Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

A Comprehensive Analysis of 33/11kV Substation Maintenance and Testing

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***Abstract*—The 33/11kV substation plays a crucial role in stepping down high-voltage electricity for local distribution. Regular maintenance ensures the safety and reliability of power delivery systems. Testing identifies faults early, preventing major equipment failures and blackouts. It helps in minimizing down-time and improving the overall efficiency of the power grid. In this project, a condition-based maintenance approach is adopted, combining routine testing with diagnostic tools such as insulation resistance testers, relay test kits, and thermal imaging. The methodology begins with identifying critical components such as power transformers, circuit breakers, isolators, and relays. Each component is subjected to specific diagnostic tests, yielding data that is analyzed against standard threshold values to ensure improved reliability and safety.**

***Index Terms*—Substation maintenance, protective devices, condition-based maintenance, power transformers, vacuum circuit breakers, diagnostic testing.**

I. Introduction

A 33/11 kV substation is critical for stepping down high voltage for safe distribution. However, poor or irregular maintenance can lead to equipment failure, power outages, and safety risks. This project focuses on identifying such issues and exploring effective maintenance and testing methods to ensure reliable and efficient substation operation. By carrying out regular maintenance and testing, we can detect faults early, prevent equipment failures, reduce power outages, and extend the life of the equipment.

A. Need for Maintenance and Testing

Substation equipment is exposed to electrical, thermal, mechanical, and environmental stresses that can cause deterioration. Without timely and testing, minor issues can escalate into serious faults, leading to costly breakdowns or even electrical hazards. Maintenance and testing ensure not only uninterrupted supply but also the safety of the equipment and personnel.

B. Methodology

The work is done through a combination of book study, field visits, and discussions with professionals. Tools such as insulation resistance testers, relay testing kits, and transformer oil testing kits are studied. The project uses a condition-based maintenance approach, which checks the actual condition of equipment before planning maintenance. This method is more efficient than fixed-time maintenance, allowing for more accurate detection of faults and timely intervention.

C. System Configuration and Single Line Diagram (SLD)

The single line diagram (SLD) of the 33/11 kV Kalyan Nagar Substation illustrates the electrical layout and major components used for power transformation and distribution. The substation receives incoming 33 kV supply from multiple interconnections including Model SS, Kalyanagar, SCADA, and J.H. Hussain Sagar. Three power transformers (PTR-1, PTR-2, and PTR-3) step down the voltage from 33 kV to 11 kV.

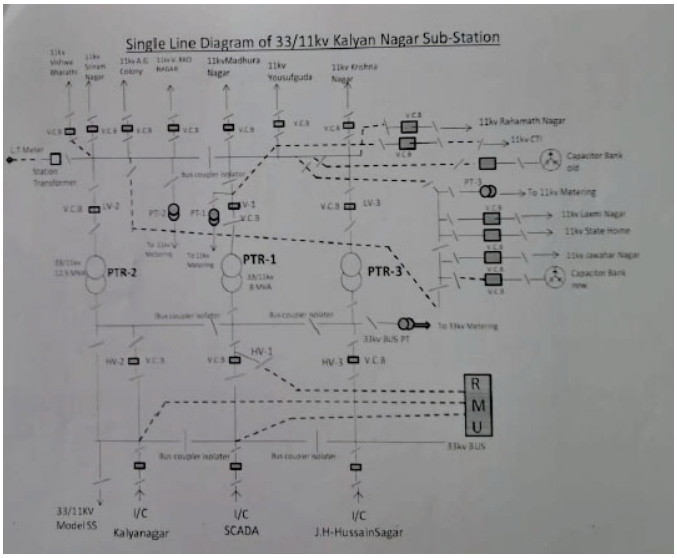

Fig. 1. Single line diagram of Kalyanagar substation.

The high-voltage (HV) side consists of vacuum circuit breakers (VCBs), isolators, and bus coupler isolators to ensure protection and sectional control. The low-voltage (LV) side supplies power to various 11 kV feeders such as Vishwa Bharathi, Sriram Nagar, A.G. Colony, and others, each protected by VCBs. Capacitor banks are installed on the 11 kV side to improve power factor and voltage stability.

II. Maintenance of Substation Equipments

Maintenance of substation equipment involves regular inspection, testing, cleaning, and servicing of key components

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 04 , April - 2026

such as transformers, circuit breakers, isolators, and relays. This ensures reliable operation, prevents faults, and extends equipment life.

A. Isolator

An isolator is a manually operated mechanical switch used in substations to ensure a section of the circuit is completely de-energized for maintenance or inspection. In a 33/11 kV substation, isolators are placed on both sides of circuit breakers and transformers. They are operated only when the circuit is already switched off, as isolators do not have arc-quenching capability. Regular maintenance tasks involve cleaning the insulators to eliminate dust and contaminants, verifying mechanical alignment, and examining contacts for signs of wear, corrosion, or overheating. Lubrication is applied to moving parts to guarantee smooth functionality.

Fig. 2. Substation Isolator.

B. Lightning Arrestor

A lightning arrester is a protective device used in substations to safeguard equipment from high-voltage surges caused by lightning or switching operations. When a surge occurs, the arrester diverts the excess voltage safely to the ground, preventing damage to the system. In a 33/11 kV substation, metal oxide gapless arresters are commonly used due to their fast response and high reliability. Routine checks include visual inspection for cracks, surface damage, or discoloration of the arrester body. The grounding system is checked to ensure it has low resistance for proper surge discharge.

C. Instrument Transformers

Instrument transformers are basically used for metering and relaying purposes.

1) Current Transformer (CT): CTs provide scaled-down current values for measuring instruments, relays, and protection devices. They convert large line currents into safe, low-level currents for easy monitoring and control. Maintenance includes examining the CT body for physical damage or oil leaks, conducting insulation resistance testing, and verifying that secondary wiring is securely fastened.

2) Potential Transformer (PT): A Potential Transformer steps down high voltages to lower, standardized levels (typically 110 V or 63.5 V) for accurate voltage measurement and protection. PTs are connected in parallel to the power line. Inspections involve checking for physical deformities and oil leakages. Voltage ratio tests are conducted to ensure the PT accurately steps down voltage, and proper grounding of the PT secondary is verified to ensure operational safety.

D. Busbars

A busbar is a metallic conductor used in substations to distribute power from incoming to outgoing circuits. In a 33/11 kV substation, it serves as a central point connecting transformers, circuit breakers, and feeders. Busbars should be visually checked for signs of physical damage, discoloration, or deformation. Dust, moisture, and bird droppings can lead to flashovers, so regular cleaning is essential. Infrared thermography is used to detect abnormal heating at joints and contact points.

E. Power Transformer

The power transformer steps up or down the voltage and transfers power from one A.C. voltage to another at the same frequency. A primary reason for using power transformers is to reduce power loss during transmission. The equation for power loss is given by:

$$P = I^2 R \tag{1}$$

Where I is the current and R is the resistance of the conductor. Lowering the magnitude of the current lessens power loss.

F. Circuit Breakers

A circuit breaker is a protective device designed to protect an electrical circuit from damage caused by overload or short circuit. Vacuum circuit breakers (VCBs) are generally preferred for 33kV systems, which are subjected to frequent faults. A VCB uses a vacuum as the arc quenching medium, which has high dielectric strength. Maintenance involves a vacuum bottle integrity test, where a 15 kV DC voltage is applied for 1 minute to check for leakage current. Contact resistance is checked to ensure it is typically $\leq 50\mu\Omega$, as high resistance indicates worn or dirty contacts.

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III. Testing of Substation Equipments

Testing a 33/11kV substation is a critical process to ensure the reliability, safety, and efficiency of the power distribution system.

A. Power Transformer Testing

Testing of power transformers is broken down into routine, type, and special tests.

1) Insulation Resistance (IR) Test: IR measurement checks the soundness of transformer solid insulation. IR measurements are taken between the windings to the body (earthed tank).

TABLE I
Insulation Resistance (IR) Measurements

Auto transformer	Two winding transformer	Three winding transformer
HV+IV to LV	HV to LV	HV+IV to LV
HV+IV to E	HV to E	HV+LV to IV
LV to E	LV to E	HV+IV+LV to E

Minimum IR values for 1-minute measurements can be determined using:

$$IR = \frac{CE}{\sqrt{KVA}} \tag{2}$$

Where $C = 1.5$ for oil-filled transformers at $20°C$, E is the voltage rating in volts, and KVA is the rated capacity.

TABLE II
General Guideline for Evaluation of Insulation

Polarization Index	Insulation Condition
Less than 1	Wet
1.0 - 1.1	Poor
1 - 1.1	Fair
1.25 - 2.0	Good
Above 2.0	Dry

2) Transformer Turns Ratio (TTR) Test: Verifies the voltage ratio between primary and secondary windings. It is conducted by applying voltage to the HV winding with the LV winding open. Acceptance criteria dictate the ratio must be within $\pm 0.5\%$.

3) Winding Resistance Test: Winding resistance checks the integrity of windings and connections. Winding temperature is calculated at $75°C$ using the following formula:

$$R75 = Rt \times \frac{235 + 75}{235 + t} \tag{3}$$

Where $R75$ is the resistance at $75°C$, Rt is the measured resistance, and t is the measured winding temperature.

4) Dielectric Strength Test (Oil Testing): This test verifies the insulating oil's ability to withstand voltage. Oil samples are collected and tested using a breakdown voltage (BDV) tester. The acceptance criteria require $BDV \geq 50kV$ for new oil and $\geq 30kV$ for in-service oil.

B. Circuit Breaker Testing

Circuit breakers protect the substation from faults and require strict testing regimens.

- **Contact Resistance Test:** A micro-ohmmeter is used to measure resistance across closed contacts, with acceptance criteria requiring resistance $< 100\mu\Omega$.
- **Timing Test:** A circuit breaker analyzer measures the time taken for open/close operations to verify mechanical integrity.
- **Insulation Resistance Test:** A 5kV megger is used to test IR between phases and phase-to-earth, requiring an IR $> 500M\Omega$.

C. Current Transformer Testing

CTs undergo Capacitance and Tan Delta measurements to evaluate solid insulation health. Tan delta measurements are taken in either UST mode (CTs with test tap) or GST mode (CTs without test tap). The Tan delta value should not increase by more than 0.1% per year. Additionally, Magnetization Characteristics are tested to determine the Knee Point Voltage, ensuring saturation levels align with design values.

D. Busbar and Isolator Testing

Busbar insulation resistance should measure $> 500M\Omega$ at 5kV between the busbar and earth, while contact resistance should be $< 50\mu\Omega$ at joints. For isolators, contact resistance is similarly tested and should measure between 50-100 $\mu\Omega$ across closed contacts.

IV. Results and Conclusions

A. Results

After carrying out maintenance and testing in the 33/11 kV substation, all major equipment such as transformers, circuit breakers, isolators, CTs, PTs, and lightning arresters were found to be in healthy condition. Test results like insulation resistance, contact resistance, and oil BDV values were within acceptable limits, indicating good operational status. Mechanical parts like isolator blades and breaker mechanisms were cleaned, lubricated, and functioned smoothly during tests. Protective relays responded accurately during simulated fault conditions.

B. Conclusion

The maintenance and testing of the 33/11 kV substation have helped ensure the reliable and safe operation of all equipment involved in power distribution. Regular checks and testing revealed that the equipment is functioning within standard limits. Issues like dust accumulation, minor misalignments, or contact wear were identified and corrected during the maintenance process. These activities reduce the chances of unexpected breakdowns and improve the overall performance of the substation. This project highlights the importance of timely preventive maintenance in ensuring uninterrupted power supply and protecting valuable electrical infrastructure.

International Journal of Engineering Research & Technology (IJERT)
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