POWER GRID CORPORATION OF INDIA LIMITED

SUMMER INTERNSHIP REPORT

Study of 400/220 kV Substation Operations and Testing Procedures

At PGCIL Rourkela Substation

Submitted by:	Medipally Saivivek
Roll No:	122EE0378
Department:	Electrical Engineering
Institution:	National Institute of Technology Rourkela
Duration:	15th May,2025 - 15th July,2025

ACADEMIC YEAR: 2025

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to all those who have contributed to the successful completion of my summer internship at Power Grid Corporation of India Limited (PGCIL).

First and foremost, I would like to thank **RAVI RANJAN SHAY**, **AM** and **Saurabh Nainwal**, **JE** for providing me with this valuable opportunity and for their continuous guidance and support throughout the internship period.

I am grateful to **Vineet Shawrav Tigga**, **Sr. DGM Station**, and all the staff members of **ROURKELA Substation** for their cooperation and for sharing their valuable knowledge and experience.

Special thanks to the technical team members who patiently explained the complex procedures and allowed me to observe critical maintenance activities and various testing methodologies.

I would also like to acknowledge the support provided by the safety team for ensuring all safety protocols were followed during field visits and maintenance activities.

Finally, I thank my college **NIT Rourkela** and **Career Development Center(CDC)** for this opportunity.

Medipally Saivivek
122EE0378

Contents

Abstract

This report presents a comprehensive study conducted during the summer internship at the Power Grid Corporation of India Limited (PGCIL), Rourkela 400/220 kV substation. The objective of the internship was to gain hands-on experience with high-voltage substation operations, safety protocols, major equipment, and diagnostic testing procedures. The report outlines in-depth technical insights into various substation components such as shunt reactors, auto-transformers, circuit breakers, current transformers, and STATCOM systems. Additionally, critical testing methodologies like Dissolved Gas Analysis (DGA), Tan Delta Test, Dynamic Contact Resistance Measurement (DCRM), and Contact Resistance Measurement (CRM) were observed and documented. Emphasis was placed on the importance of preventive maintenance and safety standards in ensuring uninterrupted power transmission. This internship significantly enhanced our understanding of substation design, grid reliability, and the practical application of theoretical electrical engineering principles.

Figure 1

Chapter 1

Introduction

The primary objective of this internship was to gain practical exposure to the functioning and operational protocols of a high-voltage substation, with a focus on equipment diagnostics, safety standards, and power system reliability. Conducted at the 400/220 kV PGCIL Rourkela substation, this internship offered a valuable opportunity to bridge the gap between academic learning and industrial practices. Through direct observation and interaction with the technical staff, we explored core components of substation infrastructure, including transformers, circuit breakers, reactors, and advanced testing mechanisms. This report documents the insights gained, equipment studied, and testing procedures witnessed, contributing to a deeper understanding of India's power transmission framework.

1.1 About Power Grid Corporation of India Limited (POWERGRID)

Power Grid Corporation of India Limited (POWERGRID) is a 'Maharatna' Public Sector Enterprise of the Government of India, incorporated on 23rd October 1989 under the Companies Act, 1956.

POWERGRID is primarily engaged in the business of power transmission through its EHVAC/HVDC transmission network. The corporation has also diversified into telecom business, consultancy services for intra-state transmission network implementation, Smart Grid projects, energy efficiency and energy audit, capacity building assignments, and other businesses including solar power generation and smart grid/smart metering solutions.

1.1.1 Key Features

- Manages over 1.7 lakh circuit km of transmission lines and more than 270 substations
- Operates at voltages up to ±800 kV HVDC and 765 kV AC
- Facilitates interstate and interregional power transfer
- Active in telecom services (through POWERTEL) and consultancy services worldwide

1.2 PGCIL Rourkela 400/220 kV Substation

The PGCIL Rourkela 400/220 kV substation is a critical node in the Indian power transmission network, facilitating power transfer across multiple regions.

1.2.1 Lines Connected to PGCIL Rourkela Substation

The following transmission lines are connected to the substation:

- Sundergarh: 4 lines(numbered 1,2,3,4)
- Ranchi: 2 lines (numbered 1,2)
- Chaibasa: 2 lines (numbered 1,2)
- Talcher:2 lines(numbered 1,2)
- Tarkera: 2 lines (numbered 1,2)

Note: Each number indicates the number of lines connected to PGCIL Rourkela substation. Except for Tarkera 1,2, all transmission lines are owned by PGCIL. The two Tarkera transmission lines are owned by Odisha Power Transmission Corporation Limited (OPTCL).

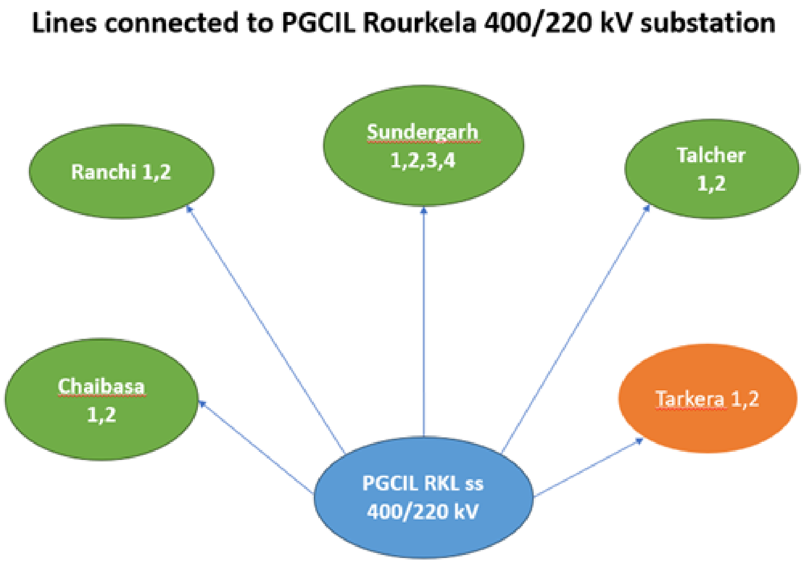

Figure 1.1: Transmission lines Connectivity of PGCIL Rourkela Substation

Chapter 2

Safety Rules and Precautions

Safety is paramount in substation operations. The following safety rules and precautions were strictly enforced at the PGCIL Rourkela substation:

1. Entry into the substation premises was not permitted unless a valid gate pass was issued.
2. Individuals arriving on motorcycles were required to wear helmets before entry was allowed.
3. The in- and out-signing procedure at the security gate was made mandatory for all visitors.
4. Safety shoes and helmets were made compulsory for all personnel entering the switchyard area.
5. Movement into the switchyard was not allowed unless accompanied by the concerned or authorized engineer.
6. Walking in switchyard was instructed to be done only on designated rocky paths; stepping over basements containing underground cables was strictly prohibited.
7. During equipment shutdowns, individuals were instructed to maintain a safe distance from the switchyard to avoid potential hazards.
8. Photographs were not to be taken without prior approval from the concerned supervising officer.
9. Emergency exit routes and assembly points were to be familiarized with by all personnel in advance.
10. The use of mobile phones was restricted in both the switchyard and control room to minimize risks and distractions.
11. Proper earthing and interlock verifications were to be carried out before entering any high-voltage area.
12. Any observed safety hazards, near-miss incidents, or accidents were expected to be reported immediately to the safety officer or shift-in-charge.
13. Operation of breakers, isolators, or electrical control systems was not to be performed by unauthorized personnel.

Chapter 3

Single Line Diagram of PGCIL Rourkela Substation

The Single Line Diagram (SLD) serves as a blueprint of the entire substation, depicting how power is transmitted, transformed, and distributed. It plays a critical role in operation, protection coordination, and maintenance planning.

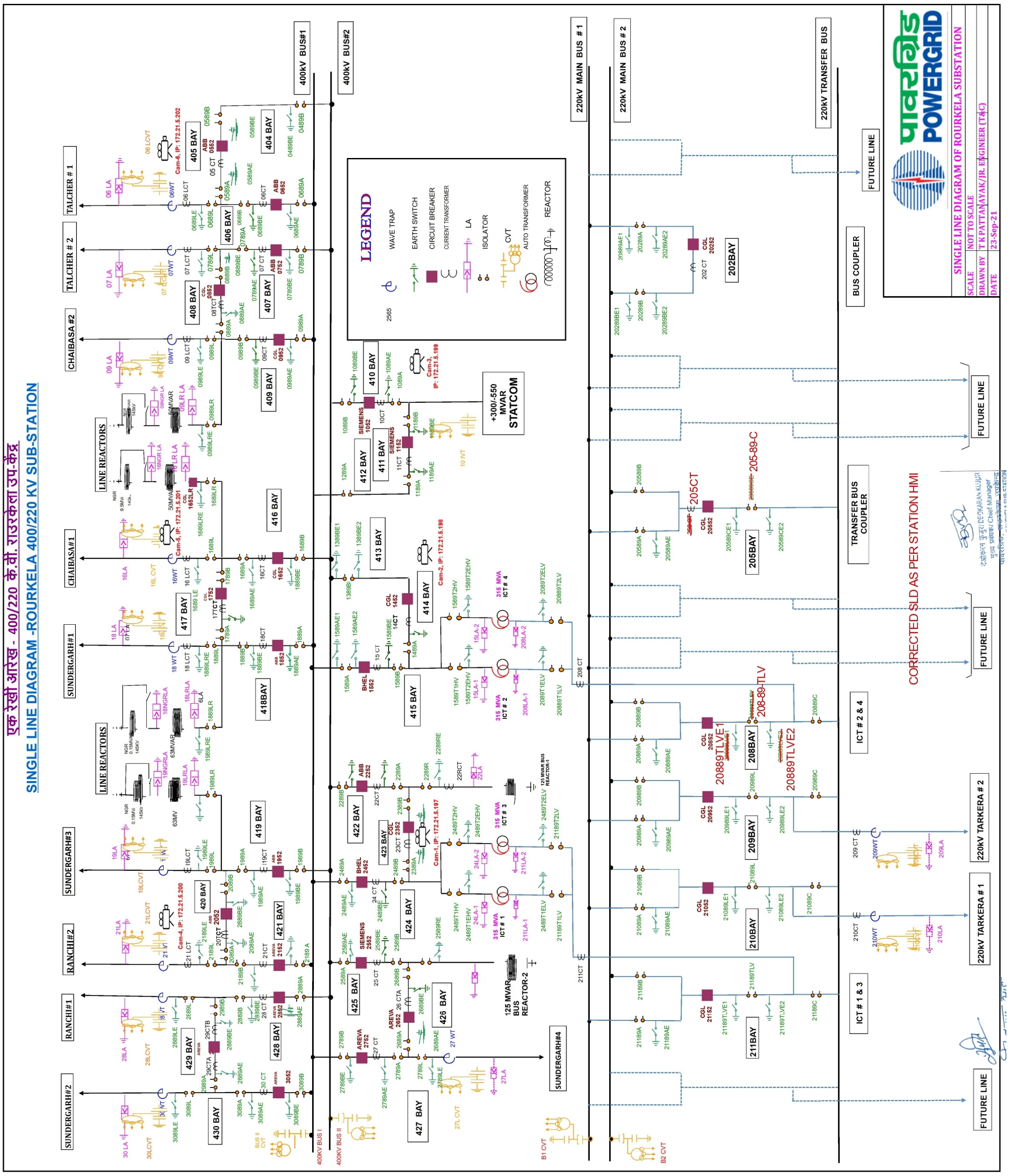

Figure 3.1: Single Line Diagram - Rourkela 400/220 kV Substation

3.1 Key Terminologies

3.1.1 BAY

A BAY is a substation unit containing complete equipment for connecting one circuit to the busbar system.

Typical Line Bay Components:

- Line arrestor
- Isolator
- Capacitive Voltage Transformer
- Wire trap
- Circuit breaker

Bus-Coupler Bay: Connects two sections of the same busbar.
Bay Configuration: In SLD, bays are vertical sections extending from horizontal busbars, forming complete circuit paths from busbar to external connections.

- Number of 400 kV BAYs: 25
- Number of 220 kV BAYs: 6

3.1.2 DIA Configuration

DIA is a scheme connecting two main busbars with intermediate connection points for lines or transformers.

Configuration Types:

1. **I Configuration**
2. **D Configuration**

(a) I Configuration (b) D Configuration

Figure 3.2: DIA Configuration Types

D Configuration Advantages:

- Equipment positioned closer together

- Reduced transmission losses compared to I configuration

  Trade off: Requires more area

The 400/220 kV Rourkela substation uses D-configuration for its DIA scheme.
Bay-DIA Relationship: 3 Bay = 1 DIA
Relation between Bay and DIA: 3 Bay = 1 DIA

3.2 Key Notations in SLD

3.2.1 Equipment Notation System

Equipment	Notation	Example
BAY (400 kV bus)	1st digit = 4	404 BAY
BAY (220 kV bus)	1st digit = 2	202 BAY
Circuit Breaker	Last digits = 52	2052 (BAY 20)
Isolator	Last digits = 89	2089A (BAY 20)
Earth Switch	Last digits = 89E	1989AE (BAY 19)
Current Transformer	BAY + LCT	21LCT
CVT	BAY + LCVT	30LCVT
Wave Trap	BAY + WT	18WT
Line Arrestor	BAY + LA	16LA

Table 3.1: Equipment Notation System

Note: First two digits indicate BAY number, with each BAY having 2 isolators (A/B) and 2 earth switches (A/B).

3.3 Symbols for Equipment in SLD

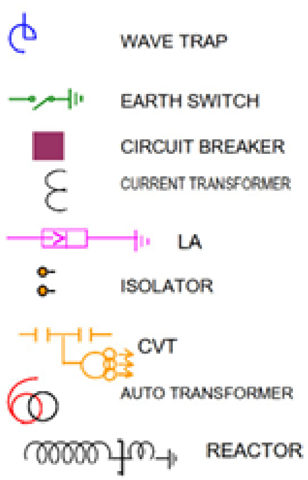

Figure 3.3: Equipment Symbols Used in Single Line Diagram

Chapter 4

Equipment Observed in 400 kV and 220 kV Switchyard

4.1 Shunt Reactor

Figure 4.1: Shunt Reactor

A shunt reactor is an electrical device used in high-voltage power transmission systems to absorb excess reactive power and stabilize voltage, particularly on long transmission lines and cable systems. It is connected in parallel (shunt) with the power system, typically at substations or along the transmission line.

4.1.1 Working Principle

A shunt reactor, connected in parallel, behaves as an inductive load that creates inductive reactance by opposing changes in current. It absorbs excess capacitive reactive power generated by long, lightly loaded transmission lines. This absorption helps control voltage rise, ensuring stability and protecting equipment. Thus, it improves system efficiency by maintaining voltage within safe limits.

4.1.2 Construction and Types

- **Core:** Made of laminated silicon steel, providing a path for magnetic flux
- **Windings:** Copper or aluminum windings generate inductive reactance
- **Insulation:** High-quality insulation ensures safe operation
- **Cooling System:** May use air, oil, or gas for cooling, depending on the rating
- **Tank:** Oil-immersed reactors are housed in sealed steel tanks

4.1.3 RKL 400/220 kV Substation Equipment Specifications

Table 4.1: Shunt Reactor Specifications

Parameter	**Value**	**Unit**
Rated reactive power	63	MVAR
Rated Voltage	420	kV (rms)
Rated current	86.6	Amperes
Number of phases	3	-
Frequency	50	Hz
Connection	Star	-
Core	Gapped core	-
Cooling type	ONAN (Oil natural, Air natural)	-
Oil	39300	litres
Total mass	125000	Kg

4.2 Auto Transformer

Figure 4.2: Auto Transformer

An auto transformer with a 400/220/33 kV rating is a critical component in high-voltage power transmission networks. It is designed to interconnect grids operating at different voltage levels (400 kV, 220 kV, and 33 kV), enabling efficient transfer and regulation of large amounts of electrical power between transmission systems.

4.2.1 Working Principle

- An autotransformer uses a single winding with taps; part of it serves both input and output sides.
- It steps voltage up or down (400 kV, 220 kV, 33 kV) based on tap positions.
- AC input creates a magnetic field inducing voltage across the winding .

- It allows bidirectional power flow and includes a 33 kV tertiary winding for harmonics, auxiliary loads, and connecting reactive components.

4.2.2 Construction Features

- **Core:** High-grade laminated steel core for efficient magnetic flux conduction
- **Windings:** Copper windings with taps for 400,220 and 33 kV connections
- **Cooling:** Typically oil-immersed with radiators, designed for outdoor installation
- **Protection:** Equipped with advanced protection systems
- **High Capacity:** ratings include 315 MVA for 400/220/33 kV auto transformers

4.2.3 Specifications

Table 4.2: Auto Transformer Specifications

Parameter	**Value**	**Unit**
Rated capacity	315	MVA
Rated voltage	400/220/33	kV
Rated current (HV/IV/LV)	454.7/826.7/1837	Amperes
Phases	3	-
Frequency	50	Hz
Cooling type	ONAN/ONAF/OFAF	-
Oil	92500	litres
Impedance	12.5	%
Total weight	171800	kg

4.3 Circuit Breaker

Figure 4.3: SF6 Circuit Breaker

Circuit breaker is an important protection equipment in transmission. The circuit breaker at Rourkela 400/220 kV substation is of SF6 type.

An SF6 (Sulfur Hexafluoride) circuit breaker is a high-voltage switching device used extensively in power transmission and distribution networks. It utilizes SF6 gas as both the insulating and arc-quenching medium, making it highly effective for managing and protecting electrical systems.

4.3.1 Working Principle

- **Arc Quenching:** When a fault occurs, the circuit breaker detects the abnormal current and triggers the opening of its contacts. This separation generates an electric arc.
- **Role of SF6 Gas:** SF6 gas is released into the arc chamber. Its high electronegativity allows it to absorb free electrons, forming heavy negative ions that rapidly quench the arc by cooling and deionizing it.
- **Contact Operation:** The breaker's moving and fixed contacts are enclosed in a sealed chamber filled with pressurized SF6 gas. The gas flows through the arc zone, extinguishing the arc and restoring insulation between the contacts.

4.3.2 Key Advantages

- **High Dielectric Strength:** SF6 has superior insulating properties, allowing compact and reliable designs
- **Excellent Arc Quenching:** Rapid and effective arc extinction ensures high interrupting capacity
- **Compact Size:** Equipment can be smaller due to the high efficiency of SF6 as an insulator
- **Low Maintenance:** Sealed systems require minimal servicing and have high operational reliability
- **Long Service Life:** Designed for decades of operation with high electrical endurance

4.3.3 Environmental Considerations

- **Greenhouse Gas:** SF6 is a potent greenhouse gas, so modern breakers are designed to minimize leakage and support gas recycling
- **Regulation:** Use and handling of SF6 are strictly regulated to limit environmental impact

4.4 Current Transformer(CT)

(a) Live CT

(b) Dead CT

Figure 4.4: Types of Current Transformers

A current transformer (CT) is a type of instrument transformer used in power transmission systems to measure high alternating currents by stepping them down to a lower, manageable value. This allows for safe monitoring, control, and protection of electrical equipment in substations and transmission lines.

4.4.1 Working Principle

- **Electromagnetic Induction:** The CT operates on the principle of electromagnetic induction. It consists of a primary winding (often a single turn or the power conductor itself), a magnetic core, and a secondary winding with many turns.

- **Current Proportionality:** The primary winding carries the high current to be measured, generating a magnetic field in the core. This induces a proportional current in the secondary winding, which is connected to measuring instruments or protective relays.

- **Secondary Circuit:** The secondary winding must always be closed (connected to a load or measuring device) during operation. An open secondary can cause dangerously high voltages and damage the CT.

Current Transformers (CTs) used in power transmission are classified as live tank or dead tank types.

4.4.2 Comparison: Live Tank CT vs Dead Tank CT

Table 4.3: Live Tank CT vs Dead Tank CT Comparison

Feature	**Live Tank CT**	**Dead Tank CT**
Tank Potential	High voltage (live)	Grounded (dead)
Core & Secondary Location	Top tank (live)	Bottom tank (earthed)
Insulation Focus	Core and secondary winding	Primary winding
Primary Winding Length	Shorter (less resistance/heat)	Longer (more resistance/heat)
Size & Cost	Compact, economical	Bulky, costly
Mechanical Stability	Less (higher center of gravity)	More (lower center of gravity)
Electrical Stability	More (robust insulation)	Less (complex insulation)
Typical Use	Space/cost-sensitive installations	Mechanically demanding locations

4.5 Capacitive Voltage Transformer

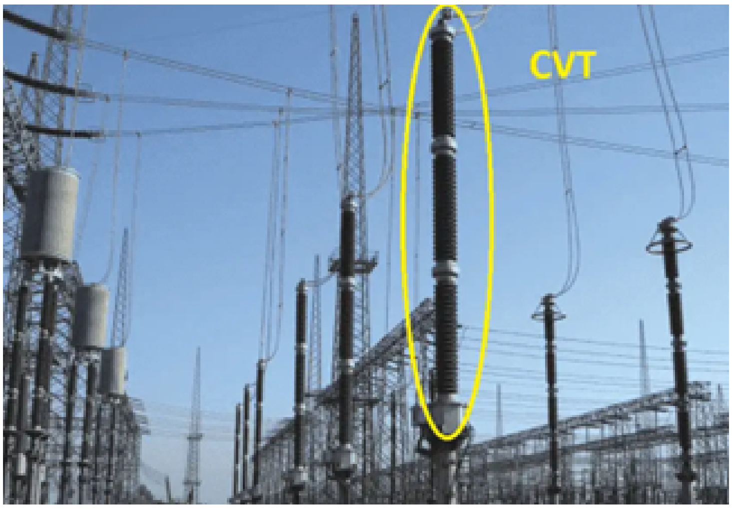

Figure 4.5: Capacitive Voltage Transformer at PGCIL Rourkela Substation

A Capacitive Voltage Transformer (CVT) is a specialized instrument transformer used in high-voltage substations. Its primary function is to step down extra high voltage (typically above 100 kV) to a lower, measurable voltage suitable for metering, protection, and control equipment.

4.5.1 Working Principle

1. The high-voltage line is connected to the capacitive divider, which reduces the voltage.

2. The intermediate voltage is fed to the electromagnetic unit, which steps it down further.

3. The output is a low, standardized voltage signal for use by meters, relays, and control systems.

4.6 STATCOM (+300/-550 MVAR) at Rourkela

Figure 4.6: STATCOM Installation at PGCIL Rourkela Substation

STATCOM stands for Static Synchronous Compensator. It continually monitors grid voltage and constantly adjusts reactive power output in response to system disturbances, thereby improving grid stability.

4.6.1 List of Elements

1. 2 × 400 kV BAYs (BAY no. 410 & 411)
2. 4 × 171 MVA 400/35.8 kV coupling Transformer
3. 2 × 125 MVAR MSR and its BAYs
4. 1 × ±150 MVAR VSC and its BAYs
5. 1 × 630 kVA 35.8/0.415 kV Auxiliary Transformer and its BAYs
6. 1 × Neutral Grounding Transformer and its BAY
7. 1 × 630 kVA 33/0.415 kV Auxiliary (Tertiary) Transformer and its BAYs
8. 1 × 500 kVA DG set

This setup is capable of providing (+ve) / absorbing (-ve) reactive current and thereby regulating voltage.

4.6.2 Key Components

VSC (Voltage Source Converter)

It can consume (-150 MVAR) and supply (+150 MVAR) reactive power. It is always in service.

MSR (Main Supply Route)

In this, the circuit breaker is open most of the time, closed only when VSC needs support. It can only consume reactive power. Each MSR has a rating of 125 MVAR.

4.6.3 Reactive Power Capability

- Reactive power can consume: $2\times(-150) + 2\times(-125) = -550$ MVAR
- Reactive power can supply: $2\times(+150) = 300$ MVAR

4.6.4 STATCOM Working Principle

- **Voltage Source Converter (VSC):** At the heart of a STATCOM is a voltage source converter, which uses semiconductor devices (like IGBTs) to generate a controllable AC voltage waveform.
- **Reactive Power Control:** By adjusting the phase and magnitude of its output voltage, the STATCOM can inject or absorb reactive power to or from the grid.
  - Injects reactive power (capacitive mode) when system voltage is low, raising the voltage
  - Absorbs reactive power (inductive mode) when system voltage is high, lowering the voltage
- **Fast Response:** STATCOMs can respond to voltage changes in less than two cycles (milliseconds), making them highly effective for rapid voltage regulation and grid stabilization.

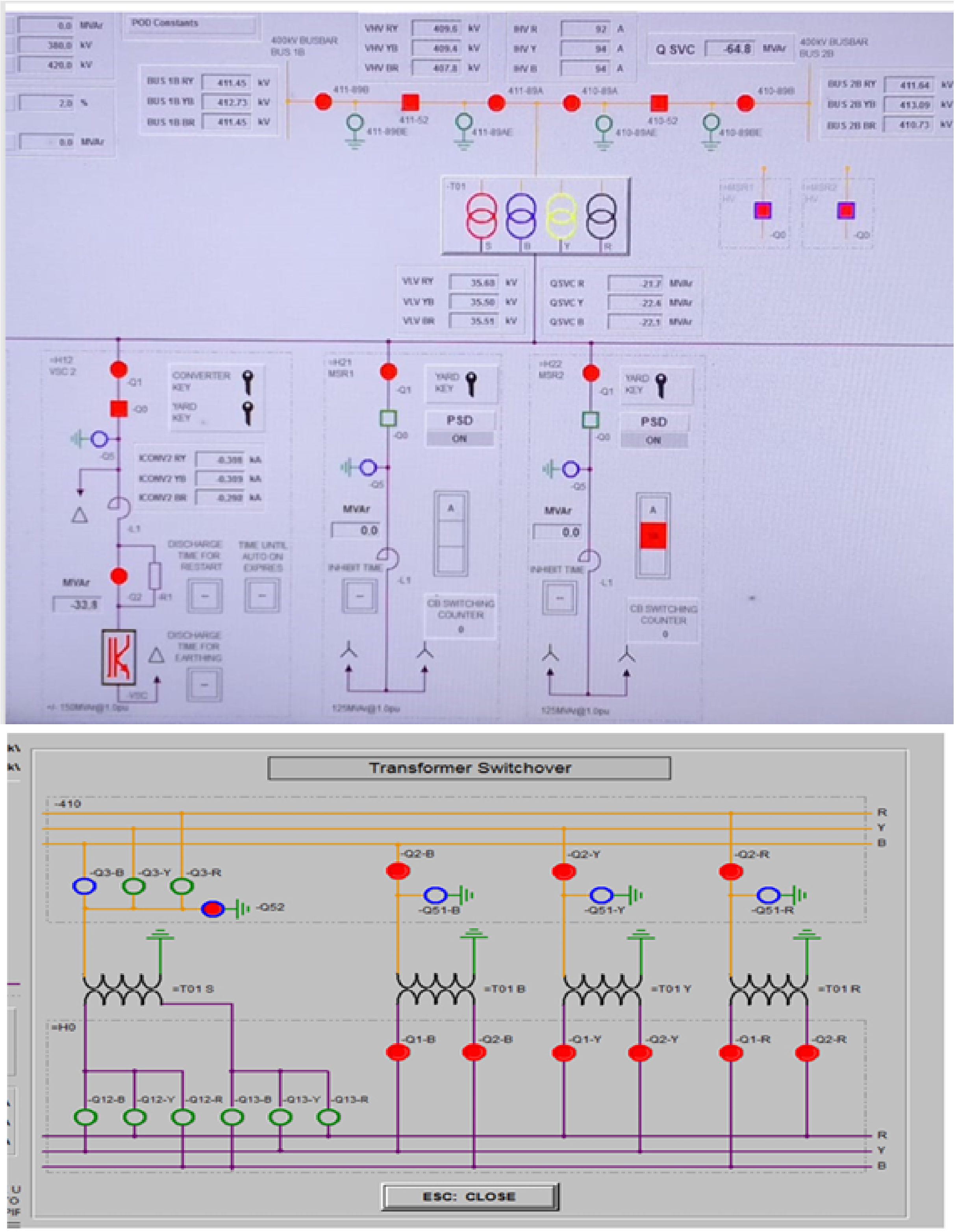

Figure 4.7: STATCOM Single Line Diagram

Chapter 5

Breaking and Closing of a Line in Rourkela Substation

5.0.1 Switching Sequence and SCADA Indication

The standard switching sequence for line operations follows specific safety protocols. For breaking a line: first open the circuit breaker, then the isolator, and finally connect the earth switch. The closing sequence reverses this order: open earth switch, close isolator, then close circuit breaker. In the SCADA system, green light indicates open position while red light indicates closed position for all switching devices.

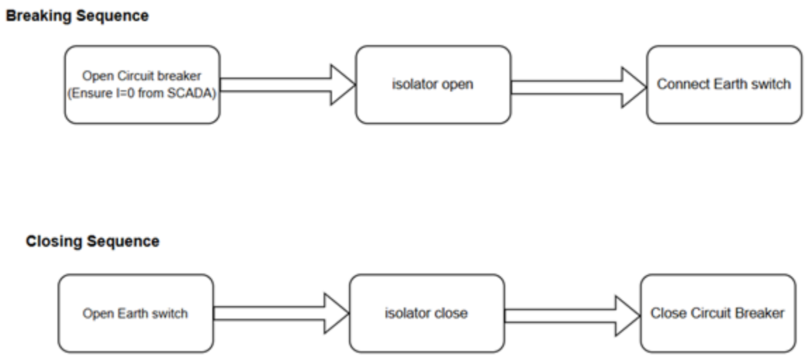

Figure 5.1: Breaking and Closing Sequence Diagram

Figure 5.2: Control Room where Breaking and Closing are monitored

Chapter 6

Specific Tests Observed at PGCIL Rourkela

During our switchyard visit, we directly witnessed several critical tests being performed. These tests are essential for maintaining the reliability and safety of the power transmission system.

6.0.1 DGA Test (Dissolved Gas Analysis)

We observed the DGA testing process on transformers and current transformers at the facility. The technicians explained that this test functions like a "blood test for humans" but uses oil to estimate transformer and CT health. Oil samples were carefully extracted from conservator tanks and analyzed for dissolved gases to identify internal faults.

Observation Process

The testing process involved collecting oil samples from transformer conservator tanks, followed by laboratory analysis of dissolved gases. This proactive approach helps detect overheating, partial discharges, and arcing through gas analysis, enabling identification of potential problems before major failures occur.

Key Gases and Their Indications

- **Hydrogen (H_2):** Indicates overheating, partial discharge, or arcing
- **Methane (CH_4):** Indicates thermal faults or partial discharge
- **Ethylene (C_2H_4):** Suggests high-temperature faults
- **Acetylene (C_2H_2):** Indicates arcing or severe overheating

Applicable Standards

- IEEE C57.104 - IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers
- IEC 60599 - Mineral oil-filled electrical equipment in service - Guidance on the interpretation of dissolved and free gases analysis
- CIGRE 296 - Detection of deterioration and determination of the degree of deterioration

Gas Concentration Limits (ppm)

Key Diagnostic Ratios

- C_2H_4/C_2H_2 Ratio: < 0.1 (Normal), $0.1 - 3.0$ (Attention), > 3.0 (Arcing)
- CH_4/H_2 Ratio: < 0.1 (PD), $0.1 - 1.0$ (Low energy), > 1.0 (High energy)

Gas	Normal Operation	Attention Level	Action Required
Hydrogen (H_2)	< 100	$100 - 700$	> 700
Methane (CH_4)	< 120	$120 - 400$	> 400
Ethylene (C_2H_4)	< 50	$50 - 100$	> 100
Acetylene (C_2H_2)	< 1	$1 - 35$	> 35
Carbon Monoxide (CO)	< 350	$350 - 570$	> 570
Carbon Dioxide (CO_2)	< 2500	$2500 - 5000$	> 5000

Table 6.1: Gas Concentration Limits for DGA Test

- C_2H_4/C_2H_6 Ratio: < 1.0 (Thermal $< 300C$), $1.0 - 3.0$ (Thermal $300 - 700C$), > 3.0 (Thermal $> 700C$)

6.1 Oil Parameter Test

We observed comprehensive oil testing procedures being conducted alongside the DGA tests. The technicians demonstrated how various oil parameters are measured to assess the overall condition of the insulating oil in transformers and other oil-filled equipment.

Applicable Standards

- IEEE C57.106 - IEEE Guide for Acceptance and Maintenance of Insulating Mineral Oil
- IEC 60296 - Fluids for electrotechnical applications - Mineral insulating oils
- ASTM D1816 - Standard Test Method for Dielectric Breakdown Voltage of Insulating Liquids

Acceptance Criteria

Parameter	New Oil	Oil in Service	Action Required
Breakdown Voltage	> 70 kV	> 40 kV	< 30 kV
Water Content	< 10 ppm	< 20 ppm	> 35 ppm
Acidity	< 0.01 mg KOH/g	< 0.10 mg KOH/g	> 0.15 mg KOH/g
Interfacial Tension	> 40 mN/m	> 25 mN/m	< 18 mN/m
Power Factor	$< 0.05\%$	$< 0.5\%$	$> 1.0\%$
Color	< 0.5	< 3.0	> 4.0

Table 6.2: Oil Parameter Test Acceptance Criteria

6.1.1 Tan Delta Test (Dissipation Factor)

We witnessed the tan delta testing process, also known as the dissipation factor test, being performed on transformers and CTs at the switchyard. The testing team explained this as a crucial method for evaluating insulation quality by measuring the tangent of the angle between resistive and reactive components of current flowing through the insulation.

Observation Process

The testing process involved applying low-frequency AC voltage to insulation systems and measuring the resulting current to calculate tan delta values. Lower tan delta values indicate better insulation quality, while higher values signify greater dielectric loss and degraded insulation. The importance of early detection of insulation deterioration was clearly demonstrated during our observation.

Applicable Standards

- IEEE 62 - IEEE Guide for Diagnostic Field Testing of Electric Power Apparatus-Electrical Machinery
- IEC 61620 - Insulation coordination for equipment within low-voltage systems
- IEEE C57.152 - IEEE Guide for Diagnostic Field Testing of Fluid-Filled Power Transformers

Acceptance Criteria

Equipment Type	Voltage Level	Acceptable Tan δ	Action Required
Power Transformers	400 kV	$< 0.5\%$	$> 1.0\%$
Power Transformers	220 kV	$< 0.5\%$	$> 1.0\%$
Current Transformers	400 kV	$< 0.5\%$	$> 1.0\%$
Capacitive Voltage Transformers	400 kV	$< 0.5\%$	$> 1.0\%$
Shunt Reactors	400 kV	$< 0.5\%$	$> 1.0\%$

Table 6.3: Tan Delta Acceptance Criteria

Oil Tan Delta Limits

- New Oil: $< 0.05\%$ at $90C$
- Oil in Service: $< 0.5\%$ at $90C$
- Action Required: $> 1.0\%$ at $90C$

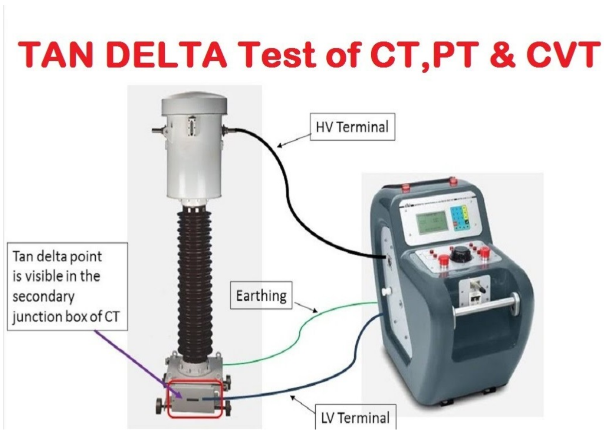

Figure 6.1: Tan Delta Test Equipment and Procedure

6.1.2 DCRM Test (Dynamic Contact Resistance Measurement)

We observed the DCRM testing process being conducted on circuit breakers at the switchyard. This diagnostic test assessed the condition of circuit breaker contacts during actual operation by measuring contact resistance as breakers opened and closed, applying controlled DC current through contacts during motion, and measuring voltage drop across contacts during dynamic operation.

Observation Process and Issues Identified

The testing process provided real-time assessment of contact condition and performance. During our observation, the team demonstrated detection of contact erosion through increased resistance measurements, misalignment identification causing uneven resistance and arcing, arcing issues that could damage contacts, and mechanical fault detection in breaker mechanisms. The maintenance team emphasized how this testing provides early fault detection, improves reliability, reduces downtime, and enables optimized maintenance scheduling.

Applicable Standards

- IEEE C37.09 - Circuit Breaker Test Procedures
- IEC 62271-100 - AC Circuit Breakers Standard
- CIGRE TB 510 - Final Report on Circuit Breaker Reliability Survey

Acceptance Criteria

Parameter	Acceptable Range	Action Required
Static Contact Resistance	$10 - 100\ \mu\Omega$	$> 200\ \mu\Omega$
Dynamic Resistance Profile	Smooth curve	Irregular spikes
Bounce Time	< 2 ms	> 5 ms
Arcing Duration	< 8 ms	> 15 ms
Contact Velocity	Per manufacturer spec	$\pm 20\%$ deviation

Table 6.4: DCRM Test Acceptance Criteria

6.2 CB Dynamic Test (Circuit Breaker Dynamic Test)

We observed comprehensive circuit breaker dynamic testing procedures at the switchyard. The technicians conducted these tests to evaluate the mechanical performance and operational characteristics of circuit breakers under actual operating conditions.

6.2.1 Our Observations Included

- Timing tests to verify proper opening and closing sequences
- Travel curve analysis to assess contact movement patterns

- Velocity measurements during breaker operation
- Assessment of mechanical wear and performance degradation

Applicable Standards

- IEEE C37.09 - Test Procedures for AC High-Voltage Circuit Breakers
- IEC 62271-100 - AC Circuit Breakers
- IEEE C37.04 - Rating Structure for AC High-Voltage Circuit Breakers

Timing Test Acceptance Criteria

Parameter	400 kV SF6 CB	220 kV SF6 CB	Action Required
Opening Time	$40 - 60$ ms	$35 - 50$ ms	Outside range
Closing Time	$60 - 90$ ms	$50 - 80$ ms	Outside range
Arcing Time	< 20 ms	< 15 ms	> 25 ms
Contact Travel	Per manufacturer	Per manufacturer	$\pm 10\%$ deviation
Velocity at Contact	Per manufacturer	Per manufacturer	$\pm 15\%$ deviation

Table 6.5: Circuit Breaker Dynamic Test Acceptance Criteria

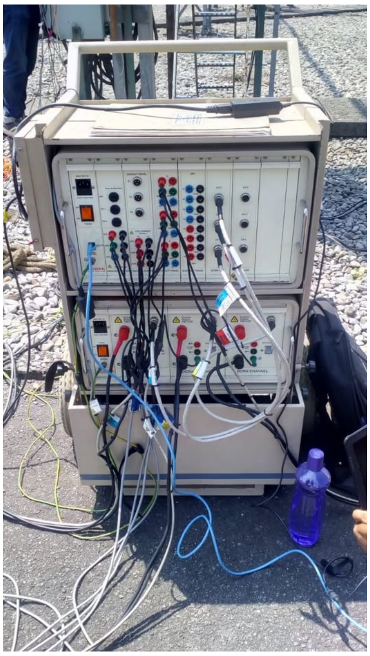

Figure 6.2: DCRM Test Setup and Measurement

6.3 Contact Resistance Measurement (CRM) Test

We witnessed static contact resistance measurement tests being performed on various electrical connections throughout the switchyard, including circuit breakers, busbars, and relay contacts.

6.3.1 What We Observed

- Technicians passing low DC current (typically 100A) through closed contacts
- Voltage drop measurements using precision micro-ohmmeters
- Resistance calculations using Ohm's Law (R = V/I)
- Identification of problematic connections and joints

6.3.2 Applications We Witnessed

- **Circuit breakers:** Testing main contact condition and performance
- **Busbars:** Ensuring proper joint connections and preventing overheating
- **Relay contacts:** Verifying proper operation and identifying contact degradation

The testing team emphasized how these measurements help prevent equipment damage, improve system reliability, and ensure operational safety.

Applicable Standards

- IEEE C37.09 - IEEE Standard Test Procedures for AC High-Voltage Circuit Breakers
- IEC 62271-100 - High-voltage switchgear and controlgear - AC circuit-breakers
- IEEE C37.04 - IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers

Acceptance Criteria

Equipment Type	Voltage Level	Acceptable Range	Action Required
SF6 Circuit Breakers	400 kV	$10 - 100\ \mu\Omega$	$> 200\ \mu\Omega$
SF6 Circuit Breakers	220 kV	$10 - 100\ \mu\Omega$	$> 200\ \mu\Omega$
Disconnectors/Isolators	400 kV	$20 - 150\ \mu\Omega$	$> 300\ \mu\Omega$
Bus Connections	All levels	$< 50\ \mu\Omega$	$> 100\ \mu\Omega$

Table 6.6: Contact Resistance Measurement Acceptance Criteria

Test Parameters

- Test Current: 100A, 200A, or 300A DC
- Phase-to-Phase Variation: $< 5\%$ acceptable
- Historical Comparison: $> 25\%$ increase indicates degradation

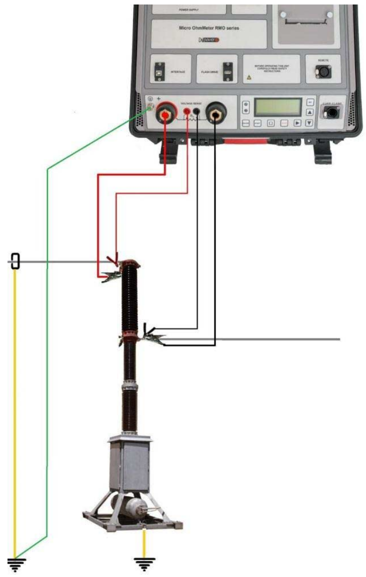

Figure 6.3: Contact Resistance Measurement Test Setup

6.3.3 General Notes

1. **Environmental Corrections:** All values should be corrected for temperature and humidity as per respective standards

2. **Trending:** Focus on trending rather than absolute values - 25% increase from baseline indicates investigation needed

3. **Manufacturer Specifications:** Always refer to manufacturer's specific limits which may be more stringent

4. **Seasonal Variations:** Some parameters may vary with seasons and should be considered during evaluation

5. **Combined Assessment:** No single test should be used for assessment - combination of multiple tests provides better diagnosis

Chapter 7

Key Observations and Learnings

During my visit to PGCIL Rourkela switchyard, I gained valuable insights into the comprehensive testing protocols that ensure power grid reliability. The systematic approach to testing, from pre-commissioning through routine maintenance, demonstrates the critical importance of proactive equipment monitoring and maintanance in power system operations.

7.1 Technical Insights

7.1.1 Equipment Design and Operation

- Understanding of high-voltage equipment design principles and their practical applications
- Appreciation of the complexity involved in managing 400/220 kV transmission systems
- Recognition of the importance of proper equipment selection and sizing for reliable operation

7.1.2 Testing Methodologies

- Comprehensive understanding of various diagnostic tests and their applications
- Learning about the correlation between test results and equipment condition
- Appreciation of the role of preventive maintenance in avoiding catastrophic failures

7.1.3 Safety Protocols

- First-hand experience of stringent safety measures in high-voltage environments
- Understanding of the critical importance of following established procedures
- Recognition of the potential consequences of safety violations

7.2 Operational Excellence

7.2.1 Maintenance Philosophy

The experienced technical team's dedication to thorough testing procedures and their willingness to share knowledge provided us with a deeper understanding of power grid testing methodologies and their practical applications in maintaining electrical system reliability.

7.2.2 Quality Assurance

- Systematic approach to equipment testing and maintenance
- Documentation and record-keeping practices
- Continuous improvement in testing procedures and techniques

7.2.3 Team Expertise

- High level of technical competence among the operational staff
- Commitment to professional development and knowledge sharing
- Strong emphasis on safety culture throughout the organization

Chapter 8

Conclusion

The summer internship at PGCIL Rourkela 400/220 kV substation provided an invaluable opportunity to gain practical exposure to high-voltage power transmission systems. The comprehensive study of substation operations, equipment specifications, and testing procedures has significantly enhanced our understanding of power grid reliability and maintenance practices.

8.1 Key Takeaways

8.1.1 Technical Knowledge

The internship provided deep insights into:

- High-voltage equipment design and operation principles
- Power system protection and control methodologies
- Advanced diagnostic testing techniques and their applications
- Grid stability and reactive power management through STATCOM systems

8.1.2 Professional Development

- Exposure to industry best practices and standards
- Understanding of the importance of continuous learning in the power sector
- Recognition of the critical role of power transmission in national infrastructure
- Appreciation of the challenges and responsibilities in power system operations

8.2 Future Implications

The knowledge and experience gained during this internship will be instrumental in:

- Pursuing advanced studies in power systems and electrical engineering.
- Contributing effectively to power sector projects and initiatives.
- Understanding the technical and operational challenges in power transmission.
- Developing innovative solutions for grid modernization and reliability improvement.