Operational Reliability Enhancement of 33/11 kV Substations through Preventive Maintenance

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Abstract

The 33/11 kV distribution substation plays a vital role in delivering reliable electrical power by stepping down high-voltage electricity for local distribution. Proper maintenance and testing are essential to ensure system safety, reliability, and uninterrupted power supply. This project focuses on the implementation of condition-based maintenance for a 33/11 kV substation to improve operational performance and reduce unexpected failures. Critical substation components such as power transformers, circuit breakers, isolators, and protective relays were identified and subjected to diagnostic tests, including insulation resistance, contact resistance, oil dielectric strength, relay testing, and thermal imaging. Test results were analyzed against standard threshold values to assess equipment condition and detect faults at an early stage. The application of condition-based maintenance enabled timely intervention, reduced unplanned outages, enhanced system reliability, and extended equipment lifespan. Although the approach requires advanced testing equipment and skilled personnel, its long-term benefits significantly outweigh the initial costs, making it an effective strategy for ensuring safe and efficient substation operation.

Keywords: 33/11 KV, operational reliability, preventive, substations.

Introduction

The 33/11 kV distribution substation is a critical link between high-voltage transmission systems and low-voltage distribution networks. It plays a key role in delivering electrical power safely and reliably to residential, commercial, and industrial consumers. The continuous and efficient operation of substation equipment is essential to ensure uninterrupted power supply and overall power system stability [1].

Substation components such as power transformers, circuit breakers, isolators, and protective relays are subjected to various electrical, thermal, mechanical, and environmental stresses during operation. Over time, these stresses can cause insulation degradation, contact wear, overheating, and mechanical failures. If not identified and addressed at an early stage, minor defects may develop into serious faults, leading to equipment damage, power outages, or safety hazards.

Regular maintenance and systematic testing are therefore essential to monitor equipment condition, detect hidden faults, and prevent unexpected failures [2]. Effective maintenance practices help improve system reliability, reduce downtime, extend equipment lifespan, and ensure the safety of operating personnel [3]. In recent years, condition-based maintenance techniques have gained importance due to their ability to identify potential issues through diagnostic testing rather than relying solely on time-based schedules [4].

This research focuses on the maintenance and testing of a 33/11 kV substation, emphasizing practical testing methods and condition-based maintenance strategies [5]. The study aims to bridge the gap between theoretical knowledge and real-world applications, demonstrating how proper maintenance and testing contribute to reliable power distribution and sustainable electrical infrastructure [6].

Maintenance of substation equipment is essential to ensure the safe, reliable, and continuous operation of the power distribution system. Regular inspection, testing, cleaning, and servicing of critical components such as power transformers, circuit breakers, isolators, and protective relays help in preventing faults, minimizing outages, and extending the service life of equipment [7]. Routine maintenance activities include transformer oil level checks, insulation resistance testing, contact resistance measurement of circuit breakers, and calibration of protective devices. The adoption of preventive and predictive maintenance practices plays a vital role in maintaining system reliability and ensuring compliance with safety standards [7].

Among the various substation components, isolators play a crucial role in ensuring operational safety. An isolator is a manually operated mechanical switching device used to disconnect a part of the electrical circuit from the power source [8]. In a 33/11 kV substation, isolators are installed on both sides of circuit breakers and transformers to provide complete electrical isolation during maintenance or inspection [9]. Unlike circuit breakers, isolators are operated only under no-load conditions, as they do not possess arc-quenching capability [10].

Figure :1 Isolator

The primary function of an isolator is to provide visible isolation, ensuring the safety of maintenance personnel working on high-voltage equipment [11]. Proper operation and maintenance of isolators enhance operational flexibility and reduce the risk of electrical hazards [12]. This study emphasizes the importance of effective maintenance practices and highlights the role of isolators in maintaining safe and reliable substation operations [13].

Literature survey

Proper maintenance of isolators in a 33/11 kV substation is vital to ensure safe switching operations and dependable equipment performance. Maintenance activities include thorough cleaning of insulator surfaces to remove dust, dirt, and other contaminants that may affect insulation quality [14]. The mechanical parts of the isolator are inspected to confirm correct alignment, smooth movement, and secure locking during operation [15]. Contact points are checked for signs of erosion, corrosion, or excessive heating, which can lead to arcing and reduced efficiency. All fasteners, including nuts, bolts, and electrical joints, are tightened to prevent loosening caused by mechanical stress or temperature variations. Moving components are lubricated periodically to ensure smooth operation and to reduce wear. Regular maintenance of isolators improves reliability, enhances safety for operating personnel, and ensures effective electrical isolation during substation maintenance work.

Figure :2 Lightning arrester

Instrument transformers are primarily used in substations for metering and protection purposes. In a 33/11 kV substation, the commonly used instrument transformers are the Current Transformer (CT) and the Potential Transformer (PT). These transformers enable safe and accurate measurement of electrical quantities by stepping down high current and voltage levels to manageable values suitable for measuring instruments and protective relays.

Current transformers are widely used to measure high currents flowing through power lines in a substation. They provide reduced current values that can be safely utilized by meters, relays, and protection devices. By converting large line currents into standardized low-level currents, CTs ensure accurate monitoring and effective control of the power system. Current transformers are connected in series with the power circuit and are typically installed on feeders, transformers, and circuit breakers. They play a critical role in the proper functioning of metering systems and protective schemes within the substation.

A Potential Transformer (PT), also known as a Voltage Transformer (VT), is an instrument transformer used in substations to reduce high system voltages to standardized low values, typically 110 V or 63.5 V, for safe measurement and protection purposes. PTs provide electrical isolation between high-voltage power circuits and low-voltage control and metering equipment.

PTs are connected in parallel with the power line and are widely used for voltage measurement, energy metering, synchronization, and operation of protective relays. In a 33/11 kV substation, PTs play a crucial role in monitoring system voltage levels, detecting abnormal conditions such as overvoltage or undervoltage, and supporting reliable relay operation.

By delivering accurate and stable secondary voltage, PTs ensure the proper functioning of control panels, indication instruments, and protection schemes. They contribute to improved system stability, enhanced operational safety, and effective voltage isolation. Proper installation, calibration, and maintenance of PTs are essential to maintain measurement accuracy and ensure dependable substation operation.

Methodlology

Testing of a 33/11 kV substation is a vital activity to ensure safe, reliable, and efficient power distribution. The primary function of a 33/11 kV substation is to reduce transmission-level voltage (33 kV) to distribution-level voltage (11 kV) for supply to consumers. The substation consists of major equipment such as power transformers, circuit breakers, isolators, busbars, current transformers (CTs), potential transformers (PTs), lightning arresters, and control panels. Regular testing helps identify hidden defects, verify equipment performance, and prevent unexpected failures that may lead to power outages or safety hazards.

Figure: 3 power transformers

Power transformers are the most critical and expensive components in a substation. Proper testing ensures their reliable operation and long service life. Transformer testing is broadly classified into routine, type, and special tests. Routine tests are carried out to verify the electrical performance and insulation condition of the transformer during operation and maintenance.

Ratio and Polarity Test:

This test confirms the correctness of the transformer turns ratio and ensures proper polarity between primary and secondary windings, which is essential for parallel operation and accurate voltage transformation.

Load Loss Test:

Load loss testing determines copper losses in the transformer windings under rated current conditions. These losses affect efficiency and heating of the transformer.

Impedance Measurement:

Impedance measurement helps in determining short-circuit current levels and voltage regulation of the transformer. It also indicates winding deformation or faults.

Insulation Resistance Test:

This test evaluates the condition of insulation between windings and between windings and earth. Low insulation resistance indicates moisture, aging, or insulation damage.

Winding Resistance Test:

Winding resistance measurement checks for loose connections, broken strands, or winding defects that can cause overheating.

No-Load Loss Test:

This test measures core losses when the transformer is energized without load, providing information about core condition and efficiency.

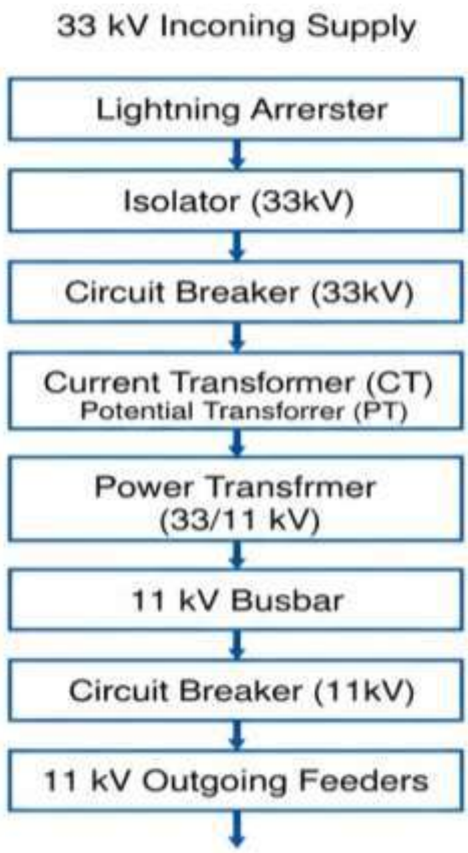

Figure: 4 proposed model block diagram

Insulation resistance (IR) measurements shall be carried out between the transformer windings and the earthed tank (body). For this purpose, all windings on each voltage level high voltage (HV), intermediate voltage (IV), and low voltage (LV)b shall be individually short-circuited. The following insulation resistance measurements shall then be performed.

Table :1Insulation 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

Results and discussions

Following the completion of maintenance and testing activities at the 33/11 kV substation, all major equipment including power transformers, circuit breakers, isolators, current transformers (CTs), potential transformers (PTs), and lightning arresters were found to be in satisfactory operating condition. Test parameters such as insulation resistance, contact resistance, and transformer oil breakdown voltage (BDV) were within prescribed limits, indicating reliable electrical performance. Mechanical components, including isolator arms and circuit breaker operating mechanisms, were thoroughly cleaned, properly lubricated, and operated smoothly during functional tests. Protective relays demonstrated accurate and timely response under simulated fault conditions. Overall, the results confirmed that the substation equipment is safe, efficient, and well-prepared for dependable power distribution, with a significantly reduced risk of operational failure.

This project, titled "33/11 kV Substation Design," was conducted at the 33/11 kV Kalyannagar Substation under the Central Power Institute of Technology to study the practical implementation of various substation tools and equipment. The project involved detailed visits to the substation and close observation of real-time operations under the guidance of experienced professionals, ensuring a thorough understanding of the processes involved.

The maintenance and testing activities carried out at the substation were crucial in ensuring the safe and reliable operation of all power distribution equipment. Regular inspections of transformers, circuit breakers, isolators, current transformers (CTs), potential transformers (PTs), and protective relays confirmed that all equipment was functioning within standard limits. Minor issues, such as dust accumulation, slight misalignments, or contact wear, were identified and promptly corrected during maintenance.

These preventive measures not only reduce the likelihood of unexpected breakdowns but also enhance the overall performance and longevity of the substation. This project emphasizes the critical role of timely preventive maintenance in maintaining uninterrupted power supply and safeguarding valuable electrical infrastructure.

Conclusion and future scope

The study and practical exposure to the 33/11 kV Kalyannagar Substation provided valuable insights into the design, operation, and maintenance of high-voltage substations. Observing real-time operations and performing maintenance checks highlighted the importance of preventive maintenance, testing, and timely inspection in ensuring the reliability and safety of electrical equipment. Regular monitoring of transformers, circuit breakers, isolators, CTs, PTs, and protective relays helps detect minor issues early, preventing major breakdowns and improving overall system efficiency. This project reinforces the significance of well-maintained substations in delivering uninterrupted power supply and protecting critical electrical infrastructure. The hands-on experience gained has enhanced practical knowledge and understanding of substation operations, which is essential for future work in the power distribution sector.

References

[1] TSTRANSCO & TSSPDCL. (n.d.). *Manuals and guidelines for Telangana substations*. Telangana State Transmission Corporation and Telangana State Southern Power Distribution Company Limited.

[2] International Electrotechnical Commission. (2013). *IEC 61869-1: Instrument transformers – Part 1: General requirements* and *IEC 61869-3: Instrument transformers – Part 3: Additional requirements for current transformers*. IEC.

[3] International Electrotechnical Commission. (2013). *IEC 61850: Communication networks and systems for power utility automation*. IEC.

[4] McDonald, J. D. (2012). *Electric power substations engineering* (3rd ed.). CRC Press.

[5] Krieg, T., & Finn, J. (Eds.). (2018). *Substations*. Springer Cham.

[6] IEEE Standards Association. (2018). *IEEE Std 80™-2000: Guide for safety in AC substation grounding*. IEEE.

[7] IEEE Standards Association. (2018). *IEEE Std 693: Recommended practice for seismic design of substations*. IEEE.

[8] IEEE Standards Association. (2023). *Guide for bus design in air-insulated substations (IEEE Std 605)*. IEEE.

[9] National Electrical Safety Code. (n.d.). *ANSI C2-NESC: National Electrical Safety Code*. IEEE.

[10] Stevenson, W. D. (1994). *Power system analysis* (3rd ed.). McGraw-Hill.

[11] Overbye, T. J., Glover, J. D., & Sarma, M. S. (2016). *Power system analysis and design* (6th ed.). Cengage Learning.

[12] Blackburn, J. L., & Domin, T. A. (2007). *Protective relaying: Principles and applications* (4th ed.). CRC Press.

[13] Gill, P. (2013). *Electrical power equipment maintenance and testing*. McGraw-Hill.

[14] Kariuki, C. K. (2025). *Design for 33/11 kV power substation, distribution and protection in the city of Nairobi* (Unpublished thesis). University of Nairobi.

[15] *Field observations at 33/11 kV substations (e.g., Kalyan Nagar Substation)*. (2026). Personal practical experience.