etc.), frequency inverters.	Interruption of metering signals, flicker.	Series reactance.
Transient overvoltages	Operation of switchgear and capacitors, lightning.	Locking of drives, unwanted tripping, destruction of switchgear, fire, operating losses.	Surge arrester, surge diverter, controlled switching, pre-insertion resistor, line chokes, static automatic compensator.
Voltage unbalance	Unbalanced loads (large single-phase loads, etc.).	Inverse motor torque (vibration) and overheating of asynchronous machines.	Balance the loads. Shunt electronic compensator, dynamic electronic voltage regulator. Increase the Scc.

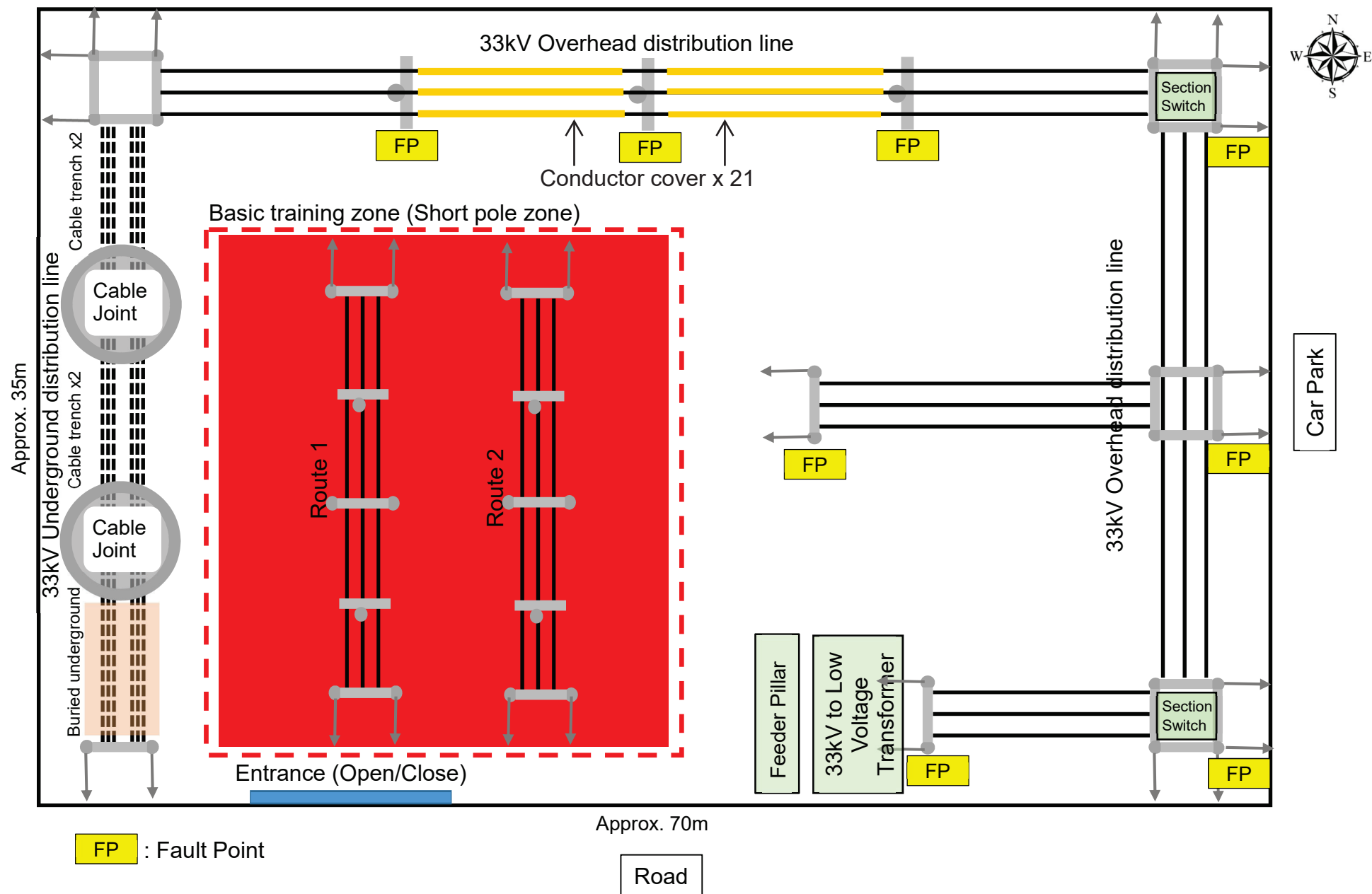
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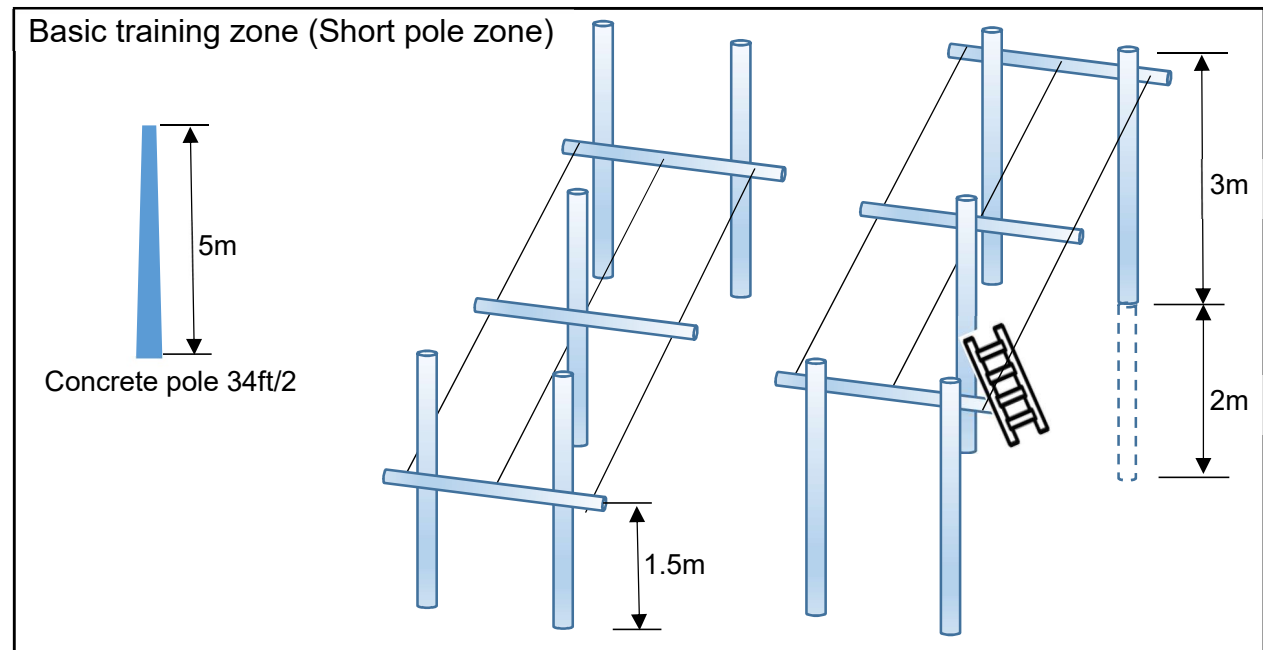
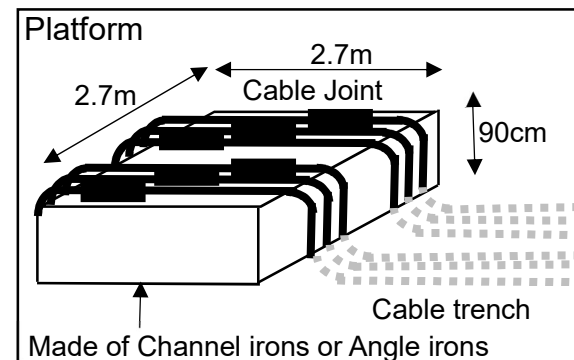
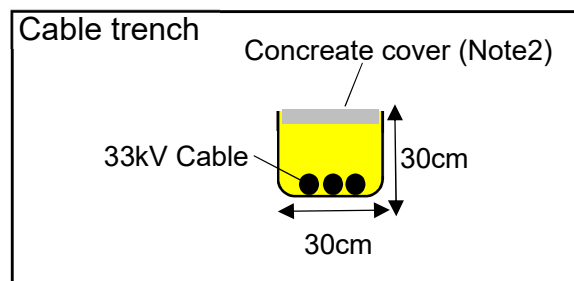
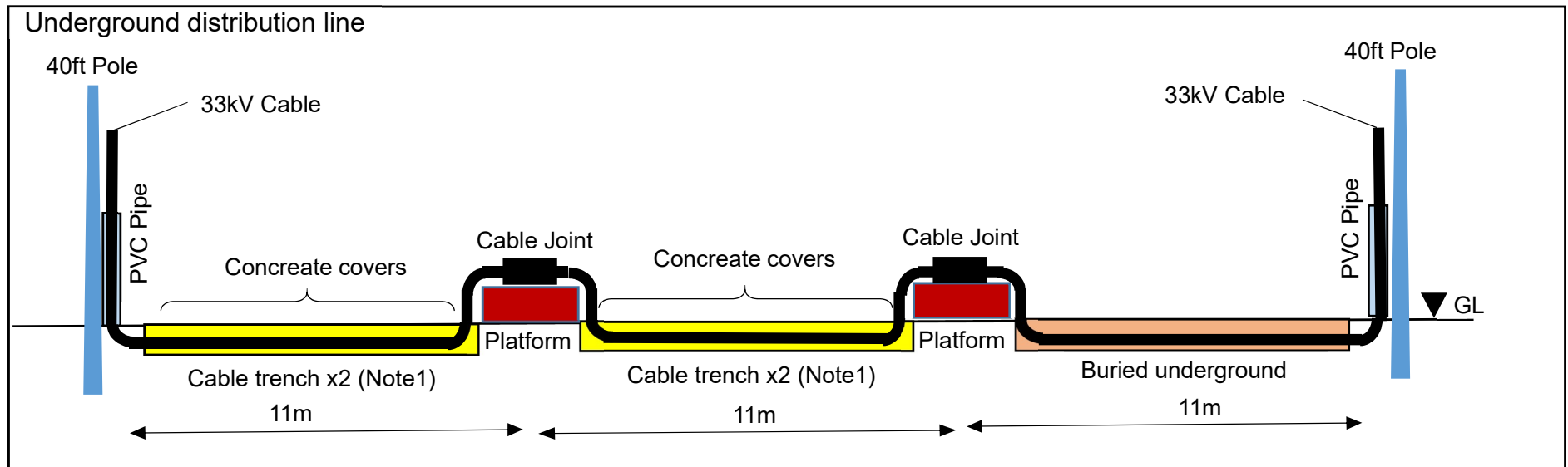




Civil works drawing for the distribution training facility

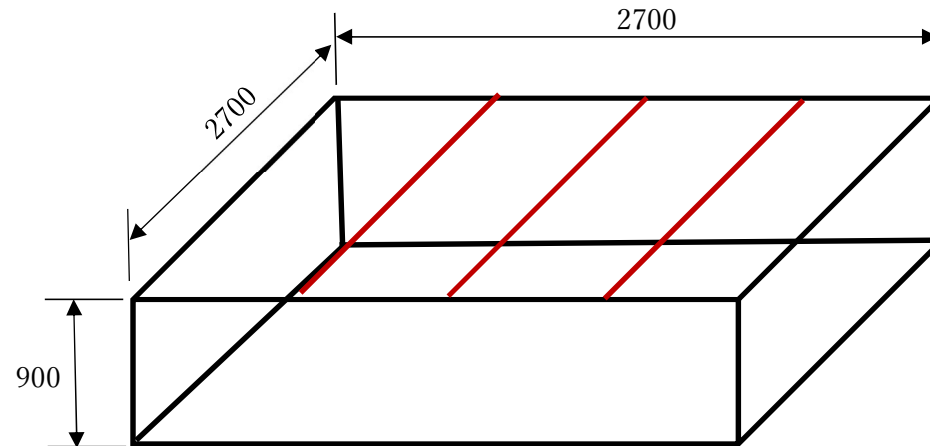
Layout plan of the distribution training facility





(Note1) Water inside the cable trench shall be drained naturally.
 (Note2) The concrete cover shall be easily lifted up by manpower.

Platform

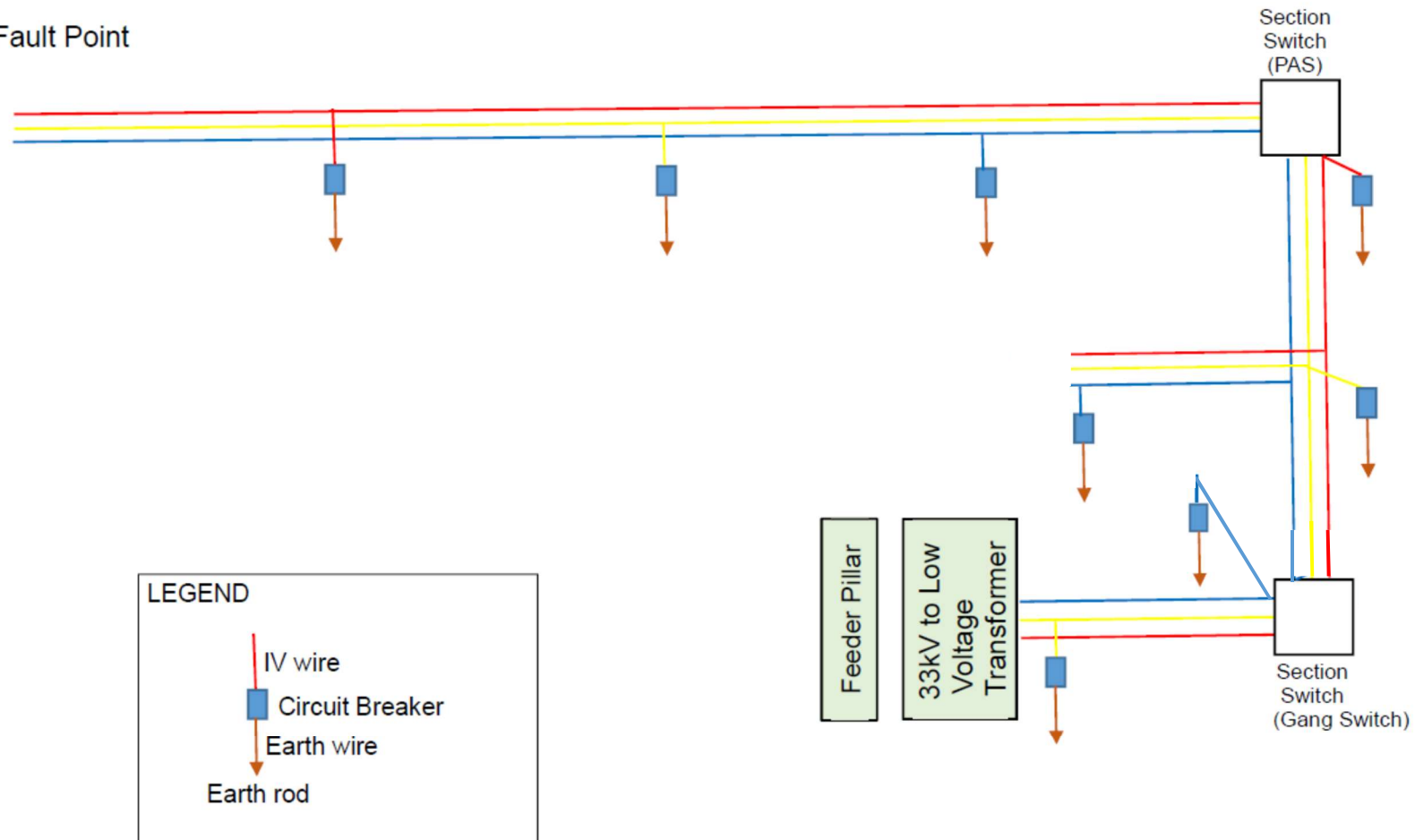


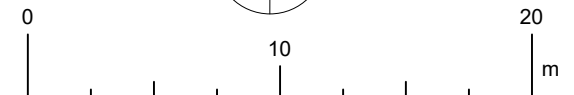
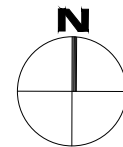
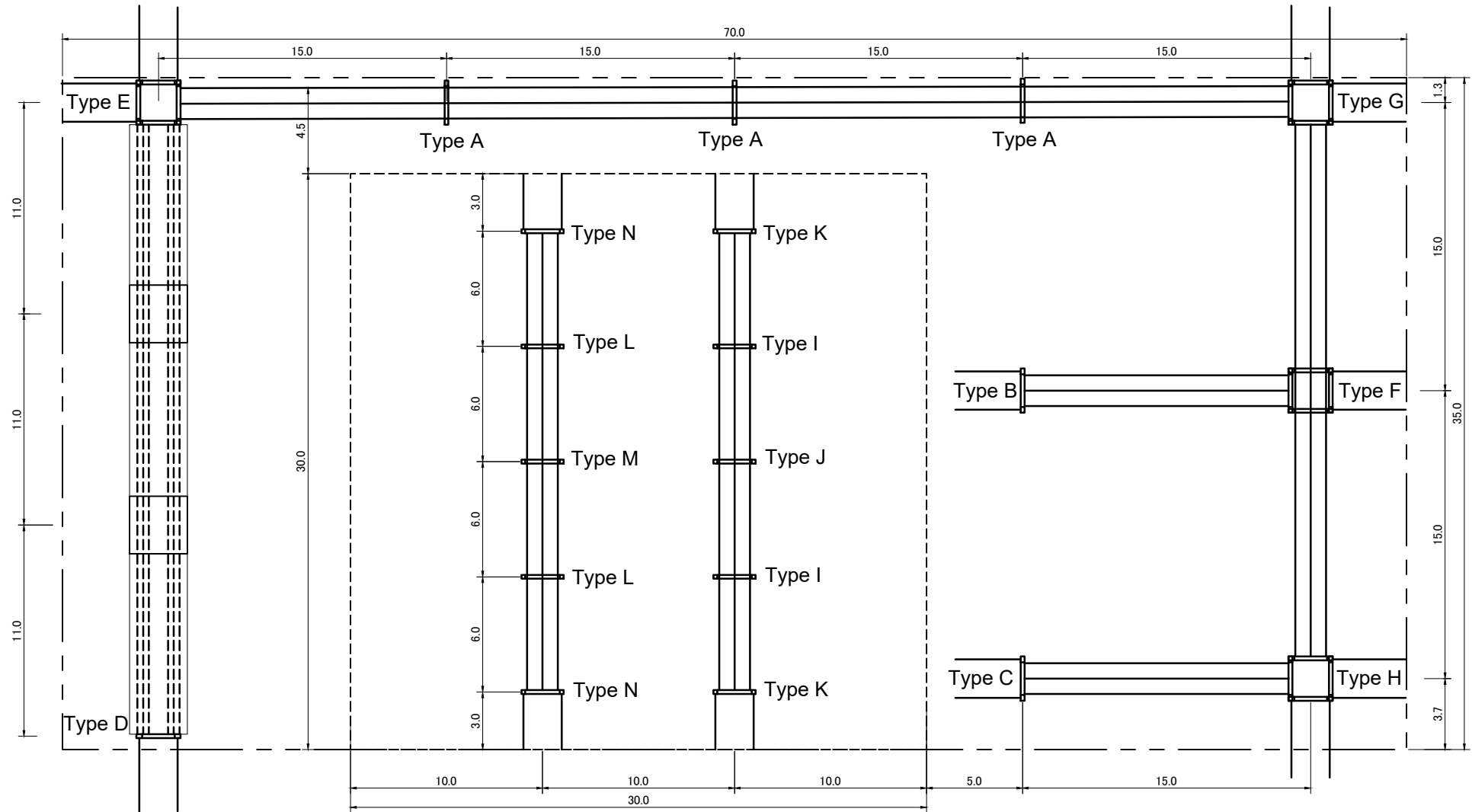
- Angle iron
- Channel iron

Platform Drawing

Revised

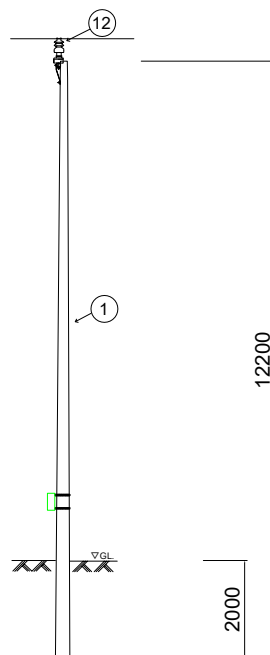
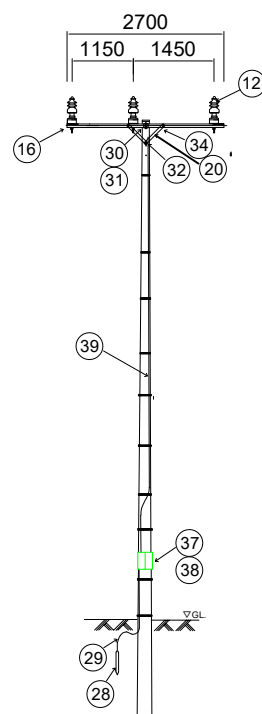
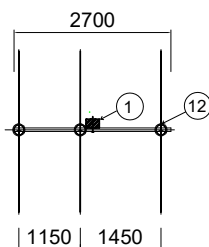
Fault Point





Layout plan of the distribution training facility for NAPTIN (Draft)
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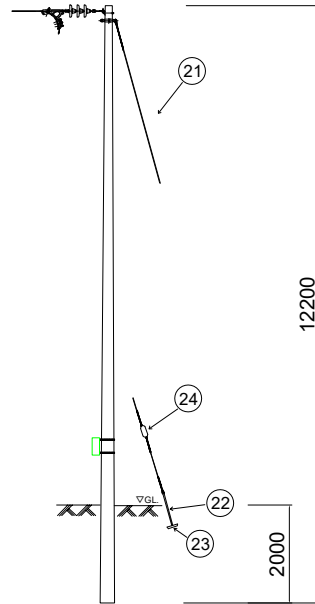
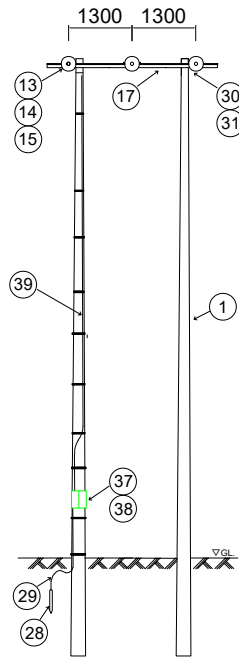
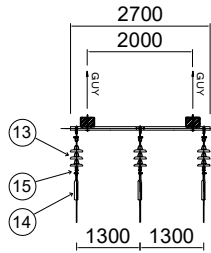
Type A



33kV Intermediate Pole

No.	Item	Unit	Q'ty	Remarks
N-1	Concrete Pole 40ft(12.2m)	no	1	
N-12	33kV Pin insulator	no	3	
N-16	Fiber crossarm	no	1	
N-20	33kV Tie-strap	no	2	
N-28	Earth rod	Unit	1	
N-29	Earth wire	m	10	
N-30	5/8 inches Washers	no	8	
N-31	Bolt and Nut 5/8 x 11 inches	no	1	280mm
N-32	Bolt and Nut 5/8 x 9 inches	no	1	220mm
N-34	Bolt and Nut 5/8 x 6 inches	no	2	150mm
N-37	Circuit Breaker	no	1	
N-38	Circuit Breaker Box	no	1	
N-39	IV wire	m	10	

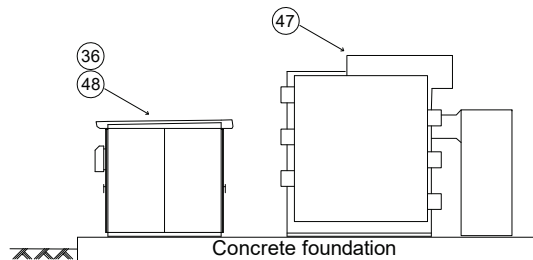
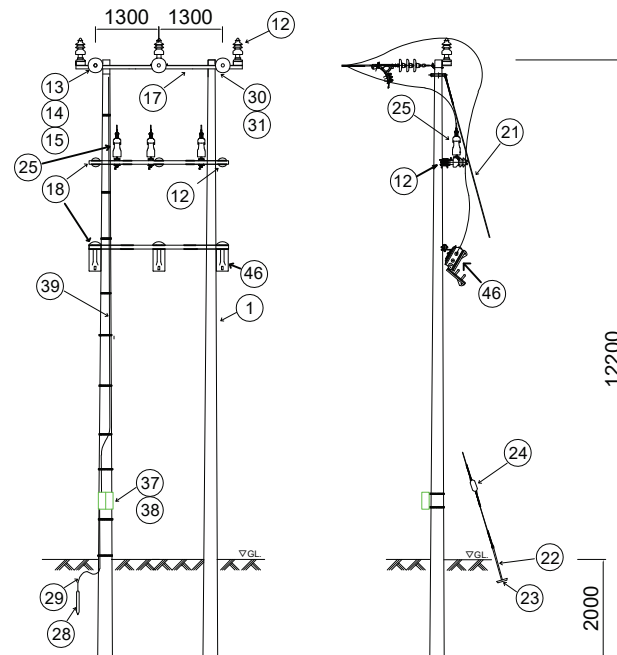
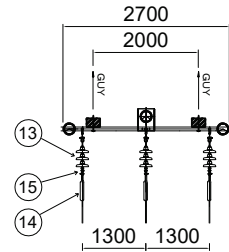
Type B



33kV Dead End Pole

No.	Item	Unit	Q'ty	Remarks
N-1	Concrete Pole 40ft(12.2m)	no	2	
N-13	33kV Silicone disk insulator	no	3	
N-14	6-Bolt clamp	no	3	
N-15	Adaptor Socket Tongue	no	3	
N-17	33kV Angle iron	no	1	
N-21	Stay wire	m	24	
N-22	Stay Rod	no	2	
N-23	Stay Block	no	2	
N-24	Stay insulator(33kV)	no	2	
N-28	Earth rod	Unit	1	
N-29	Earth wire	m	10	
N-30	5/8 inches Washers	no	8	
N-31	Bolt and Nut 5/8 x 11 inches	no	2	280mm
N-37	Circuit Breaker	no	1	
N-38	Circuit Breaker Box	no	1	
N-39	IV wire	m	10	

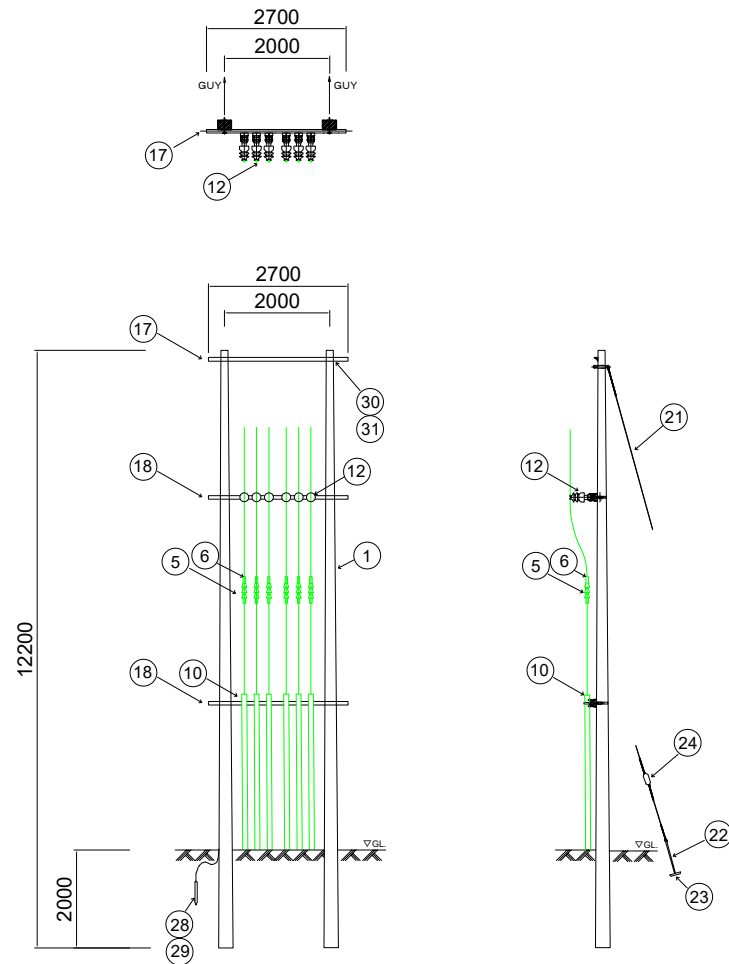
Type C



33kV Dead End Pole (Transformer)

No.	Item	Unit	Q'ty	Remarks
N-1	Concrete Pole 40ft(12.2m)	no	2	
N-12	33kV Pin insulator	no	6	
N-13	33kV Silicone disk insulator	no	3	
N-14	6-Bolt clamp	no	3	
N-15	Adaptor Socket Tongue	no	3	
N-17	33kV Angle iron	no	1	
N-18	33kV Channel iron	no	2	
N-21	Stay wire	m	24	
N-22	Stay Rod	no	2	
N-23	Stay Block	no	2	
N-24	Stay insulator(33kV)	no	2	
N-25	33kV Lightning Arrester	set	1	
N-28	Earth rod	Unit	1	
N-29	Earth wire	m	10	
N-30	5/8 inches Washers	no	24	
N-31	Bolt and Nut 5/8 x 11 inches	no	6	280mm
N-36	LV Cable	m	15	
N-37	Circuit Breaker	no	1	
N-38	Circuit Breaker Box	no	1	
N-39	IV wire	m	10	
N-46	33kV Fused Cutout Switch	unit	3	
N-47	Distribution Transformer	unit	1	AEDC
N-48	Feeder Pillar	unit	1	AEDC

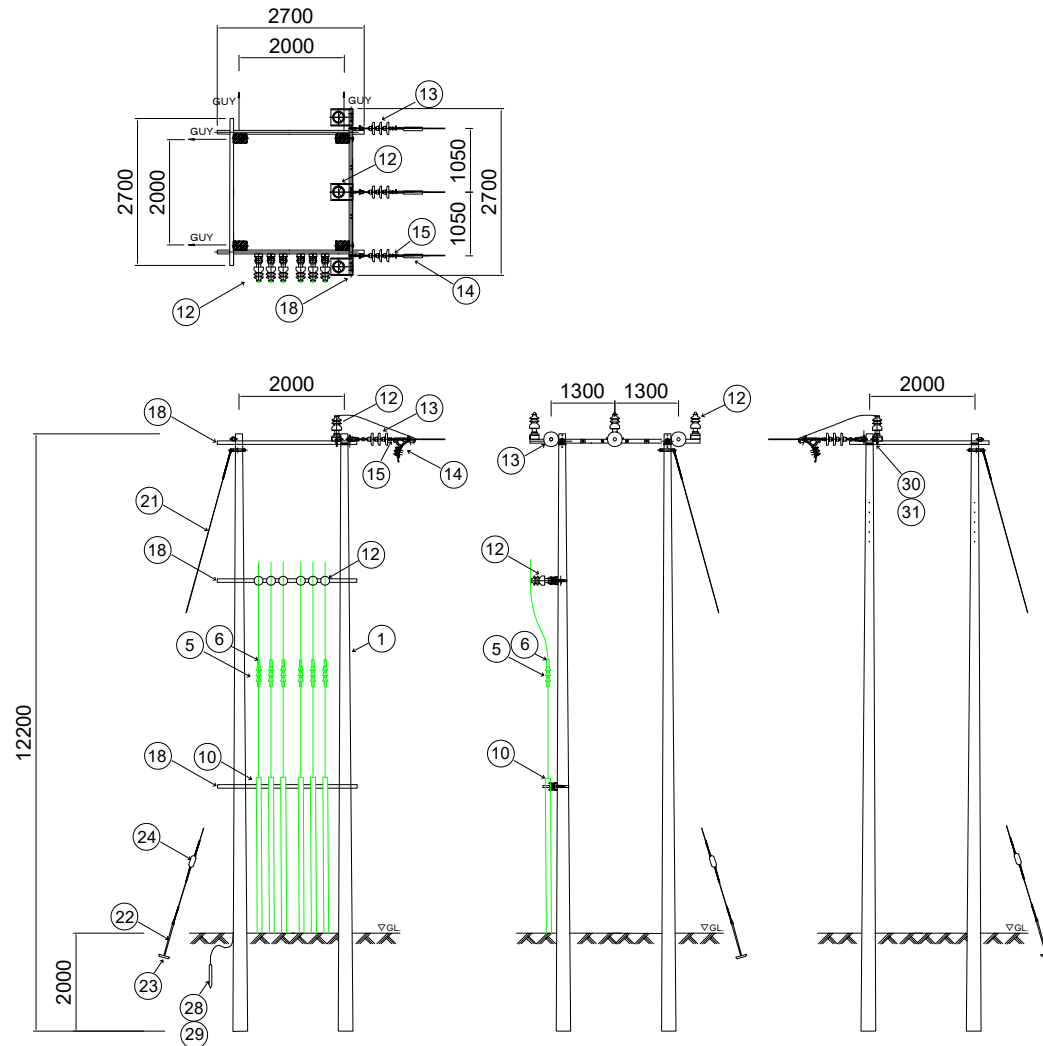
Type D



33kV Cable Pole

No.	Item	Unit	Q'ty	Remarks
N-1	Concrete Pole 40ft(12.2m)	no	2	
N-5	33kV Raychem Termination kit	kit	6	
N-6	185mm ² Cable Lug	no	6	
N-10	4"PVC Pipe	no	6	
N-12	33kV Pin insulator	no	6	
N-17	33kV Angle iron	no	1	
N-18	33kV Channel iron	no	2	
N-21	Stay wire	m	24	
N-22	Stay Rod	no	2	
N-23	Stay Block	no	2	
N-24	Stay insulator(33kV)	no	2	
N-28	Earth rod	Unit	1	
N-29	Earth wire	m	10	
N-30	5/8 inches Washers	no	24	
N-31	Bolt and Nut 5/8 x 11 inches	no	6	280mm

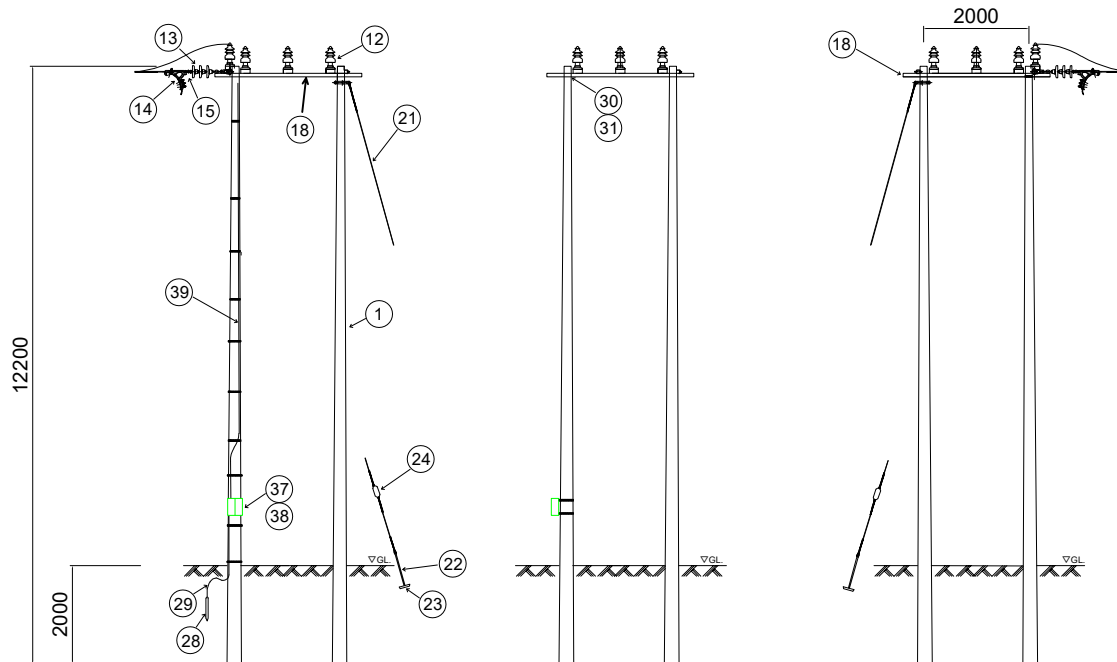
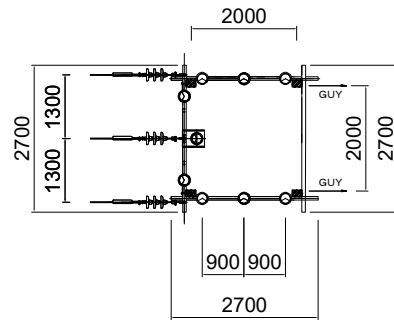
Type E



33kV Cable Termination Pole

No.	Item	Unit	Q'ty	Remarks
N-1	Concrete Pole 40ft(12.2m)	no	4	
N-5	33kV Raychem Termination kit	kit	6	
N-6	185mm ² Cable Lug	no	6	
N-10	4"PVC Pipe	no	6	
N-12	33kV Pin insulator	no	9	
N-13	33kV Silicone disk insulator	no	3	
N-14	6-Bolt clamp	no	3	
N-15	Adaptor Socket Tongue	no	3	
N-18	33kV Channel iron	no	6	
N-21	Stay wire	m	48	
N-22	Stay Rod	no	4	
N-23	Stay Block	no	4	
N-24	Stay insulator(33kV)	no	4	
N-28	Earth rod	Unit	1	
N-29	Earth wire	m	10	
N-30	5/8 inches Washers	no	48	
N-31	Bolt and Nut 5/8 x 11 inches	no	12	280mm

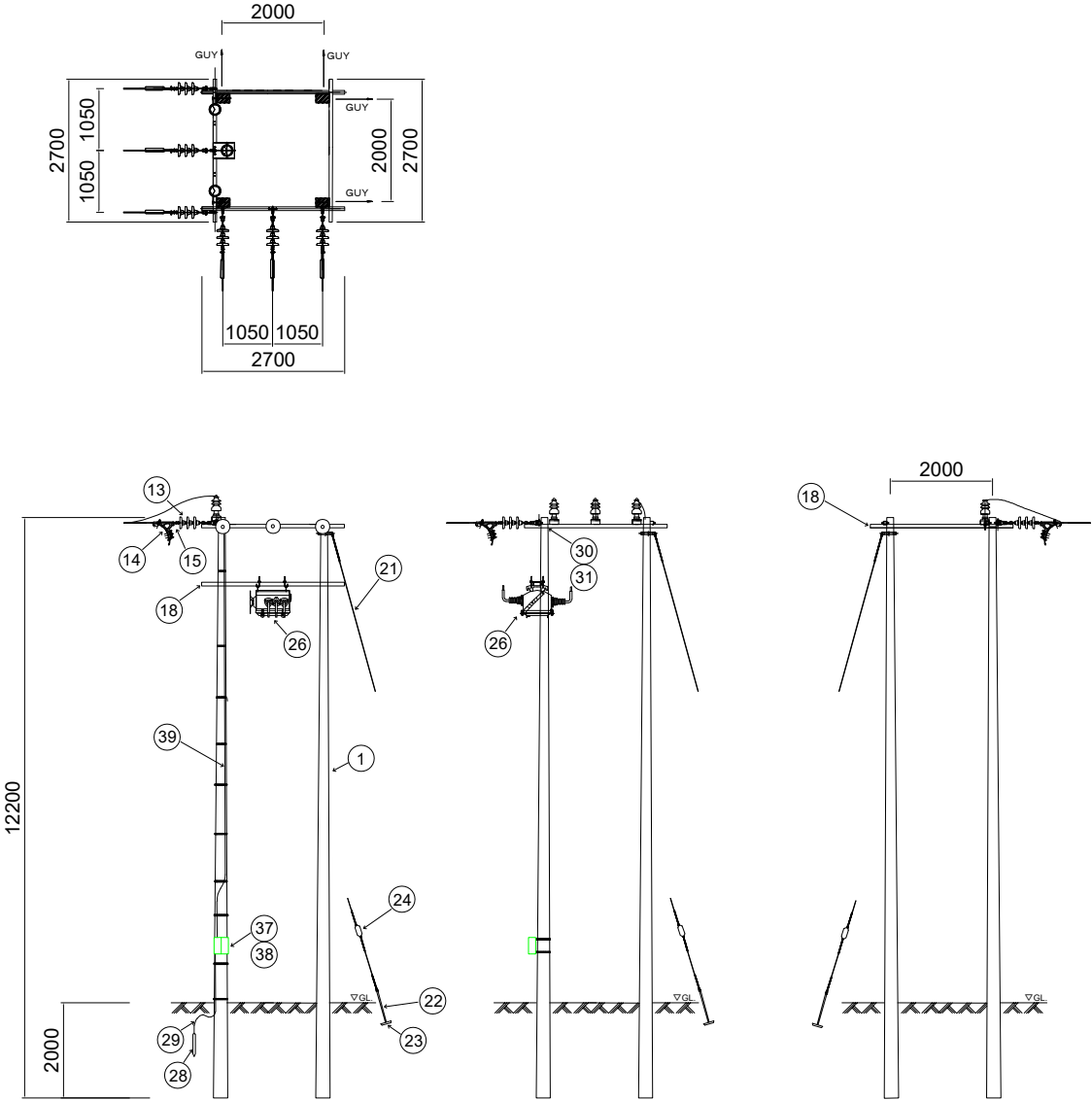
Type F



33kV Branch Pole

No.	Item	Unit	Q'ty	Remarks
N-1	Concrete Pole 40ft(12.2m)	no	4	
N-12	33kV Pin insulator	no	9	
N-13	33kV Silicone disk insulator	no	3	
N-14	6-Bolt clamp	no	3	
N-15	Adaptor Socket Tongue	no	3	
N-18	33kV Channel iron	no	4	
N-21	Stay wire	m	24	
N-22	Stay Rod	no	2	
N-23	Stay Block	no	2	
N-24	Stay insulator(33kV)	no	2	
N-28	Earth rod	Unit	1	
N-29	Earth wire	m	10	
N-30	5/8 inches Washers	no	32	
N-31	Bolt and Nut 5/8 x 11 inches	no	8	280mm
N-37	Circuit Breaker	no	1	
N-38	Circuit Breaker Box	no	1	
N-39	IV wire	m	10	

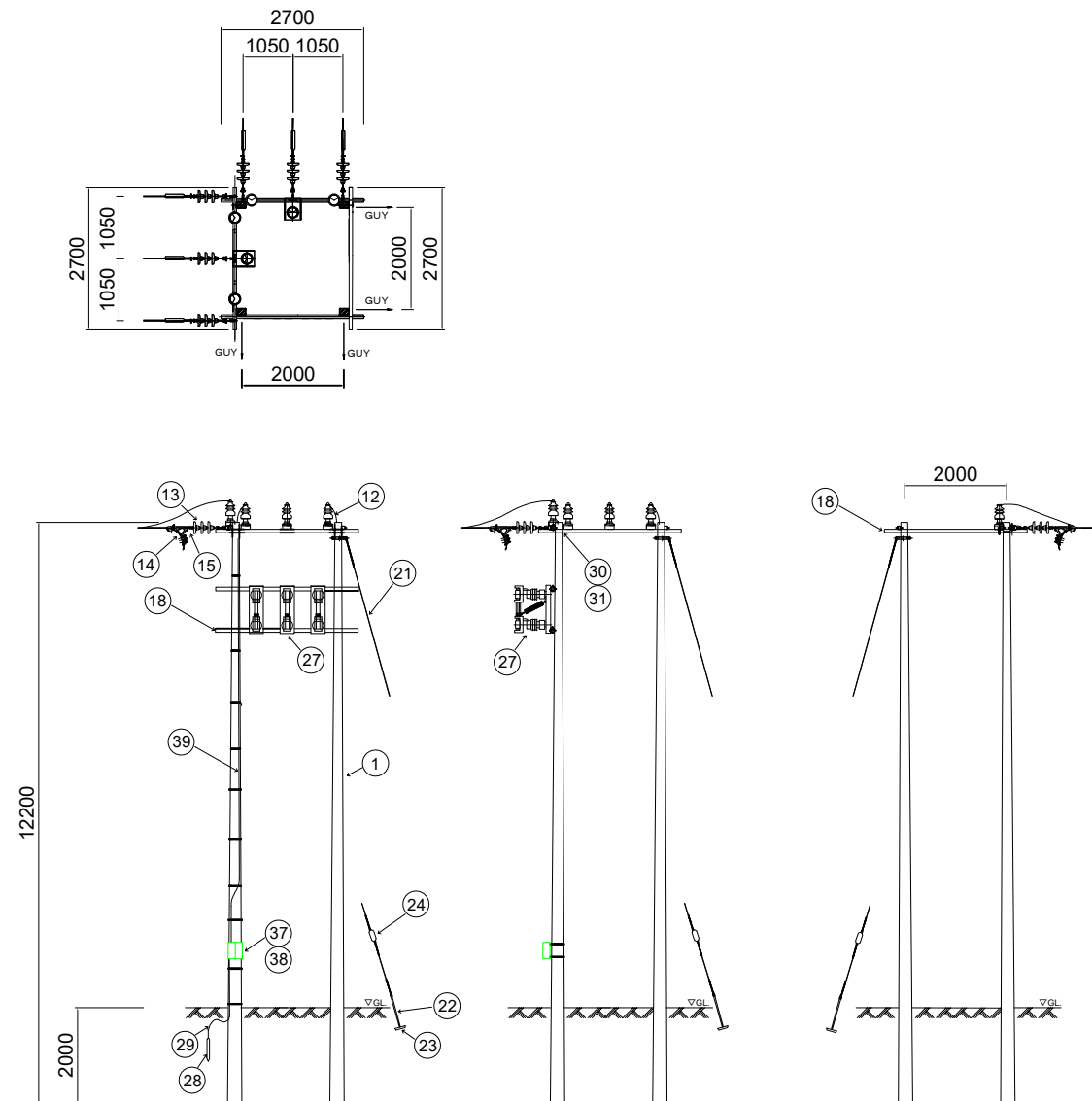
Type G



33kV Section Switch(PAS) Pole

No.	Item	Unit	Q'ty	Remarks
N-1	Concrete Pole 40ft(12.2m)	no	4	
N-12	33kV Pin insulator	no	3	
N-13	33kV Silicone disk insulator	no	6	
N-14	6-Bolt clamp	no	6	
N-15	Adaptor Socket Tongue	no	6	
N-18	33kV Channel iron	no	5	
N-21	Stay wire	m	48	
N-22	Stay Rod	no	4	
N-23	Stay Block	no	4	
N-24	Stay insulator(33kV)	no	4	
N-26	Section switch(33kV):PAS	Unit	1	
N-28	Earth rod	Unit	1	
N-29	Earth wire	m	10	
N-30	5/8 inches Washers	no	40	
N-31	Bolt and Nut 5/8 x 11 inches	no	10	280mm
N-37	Circuit Breaker	no	1	
N-38	Circuit Breaker Box	no	1	
N-39	IV wire	m	10	

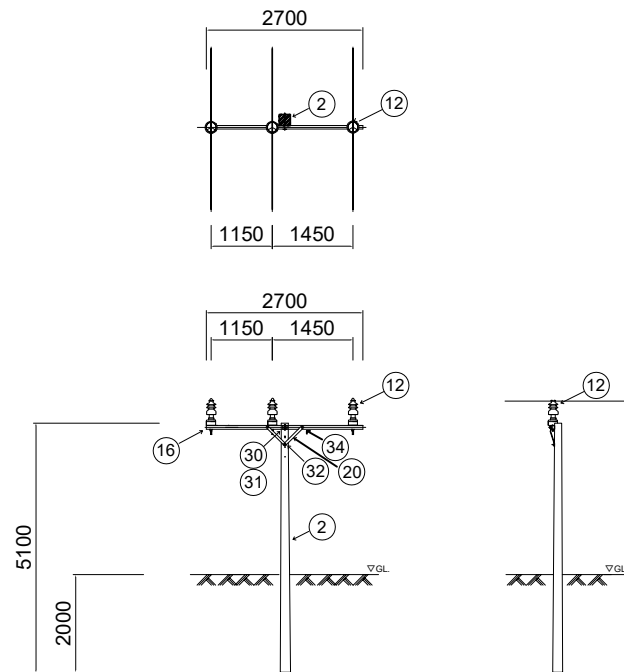
Type H



33kV Section Switch (Gang switch) Pole

No.	Item	Unit	Q'ty	Remarks
N-1	Concrete Pole 40ft(12.2m)	no	4	
N-12	33kV Pin insulator	no	6	
N-13	33kV Silicone disk insulator	no	6	
N-14	6-Bolt clamp	no	6	
N-15	Adaptor Socket Tongue	no	6	
N-18	33kV Channel iron	no	6	
N-21	Stay wire	m	48	
N-22	Stay Rod	no	4	
N-23	Stay Block	no	4	
N-24	Stay insulator(33kV)	no	4	
N-27	Section switch(33kV):Gang switch	Unit	1	
N-28	Earth rod	Unit	1	
N-29	Earth wire	m	10	
N-30	5/8 inches Washers	no	40	
N-31	Bolt and Nut 5/8 x 11 inches	no	10	280mm
N-37	Circuit Breaker	no	1	
N-38	Circuit Breaker Box	no	1	
N-39	IV wire	m	10	

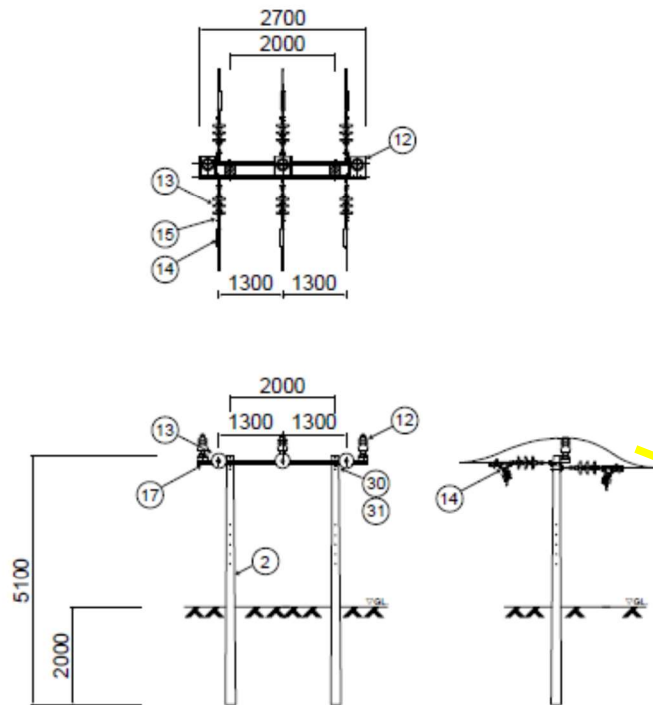
Type I



Short Intermediate Pole

No.	Item	Unit	Q'ty	Remarks
N-2	Concrete Pole 17ft(5.1m)	no	1	
N-12	33kV Pin insulator	no	3	
N-16	Fiber crossarm	no	1	
N-20	33kV Tie-strap	no	2	
N-30	5/8 inches Washers	no	8	
N-31	Bolt and Nut 5/8 x 11 inches	no	1	280mm
N-32	Bolt and Nut 5/8 x 9 inches	no	1	220mm
N-34	Bolt and Nut 5/8 x 6 inches	no	2	150mm

Type J



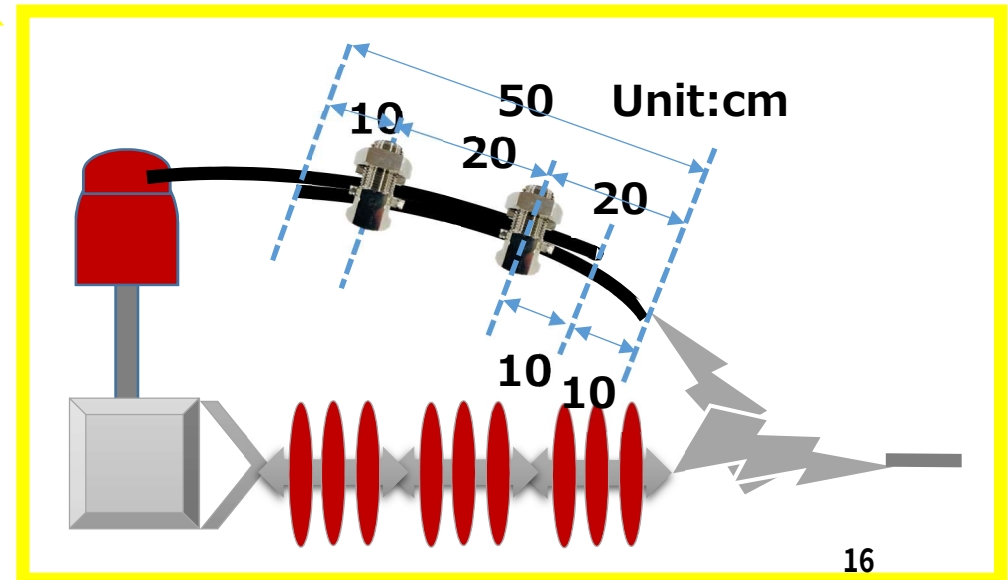
Short Section Pole

No.	Item	Unit	Q'ty	Remarks
N-2	Concrete Pole 17ft(5.1m)	no	2	
N-12	33kV Pin insulator	no	3	
N-13	33kV Silicone disk insulator	no	6	
N-14	6-Bolt clamp	no	6	
N-15	Adaptor Socket Tongue	no	6	
N-17	33kV Angle iron	no	2	
N-30	5/8 inches Washers	no	4	
N-31	Bolt and Nut 5/8 x 11 inches	no	2	280mm

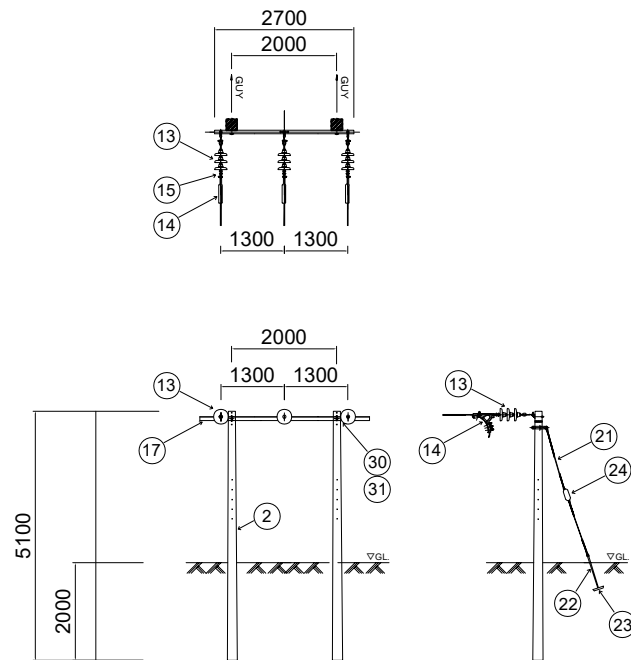
Bolt Type Connector × 6



Bolt Type Connector



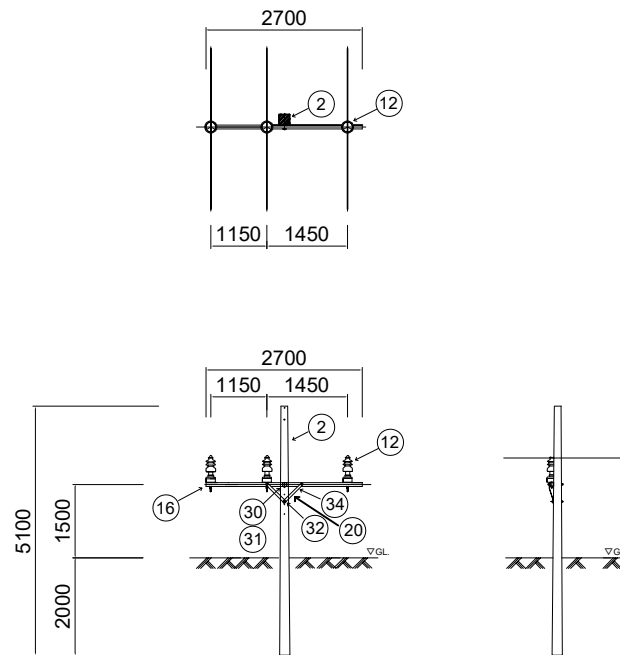
Type K



Short Dead End Pole

No.	Item	Unit	Q'ty	Remarks
N-2	Concrete Pole 17ft(5.1m)	no	2	
N-13	33kV Silicone disk insulator	no	3	
N-14	6-Bolt clamp	no	3	
N-15	Adaptor Socket Tongue	no	3	
N-17	33kV Angle iron	no	1	
N-21	Stay wire	m	10	
N-22	Stay Rod	no	2	
N-23	Stay Block	no	2	
N-24	Stay insulator(33kV)	no	2	
N-30	5/8 inches Washers	no	4	
N-31	Bolt and Nut 5/8 x 11 inches	no	2	280mm

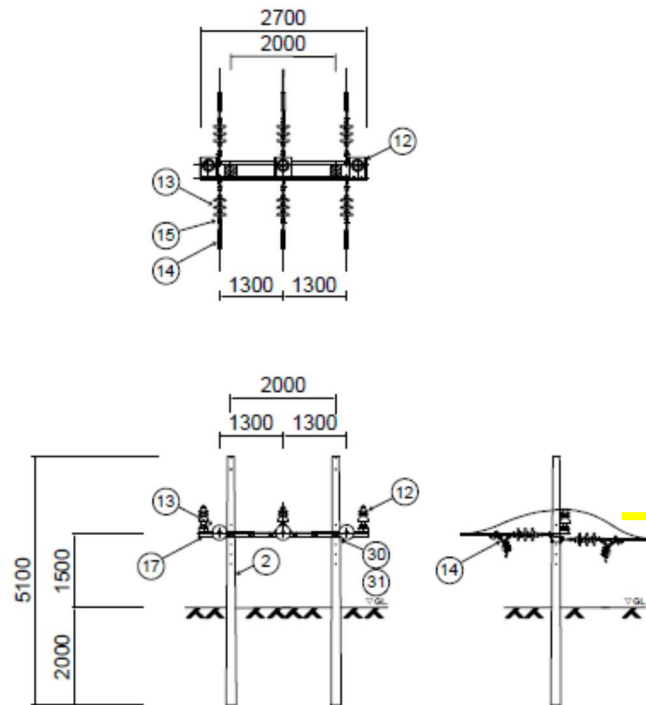
Type L



Short Intermediate Pole

No.	Item	Unit	Q'ty	Remarks
N-2	Concrete Pole 17ft(5.1m)	no	1	
N-12	33kV Pin insulator	no	3	
N-16	Fiber crossarm	no	1	
N-20	33kV Tie-strap	no	2	
N-30	5/8 inches Washers	no	8	
N-31	Bolt and Nut 5/8 x 11 inches	no	1	280mm
N-32	Bolt and Nut 5/8 x 9 inches	no	1	220mm
N-34	Bolt and Nut 5/8 x 6 inches	no	2	150mm

Type M



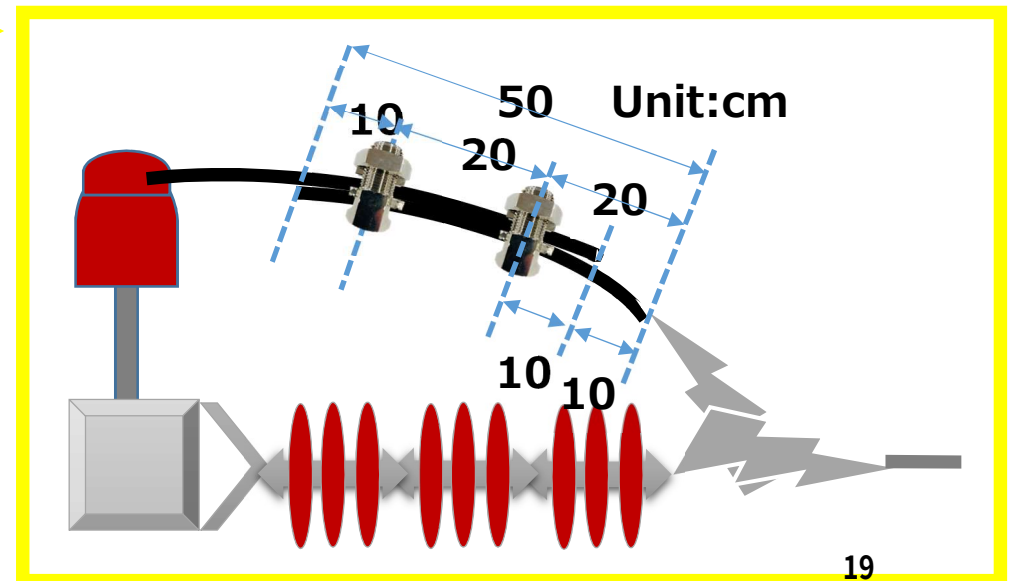
Short Section Pole

No.	Item	Unit	Q'ty	Remarks
N-2	Concrete Pole 17ft(5.1m)	no	2	
N-12	33kV Pin insulator	no	3	
N-13	33kV Silicone disk insulator	no	6	
N-14	6-Bolt clamp	no	6	
N-15	Adaptor Socket Tongue	no	6	
N-17	33kV Angle iron	no	2	
N-30	5/8 inches Washers	no	4	
N-31	Bolt and Nut 5/8 x 11 inches	no	2	280mm

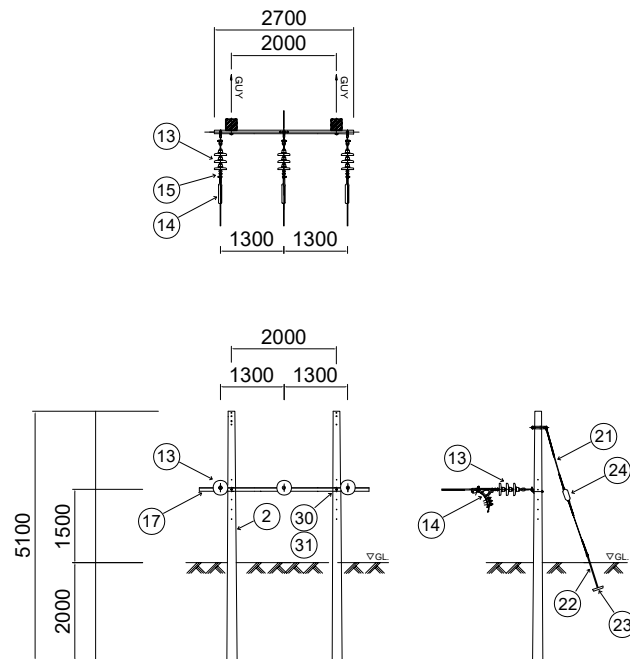
Bolt Type Connector × 6



Bolt Type Connector



Type N



Short Dead End Pole

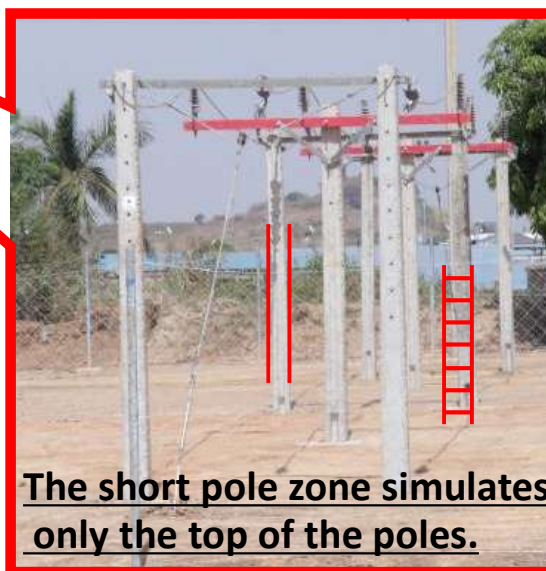
No.	Item	Unit	Q'ty	Remarks
N-2	Concrete Pole 17ft(5.1m)	no	2	
N-13	33kV Silicone disk insulator	no	3	
N-14	6-Bolt clamp	no	3	
N-15	Adaptor Socket Tongue	no	3	
N-17	33kV Angle iron	no	1	
N-21	Stay wire	m	10	
N-22	Stay Rod	no	2	
N-23	Stay Block	no	2	
N-24	Stay insulator(33kV)	no	2	
N-30	5/8 inches Washers	no	4	
N-31	Bolt and Nut 5/8 x 11 inches	no	2	280mm

Outline of training for Phase Comparison Work on distribution line



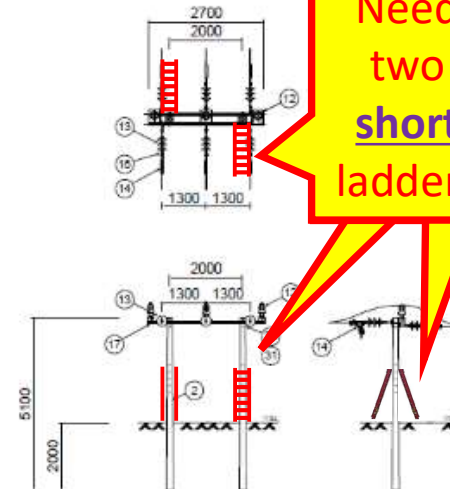
First of all, the training facility condition will be explained containing following matters

- > The short pole zone simulates only the top of the poles.
- > At the actual site where phase comparison work is performed, the jumpers are disconnected.
- > Both sides of the jumper are supplied from different power sources.



The short pole zone simulates only the top of the poles.

Type J



Need two short ladders

Step.1 Conducting the preparation works for phase comparison work based on the manual such as the assembly and operation check of Phase Comparator and appearance and airtight inspection of 33kV rubber insulating gloves.

Step.2 Demonstrating phase comparison work based on the manual at Type J poles of the short pole zone

Step.3 Confirming the operation of phase comparator based on the manual at the energized mock-up substation to be produced by AfD Project.

Training manual for phase comparison work

Purpose of phase comparison work on the distribution line

This work should be carried out in advance where different distribution lines may be connected to **avoid reverse rotation of the three-phase motor and/or occurring short circuits** (if the connection results in a loop condition by deferent power source) due to connecting the wrong phase.

How to conduct phase comparison work

1. Preparatory works

What to prepare	➤ Wireless Phase Comparator (WPC) (Model: WPC1000 manufactured by T&R Test Ltd. Company) ➤ Insulation rods for the Phase Comparator (Two rods) ➤ 33kV rubber insulating gloves (Two sets) * ➤ Ladders (Two units) ➤ Safety belts (Two sets) ➤ Helmets (Two units) ➤ Suitable attire for phase comparison work
Number of workers (Standard)	➤ Commander: 1 person ➤ Climbing-laborer: 2 persons ➤ Ground-laborer: 1 person
Preparatory work	➤ Assembly and operation check of WPC Detailed method depends on the manufacturer's instruction manual. ➤ Appearance Inspection of Insulation rods, ladders, safety belts and helmets by each Climbing-laborer (like lines man) himself or herself conducting phase comparison work ➤ Appearance and airtight inspection of 33kV rubber insulating gloves by each Climbing-laborer (like lines man) himself or herself conducting phase comparison work *

* Caution: Although WPC rods are made of insulating materials, the safety of working with bare hands has not been verified, and we have been informed by the manufacturer that wearing insulated gloves is mandatory.

(1) Assembly and operation check of WPC

If the model of WPC is WPC1000, these shall be conducted as follows.

(i) Assemble shall be conducted as shown in the following pictures.



(ii) Operation check shall be conducted as follows.

Press and hold the proving button which is located between two lamps to check the function of the internal circuitry and the condition of the battery.

(2) Appearance and airtight inspection of 33kV rubber insulating gloves

(i) Appearance inspection shall be conducted to carefully check for scratches and holes, **especially fingertips and between fingers.**

(ii) Airtight inspection shall be conducted as follows.

- > Open the cuff of the glove **vertically (perpendicular to the direction of the fingers)** to let as much air as possible inside the glove.
- > Close the cuff of the glove, and roll it up without air leakage **until it swells and changes the external shape of the glove.**
- > In this state, hold the gloves close to your ears and **listen carefully for any sound of air leakage.**



2. Phase comparison work

Caution:

1. Rubber gloves are prone to holes, so they must not be placed in the cargo area together with sharp objects such as wires. Rubber gloves should be stored in a suitable bag.
2. Since climbing-laborer can easily lose their balance when handling the long bar on the top of the ladder, climbing-laborers should have stable and safe footholds, for example by having ground crews support ladders.
3. Since the work is to be performed directly under an energized line, the work shall be performed at an appropriate position, taking into consideration a safe distance from the conductor, and working distance with the length of the operation rods (6ft about 1.8m).
4. As shown in the picture on the right, the rod has a separator like a brim. While approaching the energizing line with this rod, the climbing-laborer must not grab and hold the upper side rod of the separator.
5. When conducting phase comparison in areas where the space between phases is narrow, such as transformer terminals, be very careful not to short-circuit between phases by Rod.



The method of phase comparison work as follows.

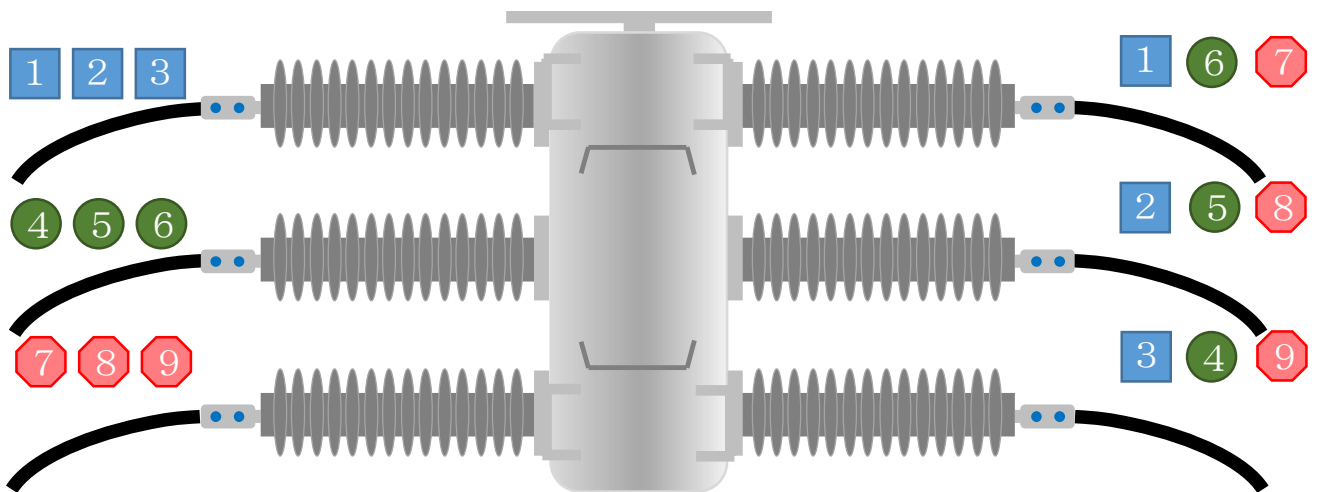
1. Ensure that preparatory work above mentioned is carried out every time for safety reasons by the climbing-laborer (like lines man) who will conduct phase comparison work.
2. Confirm that the distribution lines on both sides of the pole which phase comparison work will be carried out at are energized from different power sources.
3. Climbing-laborers climb the top of ladder and ensure the safety working environment.
4. Hanging the hook of the Phase Comparator to the first phase conductor.

Caution: Climbing-laborers must not grab and hold the upper side rod of the separator

5. Checking, basically nine times, if each phase is homeomorphism by changing the hooking points according to the established order. (The order in which the hooks are hung is described on the following page.)
6. Recording the state of phase homeomorphism by taking photographs when both side phase are matched like the photo on the right, etc.



Phase comparison order (The order in which the hooks are hung) is as follows.



The method for determining whether phase homeomorphism or not is as follows.

One side	The other side	Phase comparison (For example)	Indication of the Phase Comparator *
1	1	Homeomorphism	RED LED lighting solid, GREEN LED lighting solid and the Buzzer sounding continuously
2	2	Not- homeomorphism	Solid RED LED lighting only
3	3	Not- homeomorphism	
4	4	Not- homeomorphism	
5	5	Homeomorphism	RED LED lighting solid, GREEN LED lighting solid and the Buzzer sounding continuously
6	6	Not- homeomorphism	Solid RED LED lighting only
7	7	Not- homeomorphism	
8	8	Not- homeomorphism	
9	9	Homeomorphism	RED LED lighting solid, GREEN LED lighting solid and the Buzzer sounding continuously

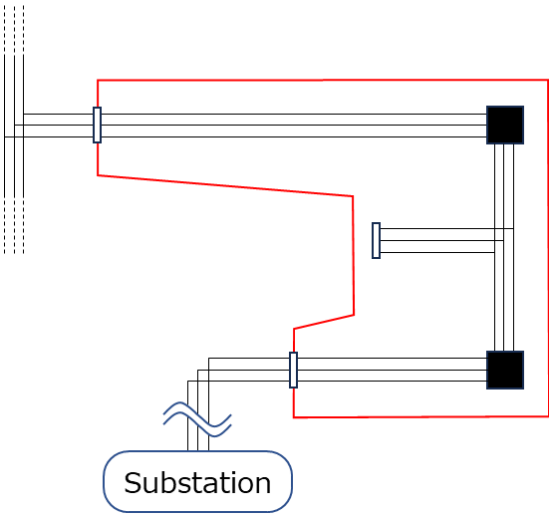
*Note: The description of this indication is for the case of WPC1000. If other phase comparator is used, please follow the indication in the respective manual.

Demonstration scenario for trainers (confidential to trainees)

[Assumption about the model feeder and training]

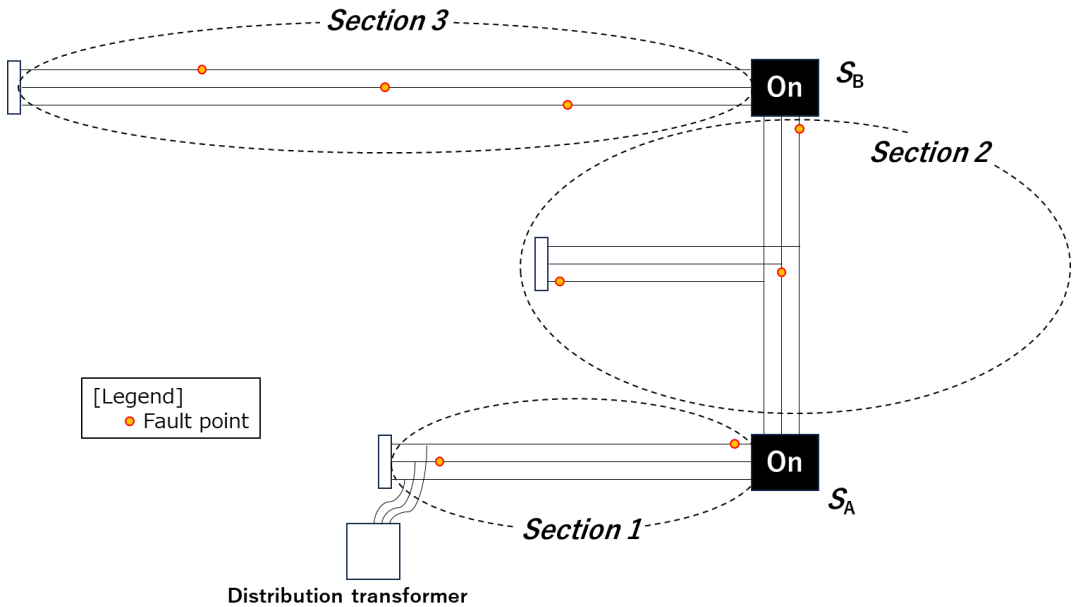
The model feeder at NAPTIN training yard is assumed to be one area of which length is the maximum distance Hipotronics can test. Therefore, the whole feeder can be described like this. The model feeder at NAPTIN training yard is shown by the red line.

The line patrol team finished patrolling the lines, but they discovered nothing visible physically. Then the team starts to test this area using Hipotronics.



[Specification of training facility]

The model feeder at NAPTIN training yard has 8 (eight) fault points as follows. Let's assume the line patrol team finished patrolling the lines, but they discovered nothing visible physically.



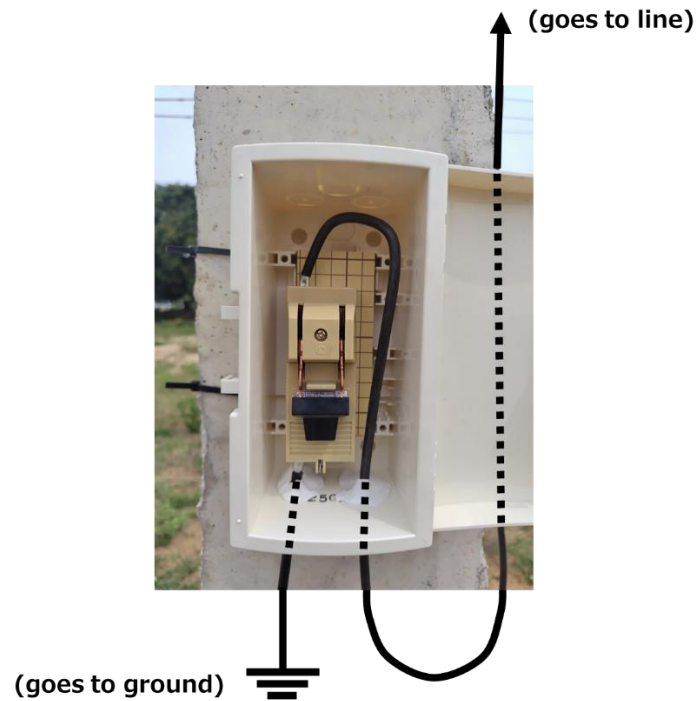
TRAINERS ONLY – Demonstration Scenario of OH fault location

[Fault point setting]

Fault points can be created by turning on the breaker in the box. When the breaker is off, the line and ground are disconnected.



For safety, before turning on and off, the wires connected to line should be discharged.

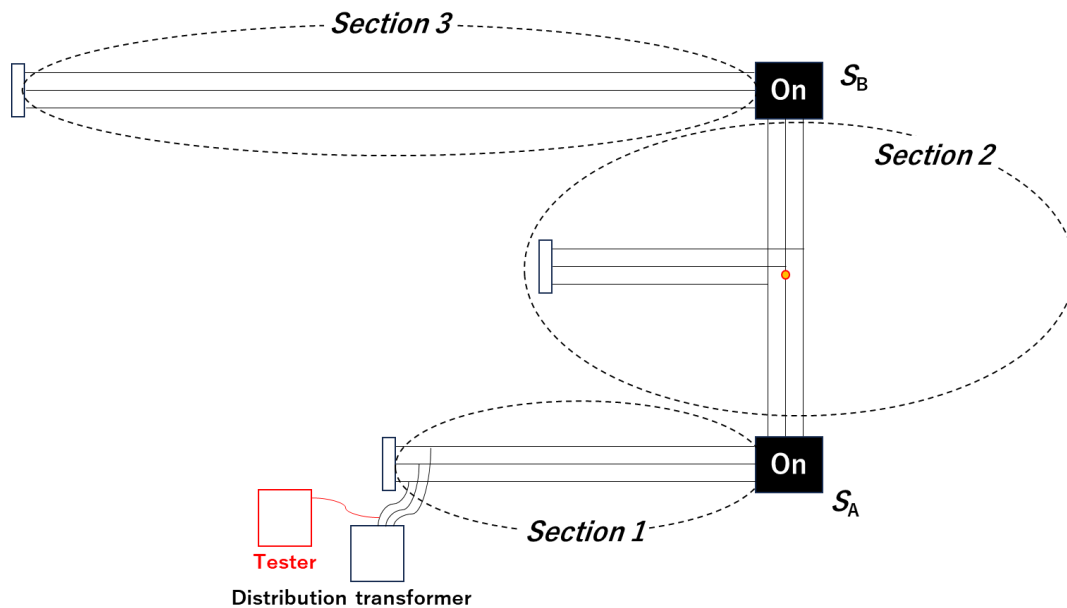


TRAINERS ONLY – Demonstration Scenario of OH fault location

EXERCISE 1 – Section 2 is faulty, and transformer is available

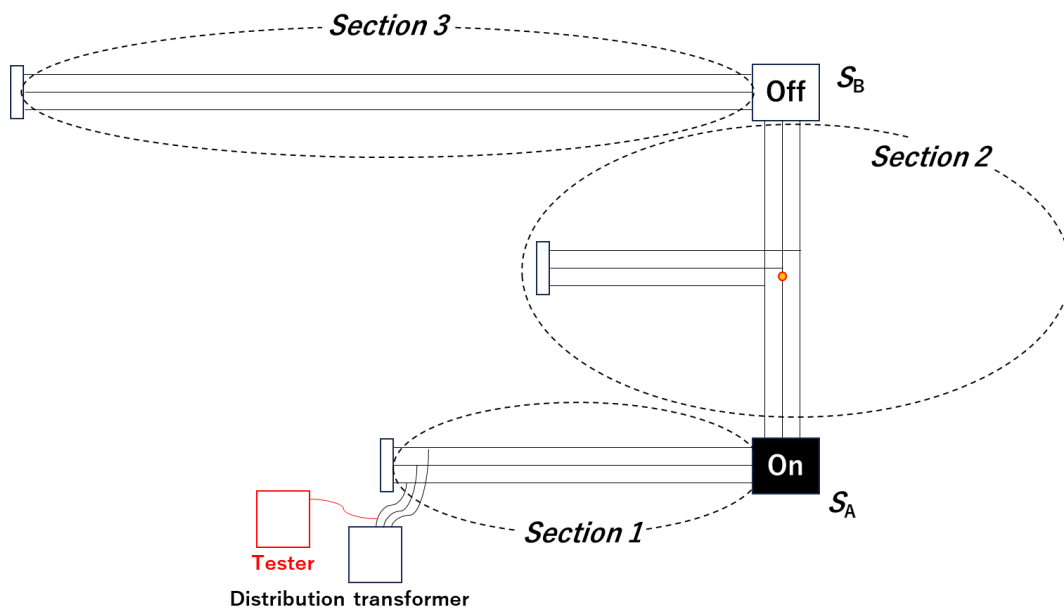
[0]

Let's assume the fault in Section 2. The following is the state when the fault occurs. At first, install the tester at the transformer connected to the line and test the whole area (i.e. Sections 1, 2, &3) to decide that this area is truly faulty or not. As the transformer is connected to the line, the tester will detect the current leakage even if the faulty phase is different from the phase the tester is connecting to. Then let's disconnect the transformer and test each phase to find the faulty phase.



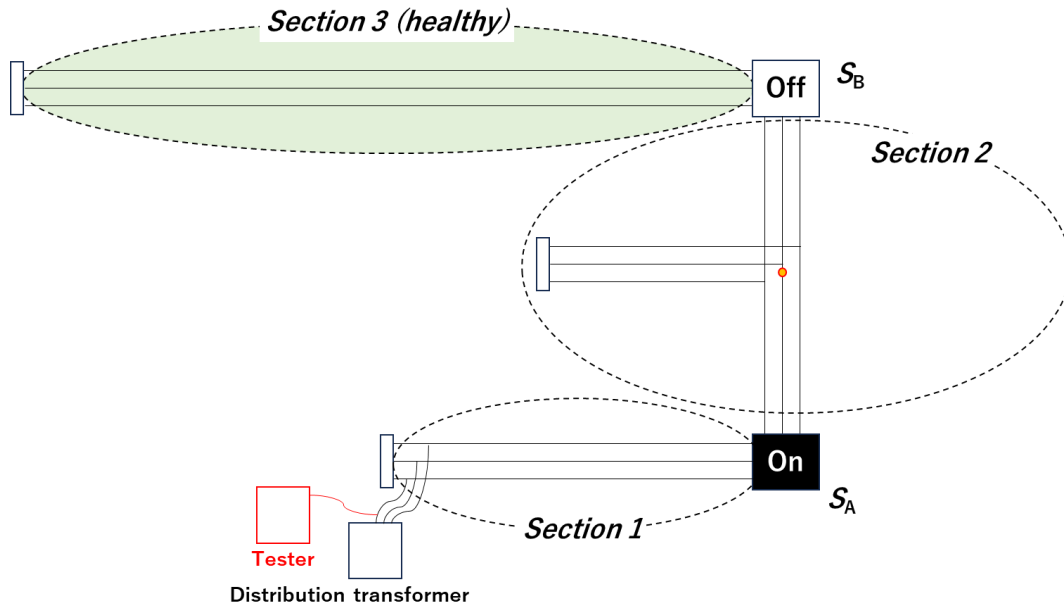
[1]

Open S_B and test again.



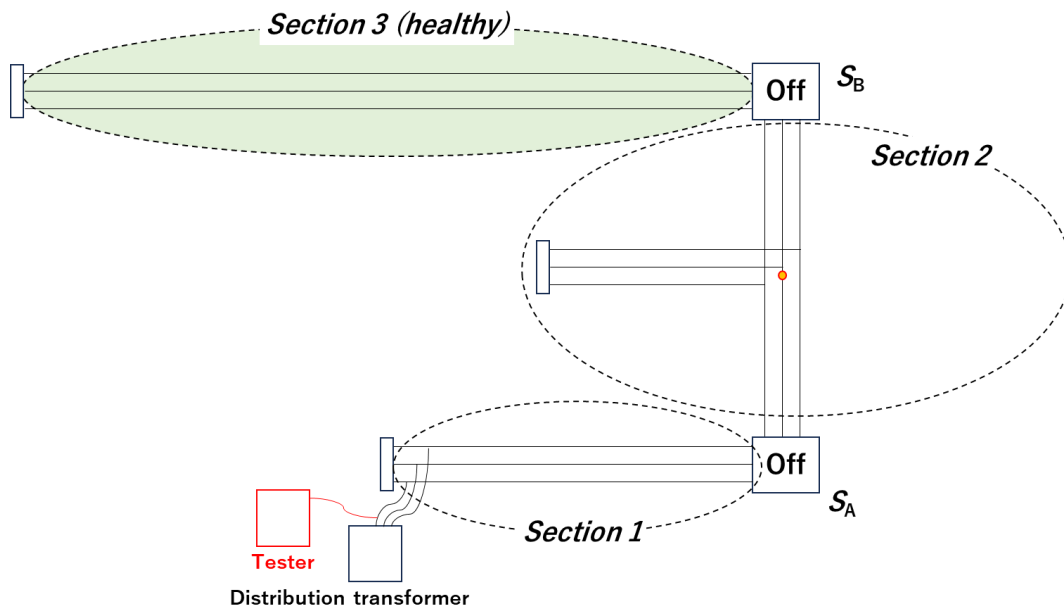
[2]

The tester will detect the current leakage, therefore there is the fault point somewhere in Section 1 & 2. Section 3 is likely to be healthy and can be energized somehow, after the section is confirmed truly healthy.



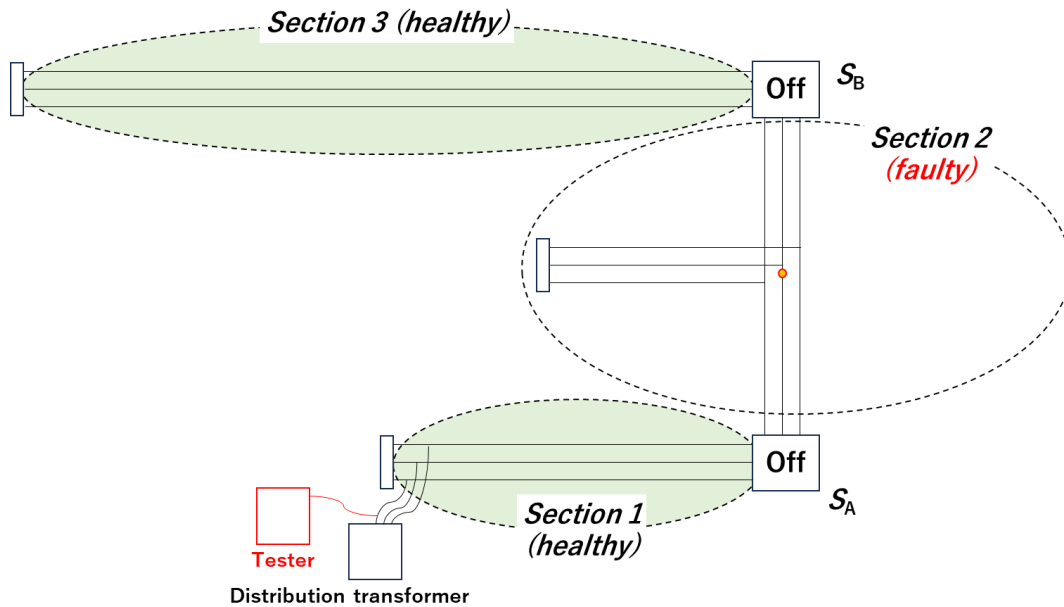
[2a]

Then, open S_A .



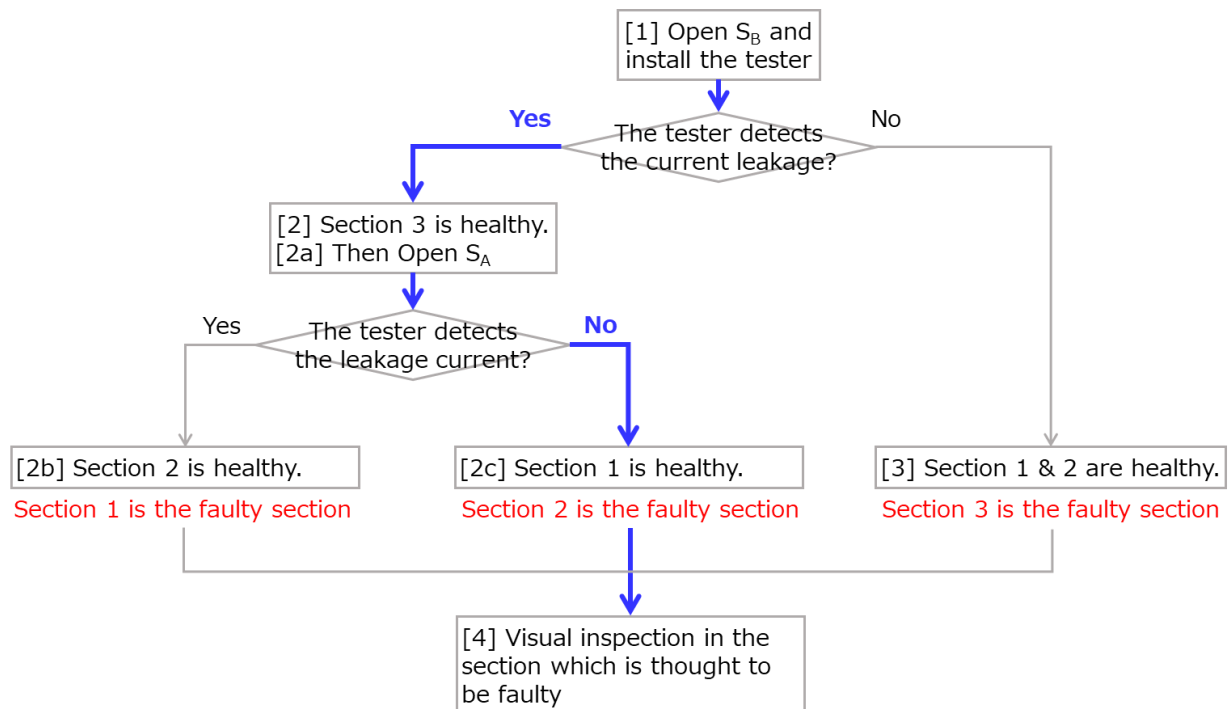
[2c]

The tester does no longer detect the current leakage, therefore there is not the fault point Section 1, and there should be the fault point in Section 2. Section 2 should be tested to confirm that this is truly faulty section (but we omit the testing of Section 2 in this demonstration to save time).



[4] Now that faulty section is identified, visual inspection should be executed to find the fault point.

The procedure above is described as the blue line in the following workflow.

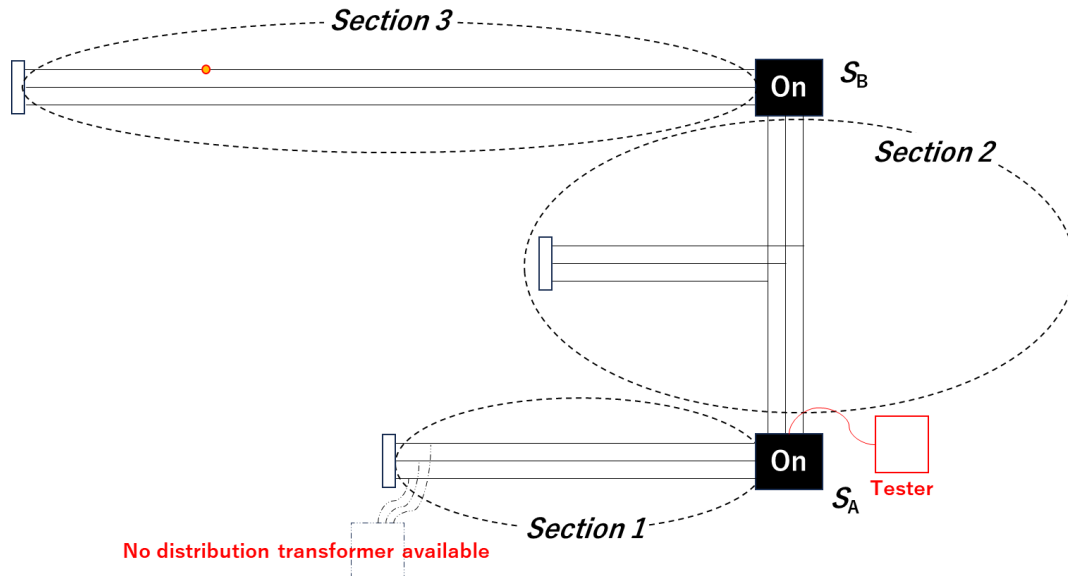


TRAINERS ONLY – Demonstration Scenario of OH fault location

EXERCISE 2 – Section 3 is faulty, and transformer is not available

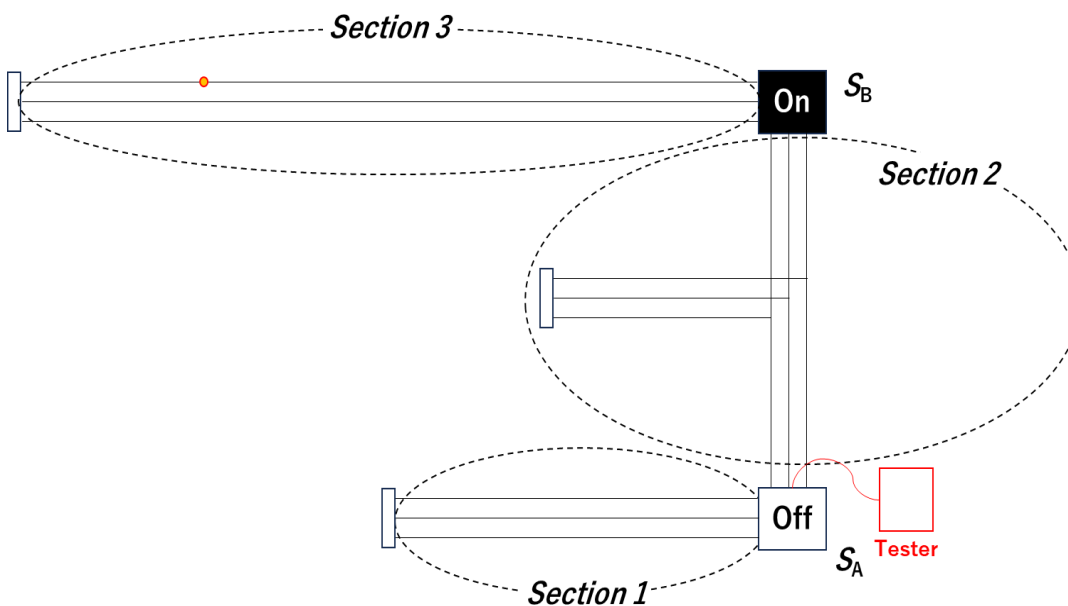
[0]

Let's assume the fault in Section 3. The following is the state when the fault occurs. Please note that there is no distribution transformer available. Now install the tester on Section-2 side of S_A and decide that this area is truly faulty or not. In this case, we have to test every phase, one by one. (Let's ask trainees why.)



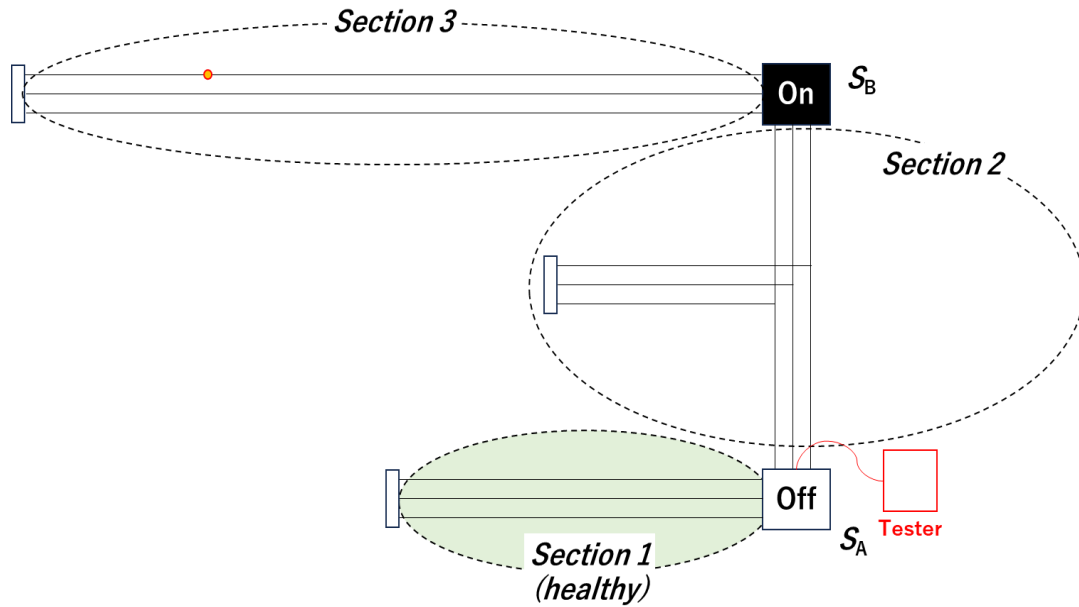
[1]

Open S_A and test again.



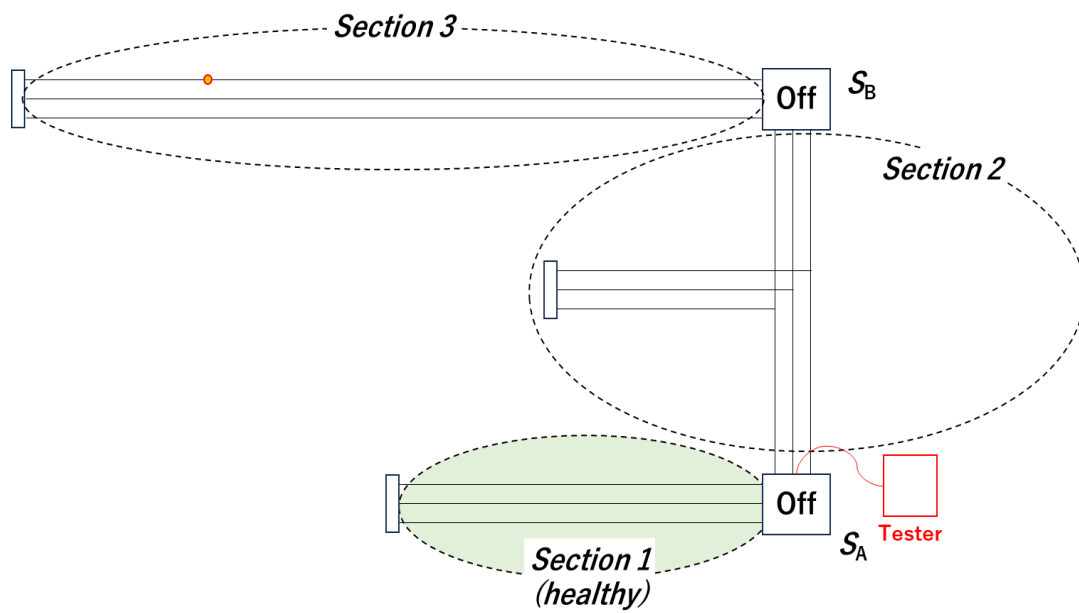
[2]

The tester detects the current leakage, therefore there is the fault point somewhere in Section 2 & 3, and Section 1 is likely to be healthy and can be energized somehow after the section is confirmed truly healthy.



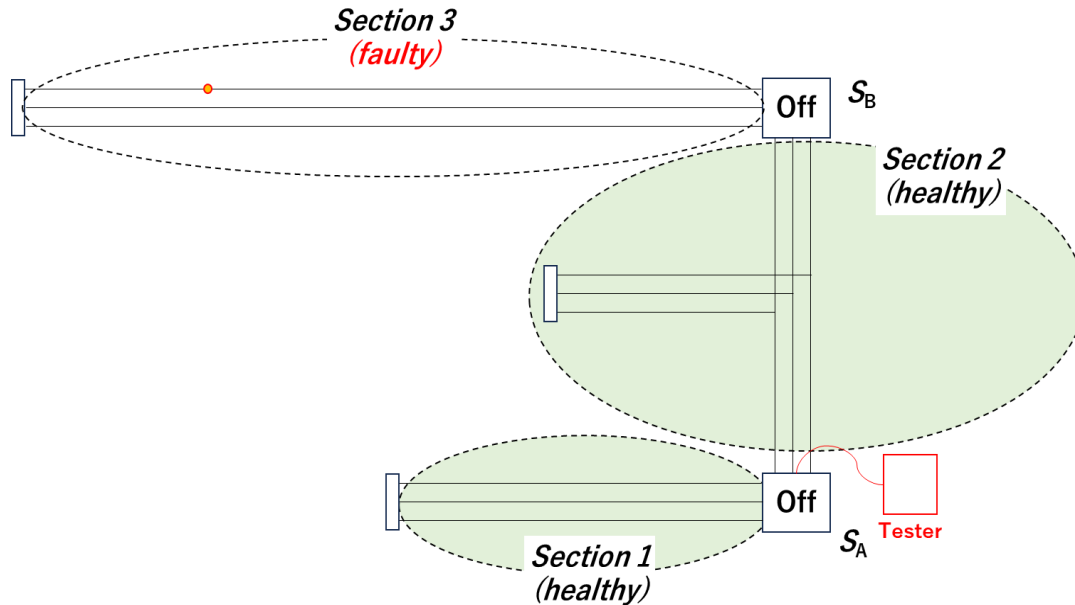
[2a]

Then, open S_B , and test again.



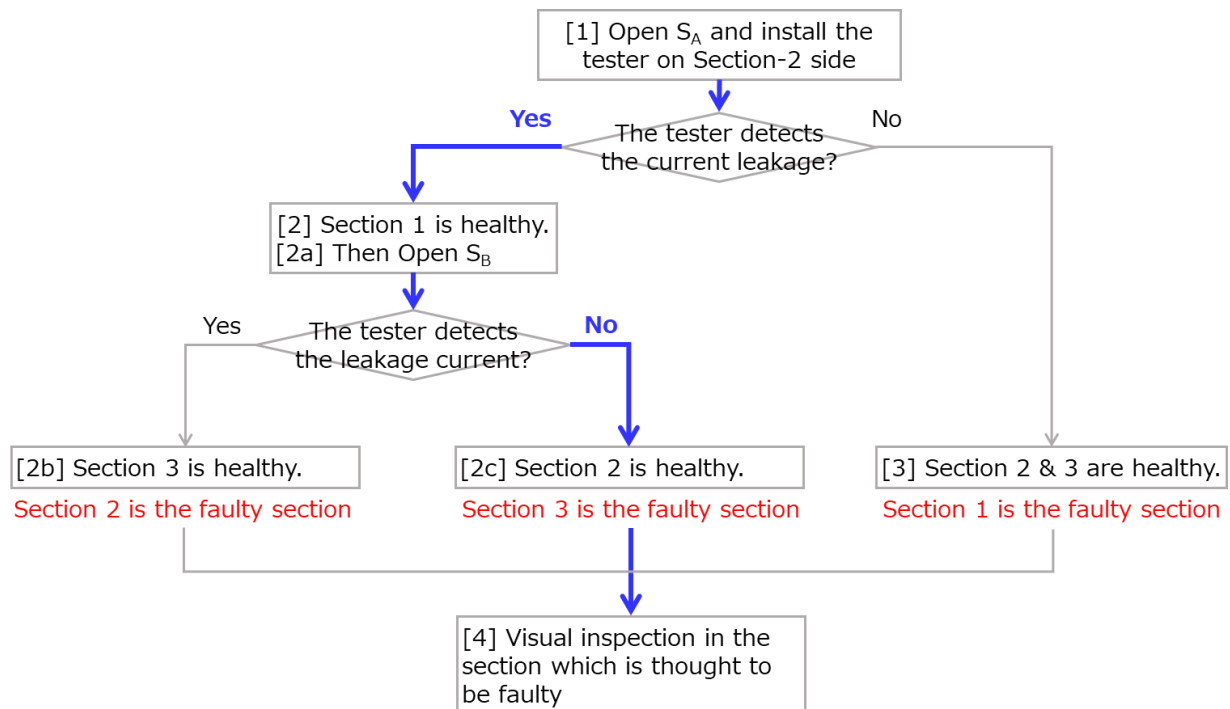
[2c]

The tester will no longer detect the current leakage, therefore there is not the fault point Section 2, and there should be the fault point in Section 3. Section 3 should be tested to confirm that this is truly faulty.



[4] Now that faulty section is identified, visual inspection should be executed to find the fault point.

The overall process of CASE 2 can be described as the following workflow.

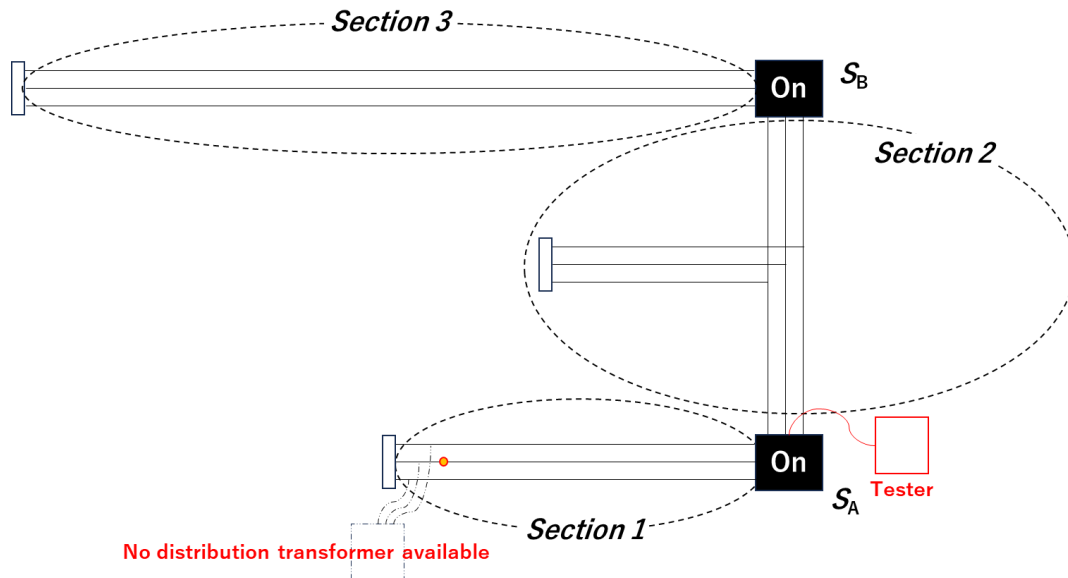


TRAINERS ONLY – Demonstration Scenario of OH fault location

EXERCISE 3 – Section 1 is faulty, and transformer is not available

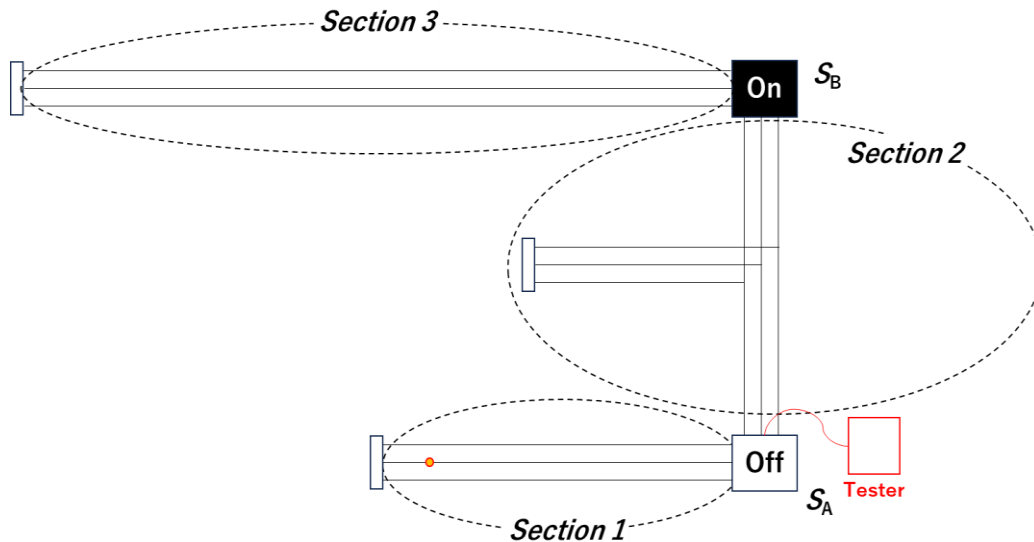
[0]

Let's assume the fault in Section 3. The following is the state when the fault occurs. Please note that there is no distribution transformer available. Now install the tester on Section-2 side of S_A and decide that this area is truly faulty or not.



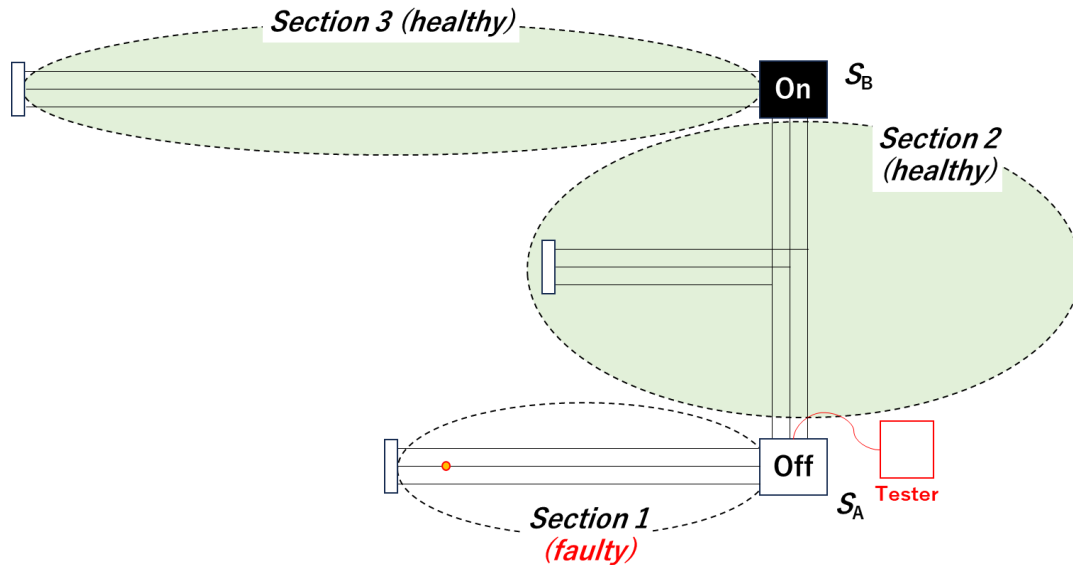
[1]

Open S_A and test again.



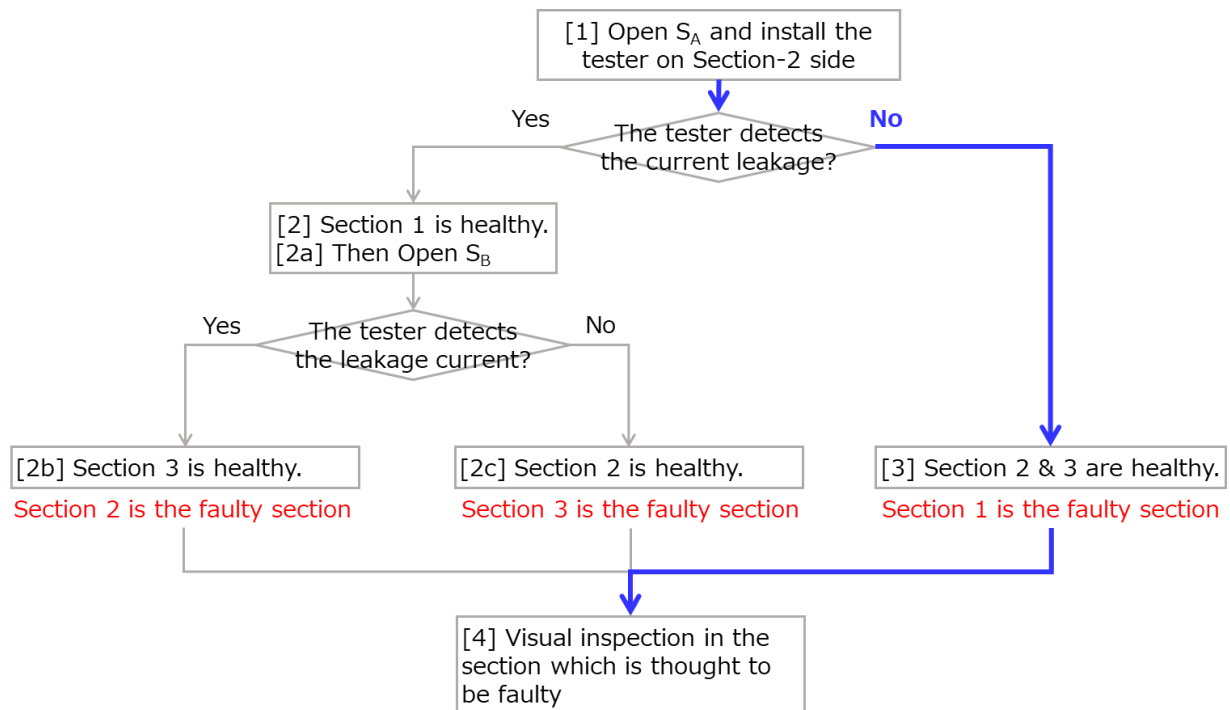
[3]

The tester does not detect the current leakage, therefore there is not the fault point somewhere in Section 2 nor 3, and these sections can be energized somehow. Now there should be the fault point in Section 1. Section 1 should be tested to confirm that this is truly faulty section (but we omit the testing of Section 1 in this demonstration to save time).



[4] Now that faulty section is identified, visual inspection should be executed to find the fault point.

The procedure above is described as the blue line in the following workflow.



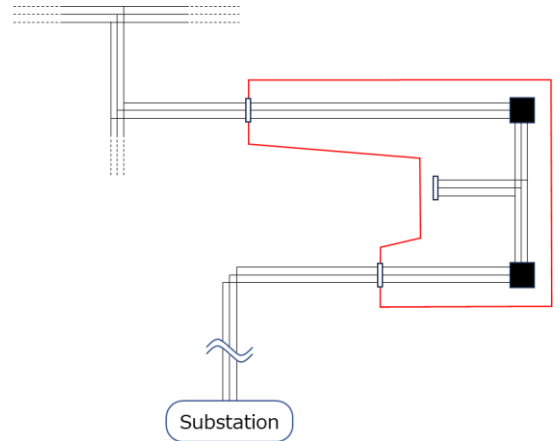
Demonstration scenario for trainees

(Case studies)

[Assumption about the model feeder and training]

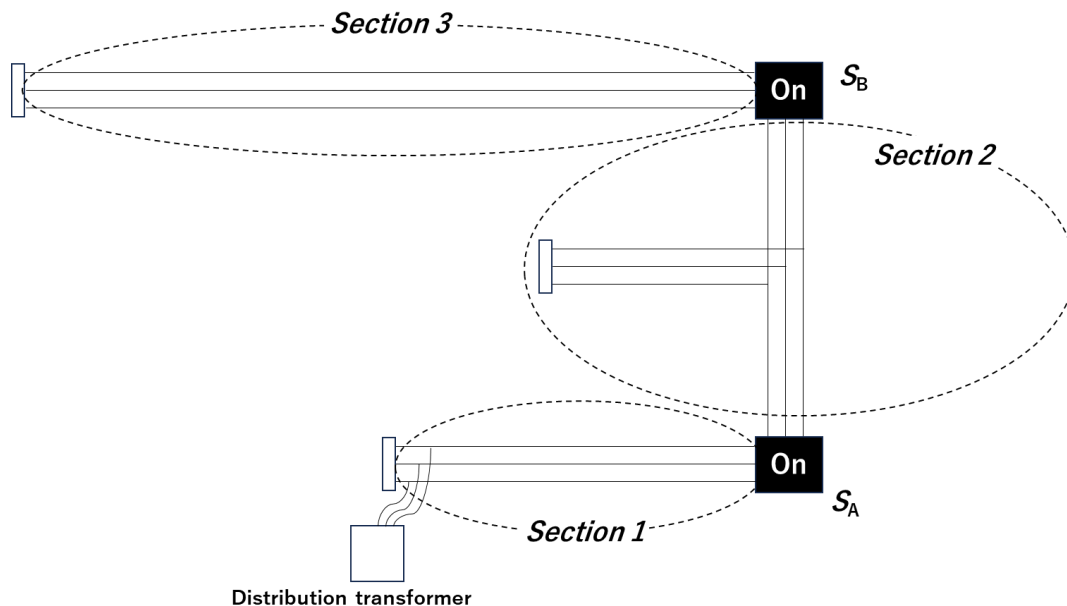
The model feeder at NAPTIN training yard is assumed to be one area of which length is the maximum distance Hipotronics can test. Therefore, the whole feeder can be described like this, and the model feeder at NAPTIN training yard is indicated by the red line.

You are a member of fault detection team. The line patrol team finished patrolling the lines, but they discovered nothing visible physically. Now you are about to start to test this area utilizing Hipotronics.



[Specification of training facility]

Let's assume that the feeder at NAPTIN training yard is divided into 3 sections (Section 1, 2, & 3) by 2 switchgears (S_A & S_B) as follows. Several fault points exist somewhere.



CASE STUDY - FAULT DETECTING PROCEDURE (v03)

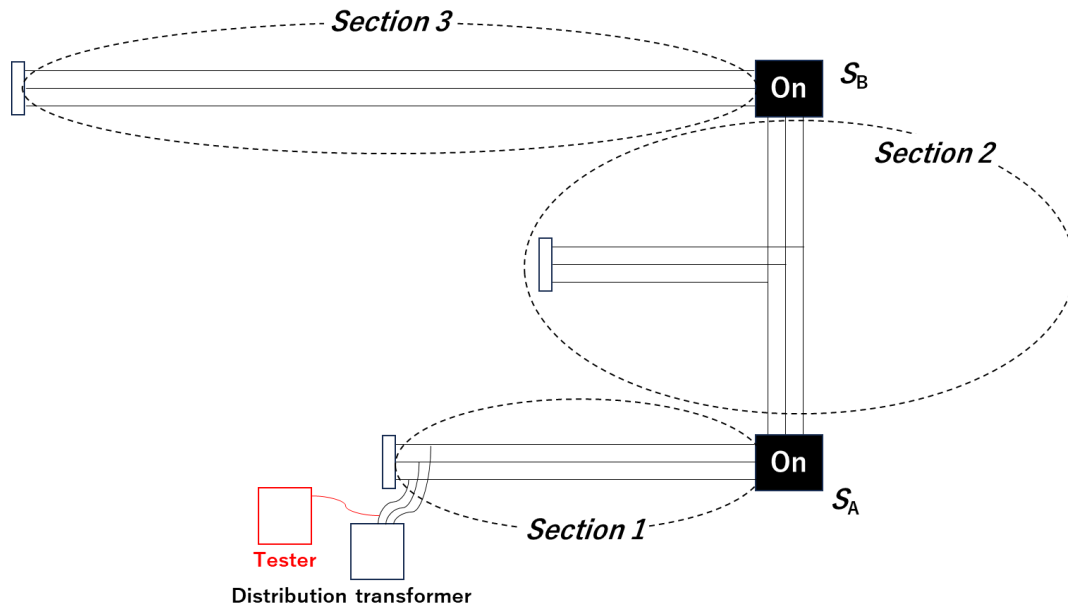
<Note>

CASE STUDY - FAULT DETECTING PROCEDURE (v03)

CASE 1 – transformer available

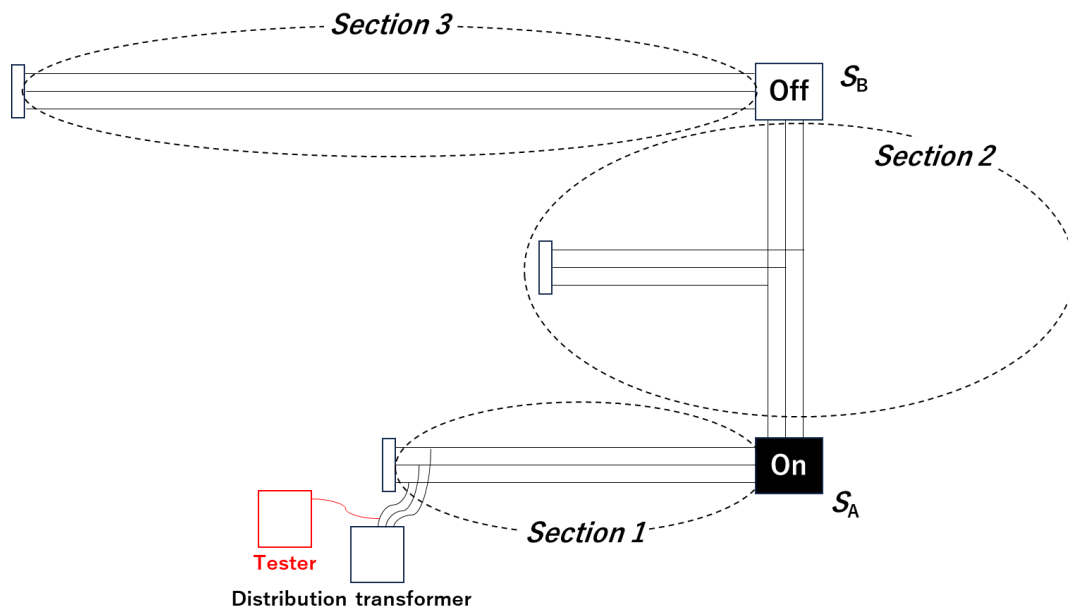
[0]

At first, install the tester at the connection of the distribution transformer and test the whole area (i.e. Sections 1, 2, &3) to decide that this area is truly faulty or not. Note that when transformer is connected to (all phases of) the line, the tester can detect the fault whichever the faulty phase is. (Why? Otherwise?)



[1]

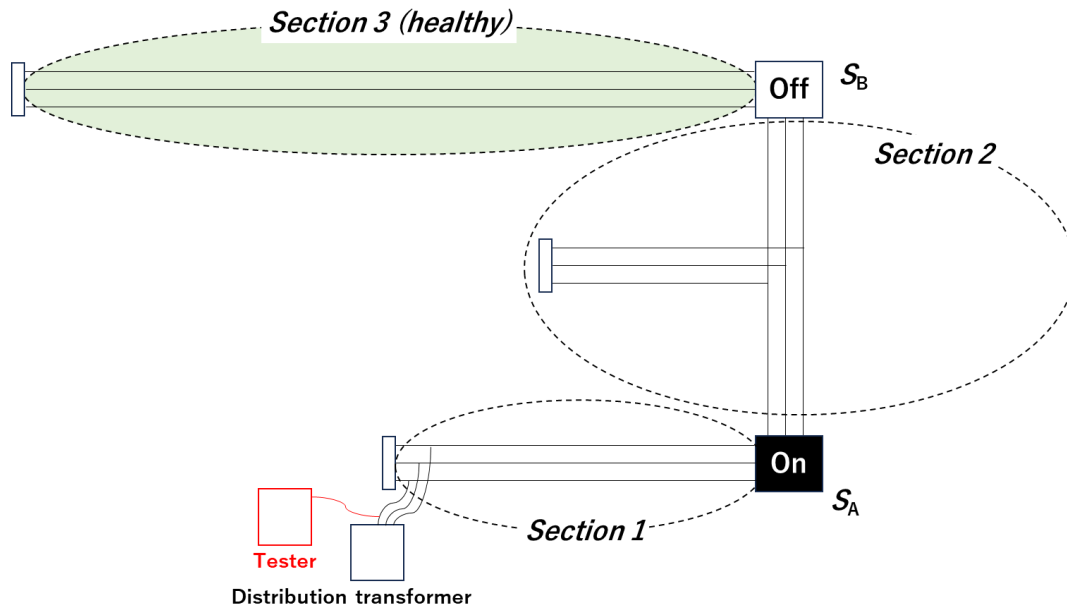
Open S_B and test again.



CASE STUDY - FAULT DETECTING PROCEDURE (v03)

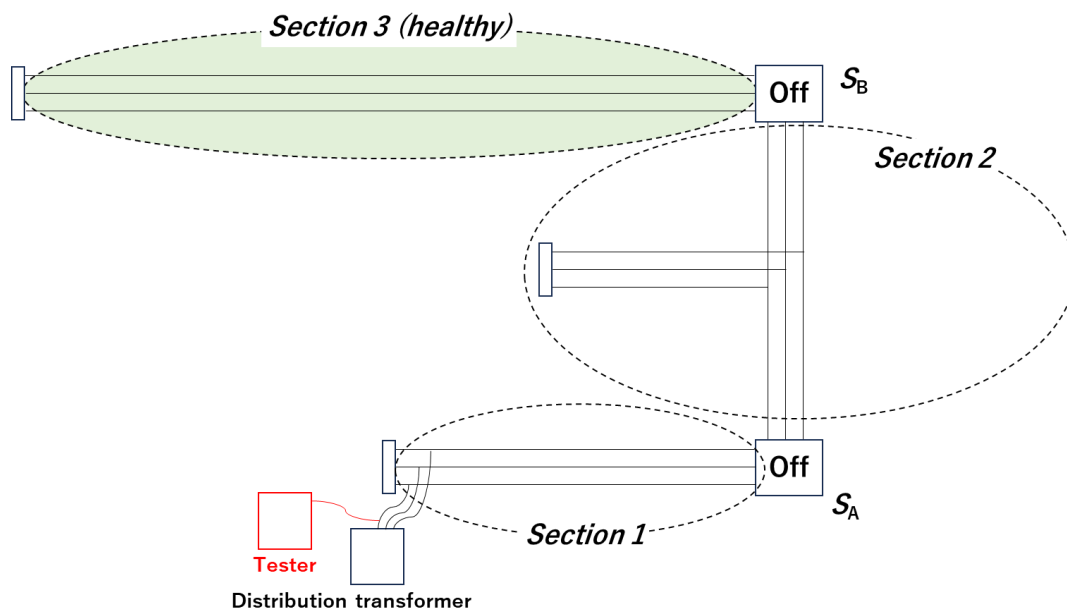
[2]

If the tester detects the current leakage, it means there is the fault point somewhere in Section 1 & 2, and Section 3 **is likely** to be healthy and can be energized somehow, **after the section is confirmed truly healthy**.



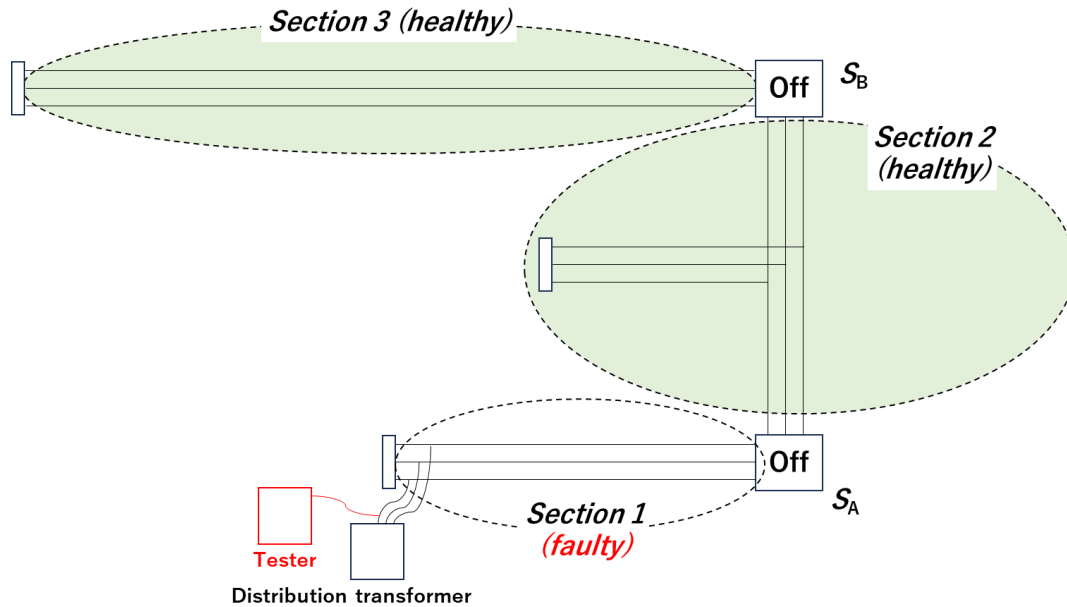
[2a]

Then in this case, open S_A .



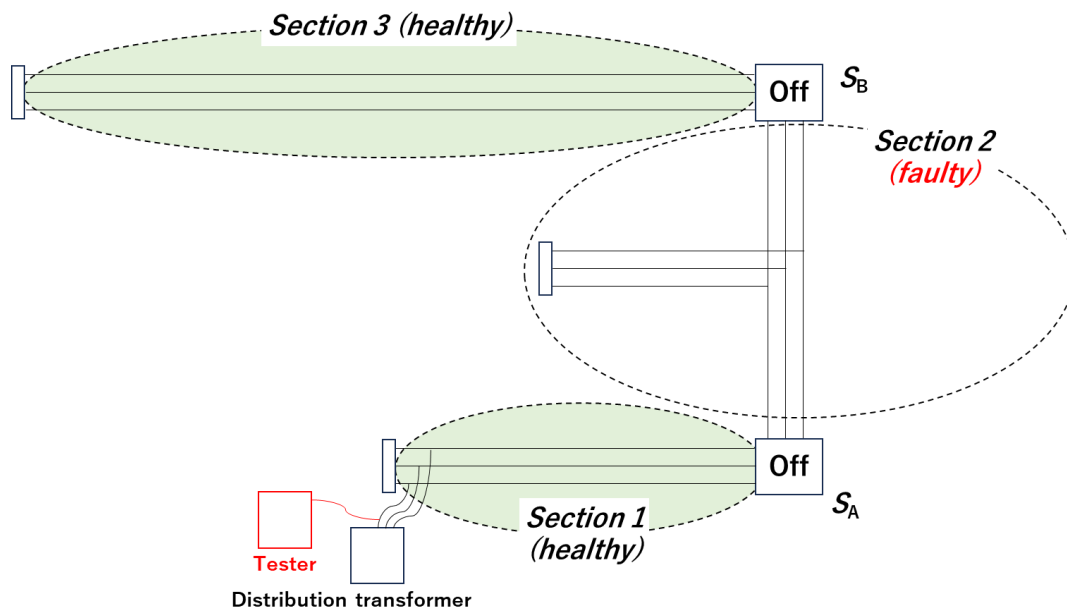
[2b]

If the tester continues to detect the current leakage, it means there is the fault point somewhere in Section 1, and Section 2 **is likely** to be healthy and can be energized somehow **after the section is confirmed truly healthy**.



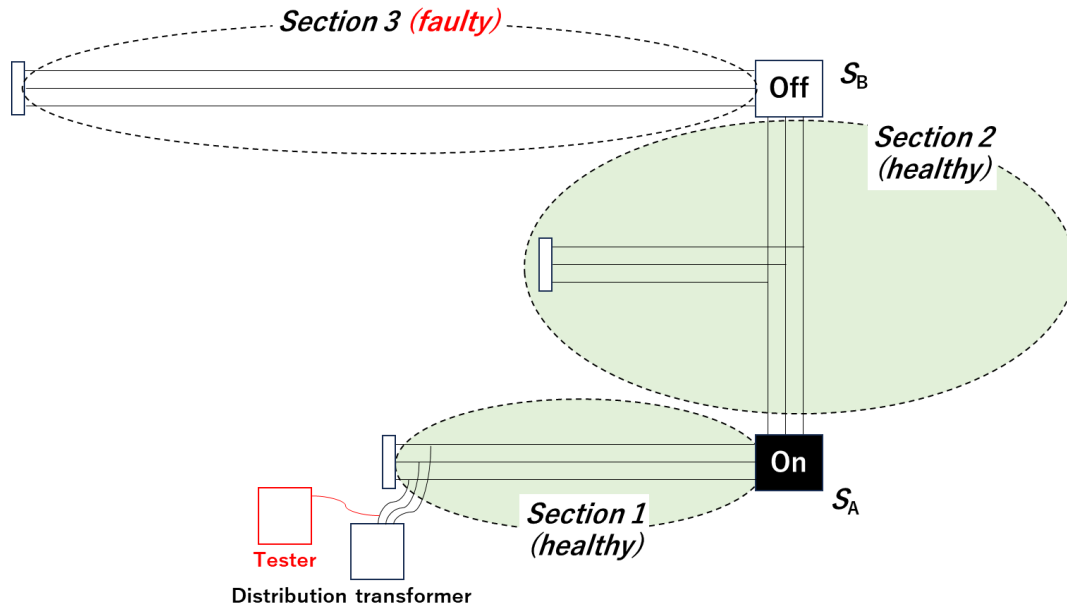
[2c]

If the tester does no longer detect the current leakage, it means there is not the fault point somewhere in Section 1, and there should be the fault point in Section 2. **Section 2 should be tested to confirm that this is truly faulty section.**



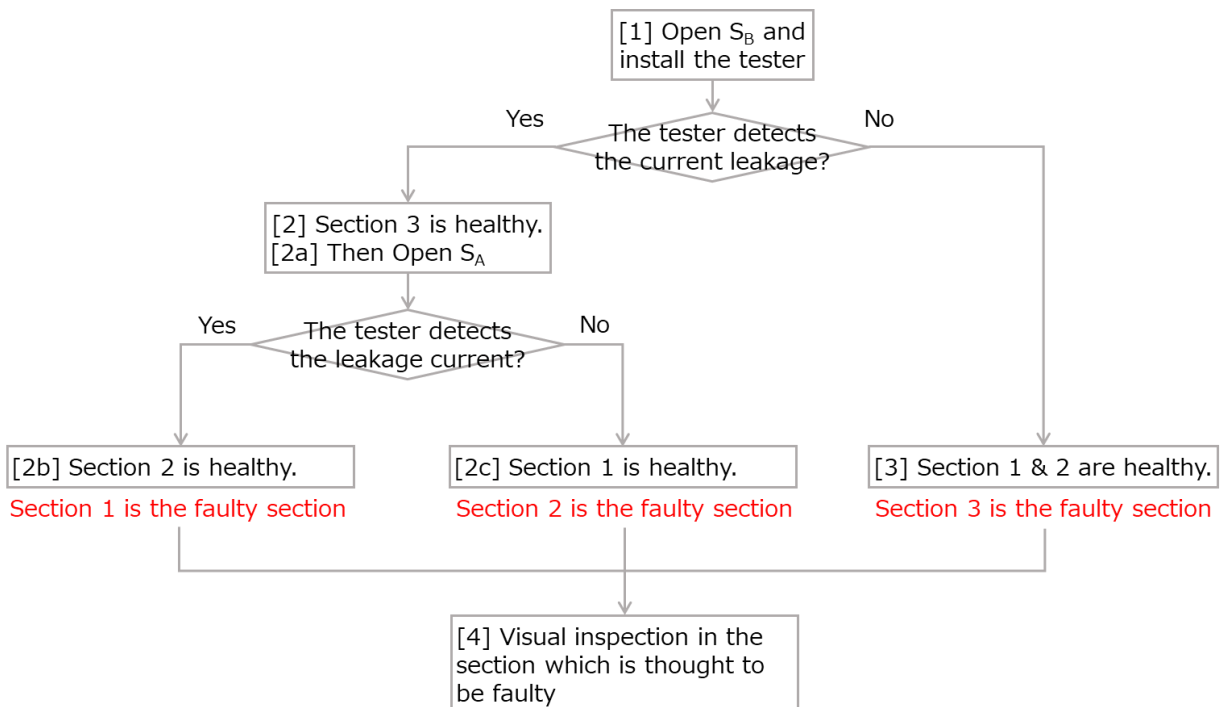
[3]

If the tester does not detect the current leakage, it means there is not the fault point somewhere in Section 1 nor 2, and these sections can be energized somehow. Now Section 3 is likely to be faulty, and should be tested to confirm that this is truly faulty section.



[4] Now that faulty section is identified, visual inspection should be executed to find the specific fault point.

The overall process of CASE 1 can be described as the following workflow.

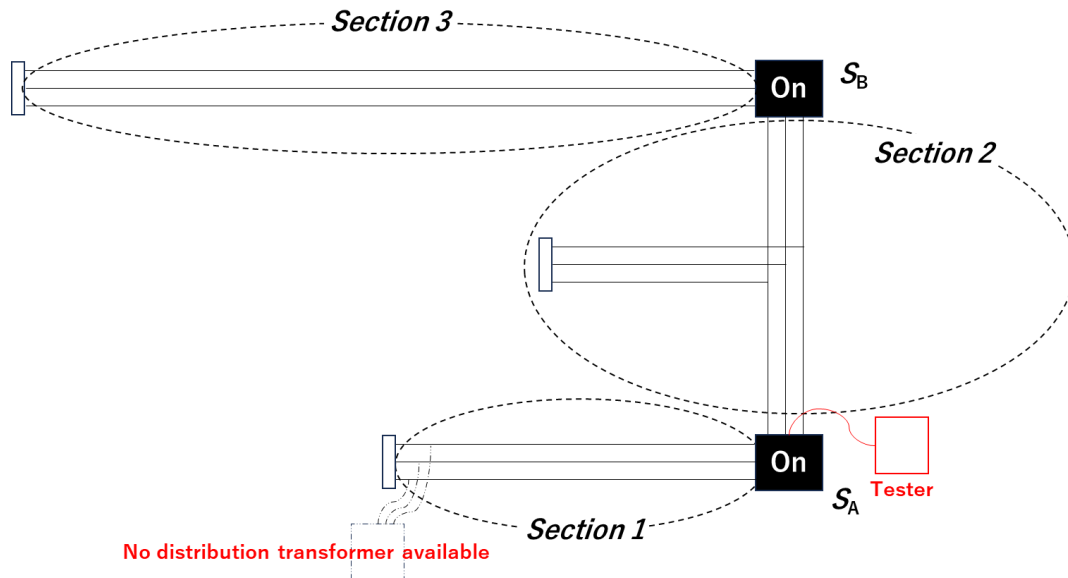


CASE STUDY - FAULT DETECTING PROCEDURE (v03)

CASE 2 – no transformer available

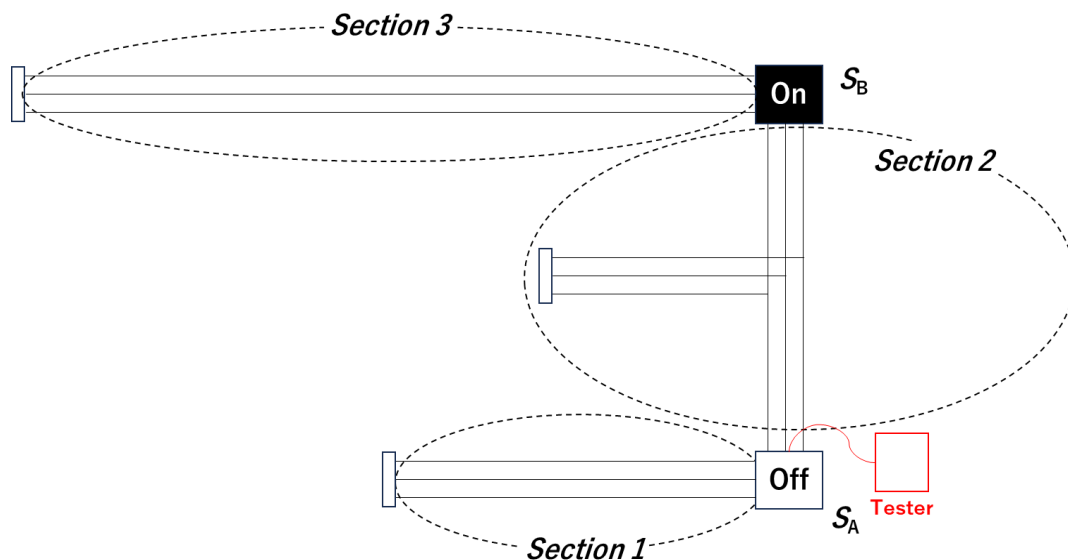
[0]

The only difference between CASE 1 & 2 is that, in CASE 2, there is no distribution transformer available, while there is in CASE 1. Therefore the tester has to be installed to different point. **So let's install the tester on Section-2 side of S_A and test the whole area.**



[1]

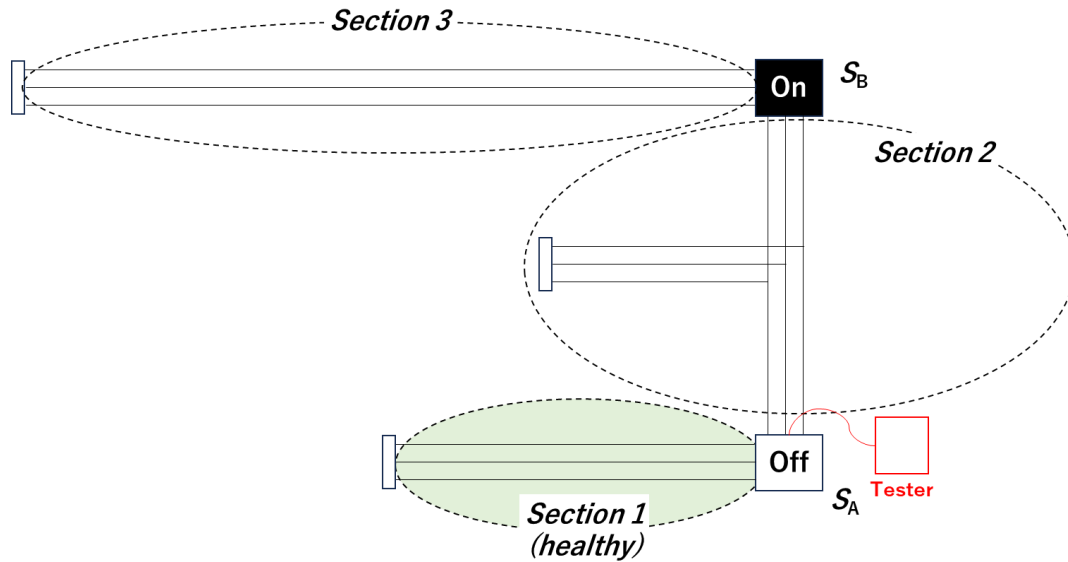
Open S_A and test again.



CASE STUDY - FAULT DETECTING PROCEDURE (v03)

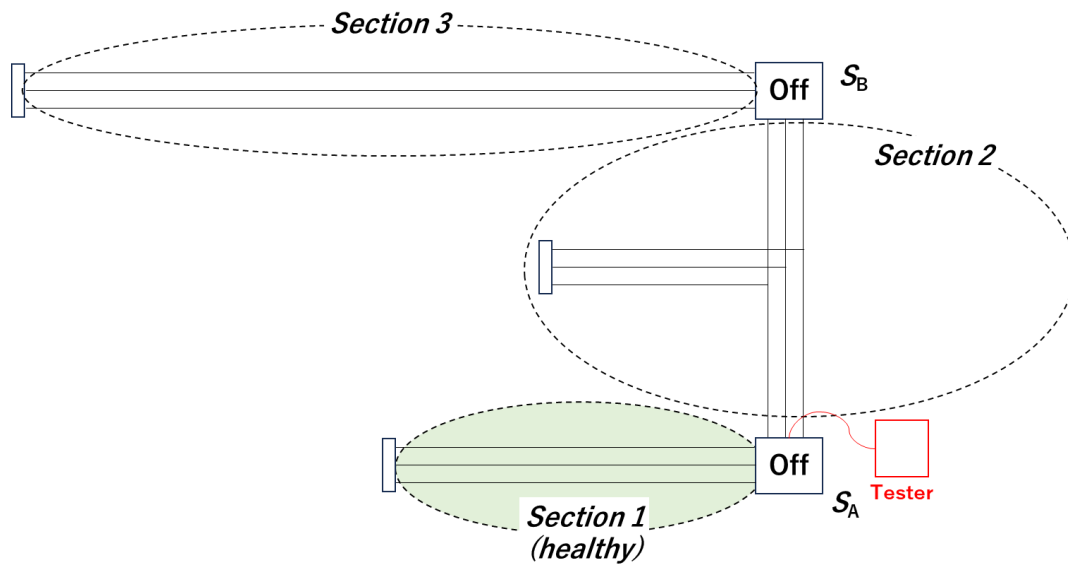
[2]

If the tester detects the current leakage, it means there is the fault point somewhere in Section 2 & 3, and Section 1 **is likely** to be healthy and can be energized somehow **after the section is confirmed truly healthy**.



[2a]

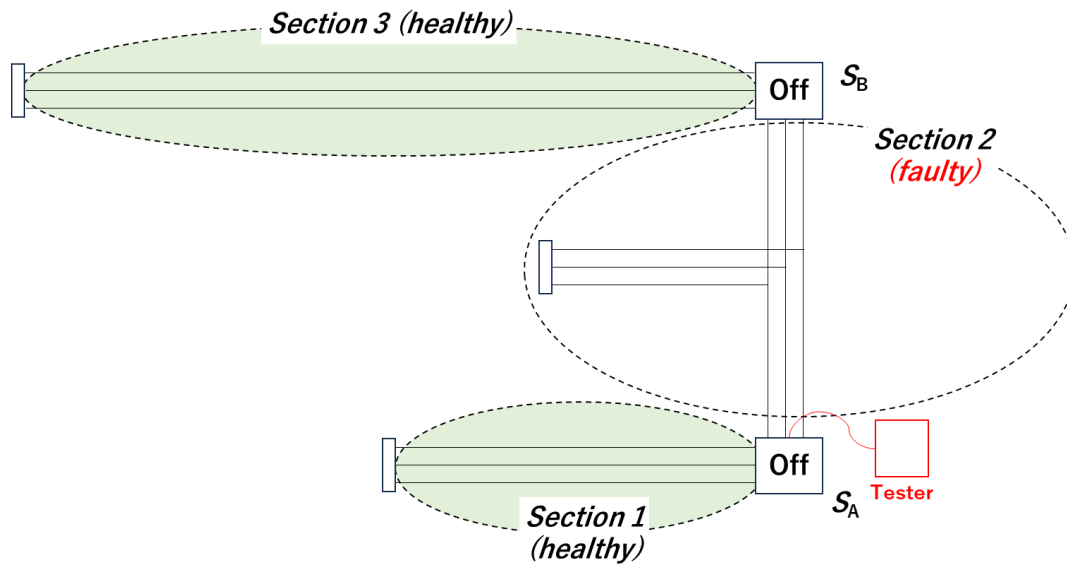
Then in this case, open S_B .



CASE STUDY - FAULT DETECTING PROCEDURE (v03)

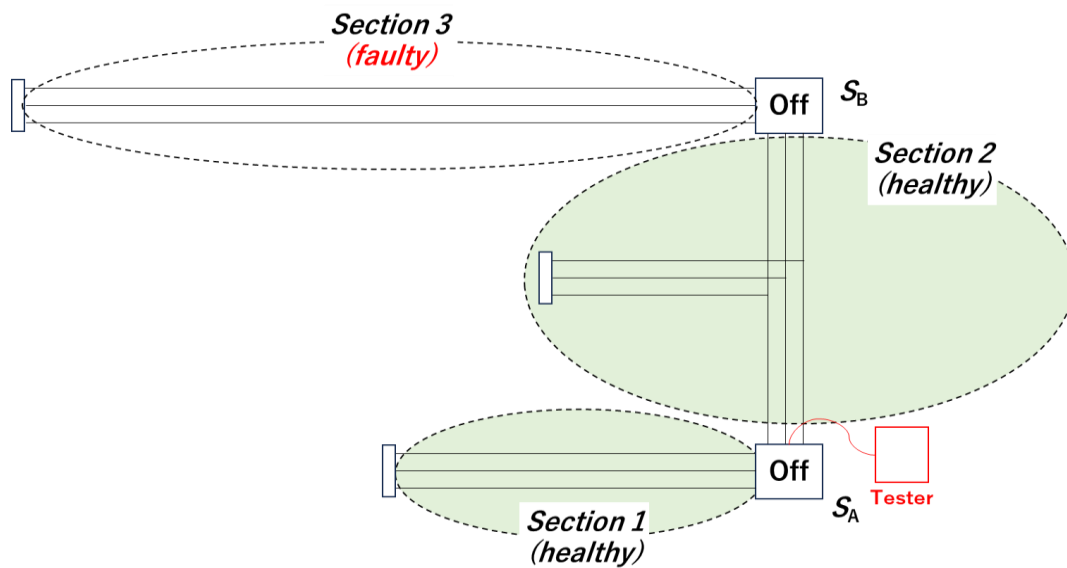
[2b]

If the tester continues to detect the current leakage, it means there is the fault point somewhere in Section 2, and Section 3 is likely to be healthy and can be energized somehow after the section is confirmed truly healthy.



[2c]

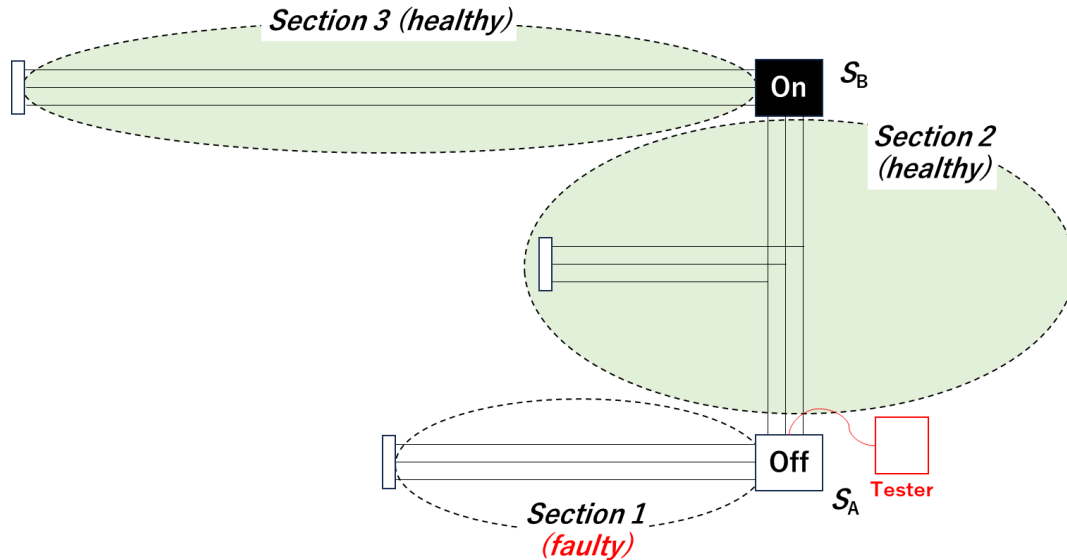
If the tester does no longer detect the current leakage, it means there is not the fault point somewhere in Section 2, and there should be the fault point in Section 3.



CASE STUDY - FAULT DETECTING PROCEDURE (v03)

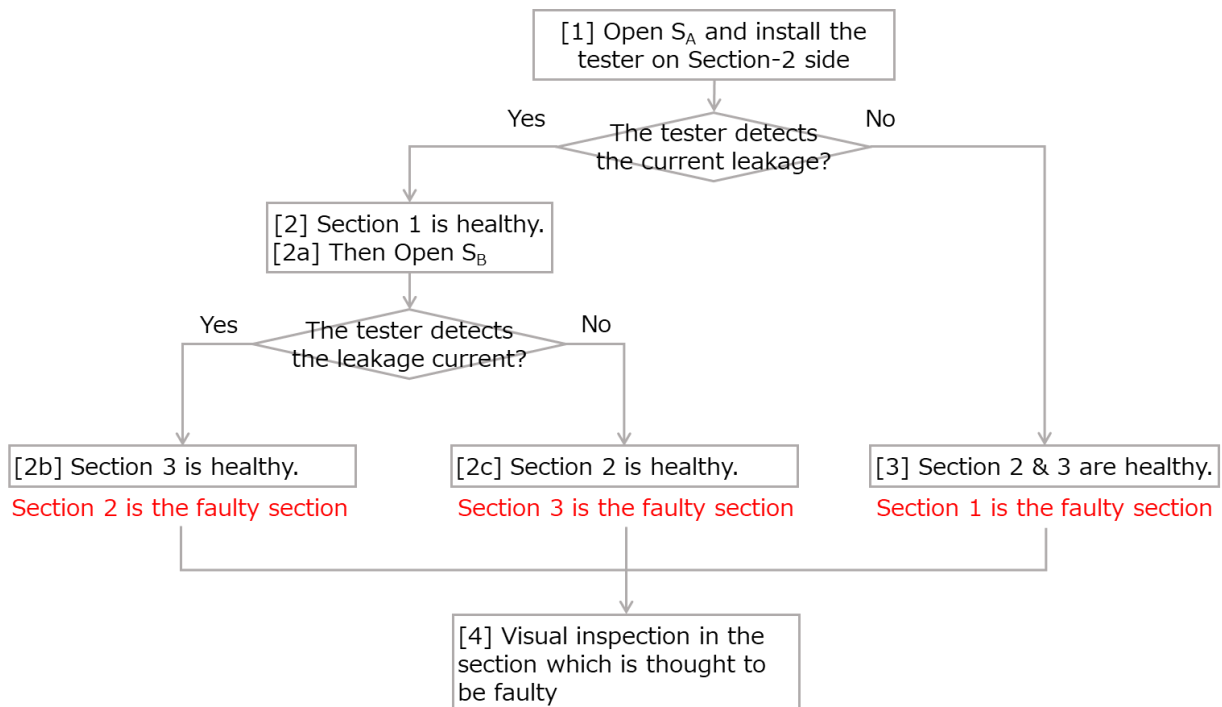
[3]

If the tester does not detect the current leakage, it means there is not the fault point somewhere in Section 2 nor 3, and these sections can be energized somehow. Now there should be the fault point in Section 1.



[4] Now that faulty section is identified, visual inspection should be executed to find the **specific** fault point.

The overall process of CASE 2 can be described as the following workflow.



Overhead fault location (v02)

Date Tuesday, 10th of July, 2025
Time 10:00-12:00

Agenda

1. Training outline 10:00-10:10

(1) Basic procedure of OH fault location

- ✓ Let's assume that the line patrol team looks for the visible and obvious fault point.
- ✓ If they do not find anything suspicious, they divide the feeder into several areas which Hipotronics tester can reach up to at maximum. Then they test each area to distinguish the healthy area(s) and faulty area(s).
- ✓ When they find a faulty area, they divide the area into several sections and test the sections to find the specific fault point.

(2) Assumption of this training

- ✓ The model feeder at NAPTIN training yard is assumed to be one area which length is the maximum distance that Hipotronics can test.
- ✓ The line patrol team finished patrolling the line, discovered nothing visible physically. Then the team decided to test this area (NAPTIN model feeder) using Hipotronics to check this area is healthy or faulty.

2. Preparation 10:10-10:40

(1) Principle of OH fault location

- ✓ Hipotronics applies the test voltage on the line, and can detect the current leakage through fault point.
- ✓ When there is no fault point, it detects no current leakage.
- ✓ When there is fault point, it detects current leakage. In this case, the current increases rapidly as the voltage increases.
- ✓ Hipotronics has the certain distance that it can test up to.
- ✓ In this training facility, test voltage should be 15kV not to damage the facility too much. In real situation, the test voltage is much higher.
- ✓ When transformer is not isolated in the faulty section, it can detect the current leakage even if it is connected to the phase that is different from faulty phase. (--> let's ask why)

(2) Connection, usage, and behavior of hipotronics

- a. When connected to faulty phase (with transformer isolated)
- b. When connected to healthy phase (with transformer isolated)

- c. When connected to healthy phase (with transformer connected)
- ✓ Before this demonstration, the transformer has to be disconnected.
 - ✓ NAPITN trainer shows how to connect and use Hipotronics, and demonstrates (2)a, b, & c above.
 - ✓ NAPITN trainer also shows the difference between the case with and without transformer connected.

3. Hands-on/practical training 10:40-12:00

- Trainers create hidden fault point for EXERCISEs.
- These will be conducted by trainees as much as time allows.

4. (Phase comparison work training) (12:00-13:00)

5. Q/A session (Answer for the questionnaire) 13:00-13:30