Proactive Measures for Moisture Control in Transformer Manufacturing to Ensure Reliability

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Abstract: *This study explores advancements in power system grids with a focus on enhancing capacity, voltage capabilities, and introducing smart functionalities for sustainable and reliable power delivery. The study delves into the crucial role of power transformers within these grids, highlighting their importance in maintaining system reliability and efficiency. Additionally, it investigates the concept of resilience in power systems, emphasizing the need for robust systems capable of withstanding various disruptions. Preventive measures for prolonging the lifespan of grid equipment and ensuring the quality of power transformers through stringent testing protocols are also examined. Furthermore, the research addresses the challenges of maintaining moisture levels during the transformer manufacturing process, proposing improved quality assurance practices and preventive strategies.*

Keywords: *Power system grids, Power transformers, System resilience, Quality assurance, Smart functionalities, Testing protocols.*

I. INTRODUCTION

The progression of technology has opened doors for fresh innovations and ingenuity in ensuring a consistent and sustainable power supply through the deployment of power system grids. These grids boast features such as increased capacity, high to ultra-voltage capabilities, smart functionality, minimal power wastage, dependable monitoring, and communication capabilities. These enhancements significantly bolster reliability for end-users. Power utility companies are under considerable pressure to reduce operational expenses and improve the availability of power system assets, necessitating the continual delivery of high-quality power and services to consumers. One approach for power utilities to cut operational costs involves prolonging the lifespan of aging grid equipment, particularly power transformers, which are essential components. Nevertheless, the escalating demand for electrical power, particularly in industrious developing nations, has resulted in the overloading of power transformers. Consequently, the risk of equipment failure escalates as they endure more rigorous operating conditions [1].

A. Power Transmission Line

The power transmission line plays a vital role in the utility grid, serving as the backbone for transferring bulk power from generating stations to load centers to meet the substantial demand for electrical power. Since 1945, there has been a significant expansion in both the length and number of transmission lines [8]. Frequent faults on these lines can result in power supply interruptions and damage to customer equipment [9]. Hence, the swift detection and accurate estimation of fault locations are crucial for promptly clearing faults and ensuring the swift restoration of power supply. To address this, various techniques and schemes have been developed for detecting, classifying, and estimating fault locations on transmission lines.

Fig. 1.1 Diverse optimization objectives for enhancing power system performance [11]

B. Power System Resiliency

The concept of "resilience," relatively novel in power system discourse, stems from the Latin term "resilio." First applied to ecological systems by Holing in 1973, resilience refers to a system's capacity to sustain its functionality in the face of disturbances. Over time, scholars have further nuanced this definition through a series of research endeavours, as elucidated in the following discourse [15]:

- In 1995, the concept of a resilient system expanded to include a buffering capability, allowing for the timely absorption of disturbances.
- In 2003, the definition of a resilient system was further enhanced to incorporate a self-healing capability, enabling the system to recover autonomously during disturbances.

C. Power Transformer

The power transformer is a critical and costly component in a power system network, often regarded as the most expensive static device. Any malfunction or failure of this equipment can result in significant losses [22]. Given its high cost, this electrical device must operate flawlessly for prolonged periods. Serving as a fundamental component in high-voltage power systems, its reliability is paramount for system operation [23][24]. The insulation condition of a power transformer is crucial and significantly influences its lifespan [24]. Hence, the monitoring of this device's condition is imperative for ensuring a reliable and uninterrupted power supply [22][25].

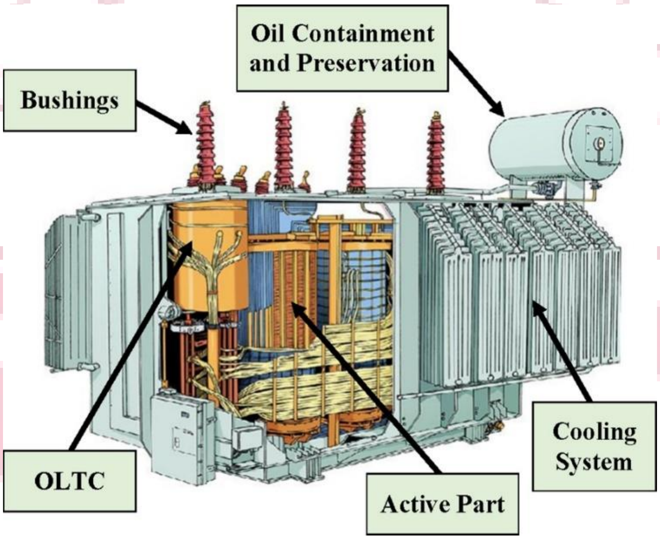


Fig. 1.2 Subsystems of a power transformer [26]

As detailed in the Energy Production and Consumption Revolution Strategy 2016–2030 [27], China has set a goal to derive 50% of its total electric power from non-fossil energy sources by 2030 [27]. However, a significant portion of renewable energy sources is concentrated in the northern and western regions of China. Hence, the transmission of electric power over long distances from these renewable sources becomes essential. To tackle this challenge, China has constructed ultrahigh voltage grids to connect the northern and western electric power sources with the densely populated eastern region. In the foreseeable future, the electric power grid will need to adapt to the integration of numerous new sources of generation and consumption, many of which operate in DC, such as photovoltaic (PV) systems, variable-speed wind turbines, electric vehicles (EVs), energy storage systems (ESS), and new electric loads in domestic or industrial applications [30,31]. Consequently, the incorporation of hybrid AC/DC grids in power distribution networks seems to be a component of future Smart Grid (SG) implementations. DC grids offer various advantages [32]:

- Enhanced control over voltage levels.
- Improved overall system efficiency.
- Increased power transmission capacity to accommodate more Distributed Energy Resources (DERs), Electric Vehicles (EVs), etc.
- Direct connections between DC/DC converters, leading to a more efficient and streamlined network.
- Longer supply connections without compromising power quality.
- Enhanced network resilience and problem management capabilities.
- Economical advantages of DC grids over AC grids in certain applications.
- Facilitation of the implementation of environmentally-friendly solutions and the utilization of more sustainable resources in production and operation.

D. Objectives of the study

- To analyse the evolution of power system grids, focusing on increased capacity, high to ultra-voltage capabilities, and smart functionalities.

- To study the concept of resilience in power systems, identifying critical factors that enhance system robustness against disruptions, including global pandemics and extreme events.

II. LITERATURE REVIEW

Kana Takenaka et al. (2015): This study explores the use of NANOMET®, an Fe81.2Co4Si0.5B9.5P4Cu0.8 alloy, for electrical power applications. A prototype transformer with a toroidal core was developed, showing low core loss and promising potential for power transformer applications despite challenges during core annealing and nano-crystallization.

Luca Benedetto et al. (2021): This research focuses on estimating question difficulty using advanced NLP models, particularly Transformers. The study demonstrates that these models outperform previous methods, especially when additional related documents are provided.

Victor A. Primo et al. (2019): The study investigates the stability of dielectric nanofluids in transformer operational environments, highlighting the importance of operating temperature, fluid composition, and manufacturing techniques on the stability of these fluids.

Dhruvesh M. Mehta et al. (2016): This research evaluates natural ester oils versus traditional mineral oils for transformer applications. It emphasizes the eco-friendly and safety aspects of natural esters, exploring their environmental impact, fire safety, and dielectric characteristics.

R. Behkam (2023): The study proposes using Frequency Response Analysis (FRA) combined with Artificial Neural Network (ANN) techniques for detecting faults in power transformers, enhancing the accuracy of fault identification.

Amol Deshpande (2019): This research introduces a modular dc-ac three-level T-type single-phase-leg power electronics building block (PEBB), highlighting its efficiency and potential for electric propulsion systems in more-electric aircraft.

Konstanty Marek Gawrylczyk (2019): The study presents a method for modeling transformer winding inductance, utilizing finite element method (FEM) and Frequency Response Analysis (FRA) measurements, improving the accuracy of transformer models.

Zhu, N. et al. (2023): The research develops an electromagnetic solid mechanics coupled finite element model for simulating the transient evolution of winding faults in transformers, offering insights into fault detection and preventive maintenance.

Babagana Ali Dapshima (2023): This study utilizes fuzzy logic for fault detection and protection in power transformers, demonstrating its effectiveness in rapidly identifying electrical faults and mechanical failures to prevent damage and reduce maintenance costs.

III. PROBLEM INVESTIGATION & ANALYSIS

The power transformer stands as a cornerstone within the power system, playing a pivotal role in determining the overall reliability of the associated unit. Its significance lies not only in its functionality but also in its efficiency and longevity. Manufacturers undertake meticulous measures to ensure the utmost quality and performance of these transformers. Beginning with the design phase, manufacturers employ proven methodologies and techniques to develop transformers that meet stringent standards and specifications. This includes comprehensive quality management systems implemented throughout the entire manufacturing process. From the sourcing of raw materials to the final testing phase, every step is meticulously planned and executed to uphold quality standards.

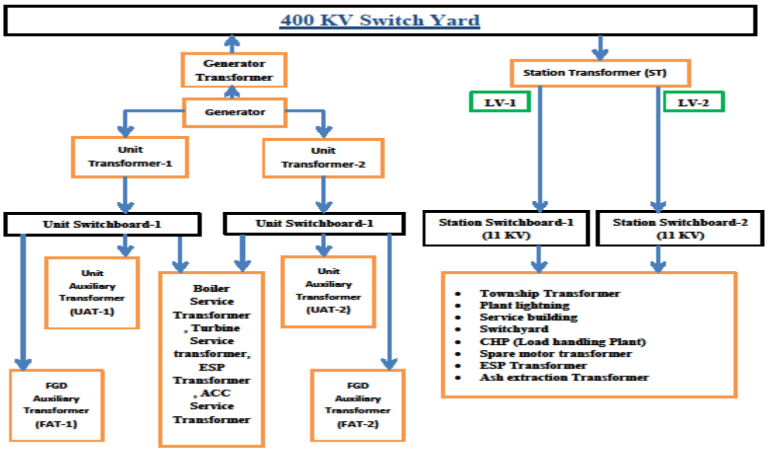


Fig. 1 Different type of transformer in thermal power plant (General layout)

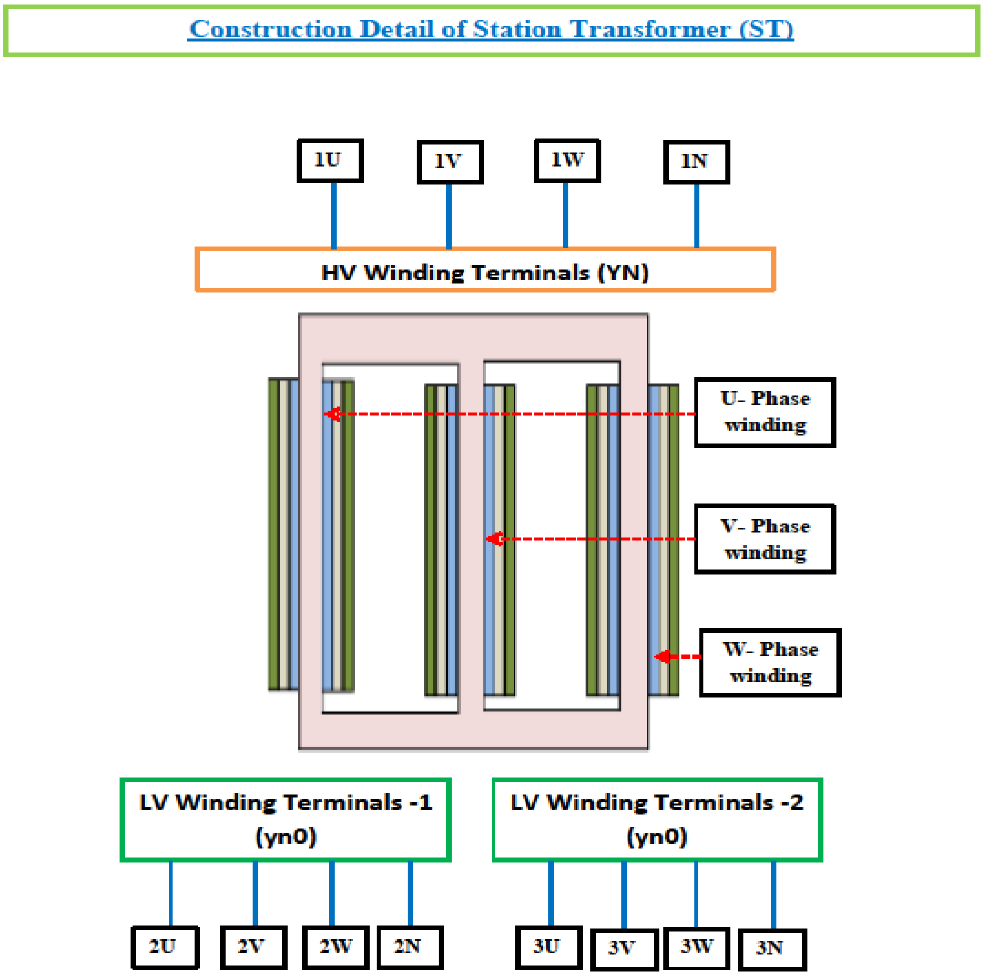


Fig. 2 Construction Detail of station transformer (ST)

A. Problem Description

Station Transformer successfully passed following tests;

The testing procedures listed are integral to assessing the functionality and reliability of power transformers. Firstly, the measurement of winding resistance evaluates the integrity of the transformer windings, detecting any abnormalities that could indicate faults. Secondly, the measurement of voltage ratio and polarity confirms that the transformer operates within specified parameters and aligns with the system's requirements to prevent phase discrepancies. The magnetic balance test ensures the distribution of magnetic flux within the core is optimal for efficient performance. Measuring magnetizing current assesses the core's saturation levels to prevent overheating and losses. Insulation resistance and polarization index measurements evaluate the insulation's ability to withstand electrical stresses and detect moisture or contamination. Additionally, the measurement of no-load losses and current provides insights into energy efficiency, while load loss and impedance measurements assess performance under load conditions. Finally, the separate source test evaluates the transformer's ability to withstand abnormal operating conditions, ensuring reliable operation even under adverse circumstances. Overall, these tests are critical for ensuring the quality, reliability, and safety of power transformers in electrical power distribution systems.

B. Test Data

Table 3.3 Measurement of winding Resistance

Temperature (Top) 32 ^{0}C		Temperature (Bottom) 31. ^{0}C	
Winding Resistance (HV/N)			
Tap	Measured Winding Resistance, Ohm		Resistance at 75^{0} C (Ohm)

Position	'U' Phase	'V' Phase	'W' Phase	Measured Average Resistance (Ohm)	
	1U-1N	1V-1N	1W-1N		
1(Max.)	1.4634	1.4617	1.4687	1.4646	1.7165
2	1.4355	1.4337	1.4405	1.4366	1.6837
3	1.4089	1.4072	1.4136	1.4099	1.6524
4	1.3810	1.3792	1.3854	1.3819	1.6196
5	1.3544	1.3529	1.3586	1.3553	1.5884
6	1.3264	1.3250	1.3302	1.3272	1.5555
7	1.2997	1.2987	1.3034	1.3006	1.5243
8	1.2716	1.2709	1.2750	1.2725	1.4914
9 (Nor.)	1.2421	1.2408	1.2436	1.2422	1.4559
10	1.2714	1.2708	1.2744	1.2722	1.4910
11	1.2979	1.2972	1.3013	1.2988	1.5222
12	1.3262	1.3252	1.3299	1.3271	1.5554
13	1.3528	1.3516	1.3567	1.3537	1.5866
14	1.3810	1.3796	1.3852	1.3819	1.6196
15	1.4077	1.4057	1.4121	1.4085	1.6508
16	1.4360	1.4335	1.4406	1.4367	1.6838
17 (Min.)	1.4642	1.4615	1.4691	1.4649	1.7169

The recorded values provide valuable insights into the variation of winding resistance across different tap positions and phases, allowing engineers and technicians to assess the transformer's condition and make informed decisions regarding its operation and maintenance. Additionally, the resistance values at 75°C offer crucial data for evaluating the transformer's performance under normal operating temperatures. Overall, these measurements contribute to ensuring the reliability and efficiency of the transformer in electrical power distribution systems.

Table 3.4 Measurement of Winding Resistance for LV1/N Tap Position

Winding Resistance (LV1/N)					
Tap Position	Measured Winding Resistance, Ohm			Measured Average Resistance (Ohm)	Resistance at 75^0 C (Ohm)
	'U' Phase	'V' Phase	'W' Phase		
	2U-2N	2V-2N	2W-2N		
-	0.002067	0.002097	0.002131	0.002098	0.002459

The provided data presents measurements of the winding resistance for the low-voltage (LV1/N) section of a transformer at a specific tap position. At tap position 2, the measured winding resistance values for each phase (U, V, W) are recorded, along with the average resistance and the resistance at 75°C. These measurements are crucial for assessing the health and performance of the transformer's LV1/N winding. For the U, V, and W phases, the measured winding resistance values are 0.002067 Ohm, 0.002097 Ohm, and 0.002131 Ohm, respectively. These values provide insights into the electrical characteristics of the transformer's winding at tap position 2. Additionally, the average resistance across all phases is calculated as 0.002098 Ohm, indicating the overall resistance of the winding at this tap position.

Furthermore, the resistance at 75°C is recorded as 0.002459 Ohm, which offers valuable information about the winding's performance under normal operating temperatures. This data is essential for evaluating the transformer's efficiency and reliability in electrical power distribution systems. To sum up, the provided measurements of winding resistance at tap position 2 for the LV1/N section of the transformer contribute to the comprehensive assessment of its condition and aid in making informed decisions regarding its operation and maintenance.

Table 3.5 Winding resistance measurement for LV2/N tap position

Winding Resistance (LV2/N)					
Tap Position	Measured Winding Resistance, Ohm			Measured Average Resistance (Ohm)	Resistance at 75^0 C (Ohm)
	‘U’ Phase	‘V’ Phase	‘W’ Phase		
	3U-3N	3V-3N	3W-3N		
-	0.002039	0.002047	0.001985	0.002024	0.002372

The provided table outlines the winding resistance measurements for the low-voltage (LV2/N) section of a transformer at a specific tap position. Recorded at tap position 3, the winding resistance values for each phase (U, V, W) are documented, along with the average resistance and the resistance at 750°C. These measurements offer valuable insights into the electrical characteristics and performance of the transformer's LV2/N winding.

C. Measurement of Voltage ratio

HV/LV1

Table 3.6 Measured values of winding resistance with tolerance range

Tap Position	Specified ratio	U Phase (1U-1N/2U-2N)	V Phase (1V-1N/2V-2N)	W Phase (1W-1W/2W-2W)	
1 (Max.)	38.261	38.281	38.299	38.313	All measured values are within + 0.5% tolerance of the specified values.
2	37.826	37.841	37.861	37.857	
3	37.391	37.415	37.435	37.451	
4	36.957	36.981	36.987	36.015	
5	36.922	36.575	36.579	36.575	
6	36.087	36.107	36.139	36.139	
7	35.652	35.699	35.717	35.721	
8	35.217	35.251	35.261	35.289	
9 (Nor.)	34.783	34.813	34.821	34.839	
10	34.348	34.365	34.381	34.381	
11	33.913	33.949	33.963	33.981	

12	33.478	33.493	33.509	33.531	
13	33.043	33.085	33.111	33.119	
14	32.609	32.647	32.657	32.672	
15	32.174	32.222	32.250	32.253	
16	31.739	31.781	31.797	31.821	
17 (Min.)	31.304	31. 343	31.358	31.375	

The provided data presents the specified ratio and measured values for different tap positions of a transformer across its U, V, and W phases. These measurements are crucial for ensuring the transformer operates within specified tolerances and meets performance standards. All measured values are noted to be within +0.5% tolerance of the specified values, indicating compliance with the required specifications.

At tap position 1 (Max.), the specified ratios for the U, V, and W phases are 38.261, 38.281, and 38.299, respectively. The measured values for these phases closely align with the specified ratios, ensuring consistency and accuracy in the transformer's performance. Similarly, at tap position 17 (Min.), the specified ratios for the U, V, and W phases are 31.304, 31.343, and 31.358, respectively. The measured values for these phases also fall within the specified tolerances, indicating that the transformer maintains its desired performance even at the minimum tap position. Throughout the various tap positions, including those ranging from the maximum to the minimum, the measured values for the U, V, and W phases demonstrate consistent adherence to the specified ratios. This consistency reflects the transformer's ability to maintain stable and reliable electrical characteristics across a range of operating conditions.

In summary, the measured values of the specified ratios for different tap positions confirm the transformer's adherence to performance standards and ensure its reliable operation within the specified tolerances. This data is essential for verifying the transformer's performance and ensuring its suitability for its intended application.

HV/LV2

Table 3.7 Measured values of winding resistance with tolerance range

Tap Position	Specified ratio	U Phase (1U-1N/3U-3N)	V Phase (1V-1N/3V-3N)	W Phase (1W-1W/3W-3W)	
1(Max.)	38.261	38.267	38.295	38.313	All measured values are within + 0.5% tolerance of the specified values.
2	37.826	37.851	37.845	37.873	
3	37.391	37.409	37.443	37.449	
4	36.957	36.983	37.001	37.001	
5	36.522	36.569	36.573	36.599	
6	36.087	36.117	36.131	36.441	
7	35.652	35.685	35.731	35.739	
8	35.217	35.255	35.267	35.287	
9 (Nor.)	34.783	34.805	34.825	34.839	
10	34.348	34.369	35.395	34.393	
11	33.913	33.945	33.969	33.983	
12	33.478	33.511	33.529	33.539	
13	33.043	33.099	33.109	33.119	
14	32.609	32.637	32.657	32.668	
15	32.174	32.222	32.241	32.260	

16	31.739	31793	31.801	31.822	
17 (Min.)	31.304	31.335	31.260	31.375	

LV1/LV2

Specified ratio	U Phase (2U-2N/3U-3N)	V Phase (2V-2N/3V-3N)	W Phase (2W-2W/3W-3W)	All measured values are within + 0.5% tolerance of the specified values.
1.000	1.0015	1.0010	1.0013	

Table 3.8 Magnetic balance test

Magnetic Balance Tast carried out on HV					
Single Phase AC Voltage to		Voltages were measured across			
1U-1N	232. 5 Volts	1V-1N	218.7 Volts	1W-1N	13.3 Volts
1V-1N	231.7 Volts	1W-1N	88.5 Volts	1U-1N	144.5 Volts
1W-1N	232.3 Volts	1U-1N	13.7 Volts	1V-1N	220.4 Volts

Table 3.9 Measurement of magnetizing current at low voltage

Three phase AC voltage applied across LV1 Terminals			
2U, 2V, 2W = 399V, 400V, 398V			
	Current in milli Amp		
	2U-Phase	2V-Phase	2W-Phase
LV1	176	152	237

Three phase AC voltage applied across LV2 Terminals			
3U, 3V, 3W = 409V, 405V, 405V			
	Current in milli Amp		
	3U-Phase	3V-Phase	3W-Phase
LV2	143	242	173

D. Measurement of Insulation Resistance (Before and after dielectric test)

Table 3.10 Measurement of insulation resistance before dielectric test

Insulation resistance in mega Ohms (By 5.0 kV Megger)				
Temperature : 43.00 ^{O}C				
Between	15 Seconds	60 Seconds	600 Seconds	PI
HV/LV1+LV2+E	2170	3800	7980	2.10
LV1/HV+LV2+E	3250	4160	11640	2.80
LV2/HV+LV1+E	3160	5230	15160	2.90

HV/LV1	5340	6420	16050	2.50
HV/LV2	6080	8540	19640	2.30
LV1/LV2	7130	12650	26560	2.10

After dielectric test

Insulation resistance in mega Ohms (By 5.0 kV Megger)				
Temperature : 30.00 ^{O}C				
Between	15 Seconds	60 Seconds	600 Seconds	PI
HV/LV1+LV2+E	1430	2000	5150	2.58
LV1/HV+LV2+E	1790	3090	9730	3.15
LV2/HV+LV1+E	1970	3480	11100	3.21
HV/LV1	2950	4590	14600	3.18
HV/LV2	3050	4860	17200	3.55
LV1/LV2	3990	7120	22000	3.09

Table 3.11 Measurement of no load loss & current

Transformer energized from LV side							
Tap Position no.					**9b Normal**		
Guaranteed No- Load loss at nominal Voltage					**88 Kw (Max)**		
Nominal Voltage %	Voltage, kV		Form Factor	No. load current lo Amps.	% lo at 120 MVA	Losses, kW	
	RMS	Average	Vrms/Vacg x 1.11			Measured Pm	Corrected Po
90%	10.345	10.387	1.11	10.027	0.33	53.155	53.374
100%	11.473	11.560	1.10	21.383	0.71	68.159	68.675
110%	12.646	12.688	1.11	39.904	1.32	90.323	90.623

Table 3.12 Measurement of load loss & impedance voltage

Tap Pos.	**Test Frequency Hz**	**Rated Current A**	**Measured Impedance, 120 MVA base, %**	**Load Loss at 75°C, kW**	**Current A**	**Voltage kV**	**Loss kW**	**Load Loss, kW**	**I2R Loss, kW**
1	50.220	157.46	157.27	67.116	305.37	15.21	306.11	220.07	332.47
9b	50.209	173.21	173.47	58.673	284.52	14.59	283.67	222.82	314.64

17	50.243	192.45	192.49	53.730	331.08	14.85	330.94	274.30	371.96

Table 3.13 Separate source voltage withstand test

Phase	kV	Time in seconds	
HV	50	60	OK
LV1	28	60	OK
LV2	28	60	OK

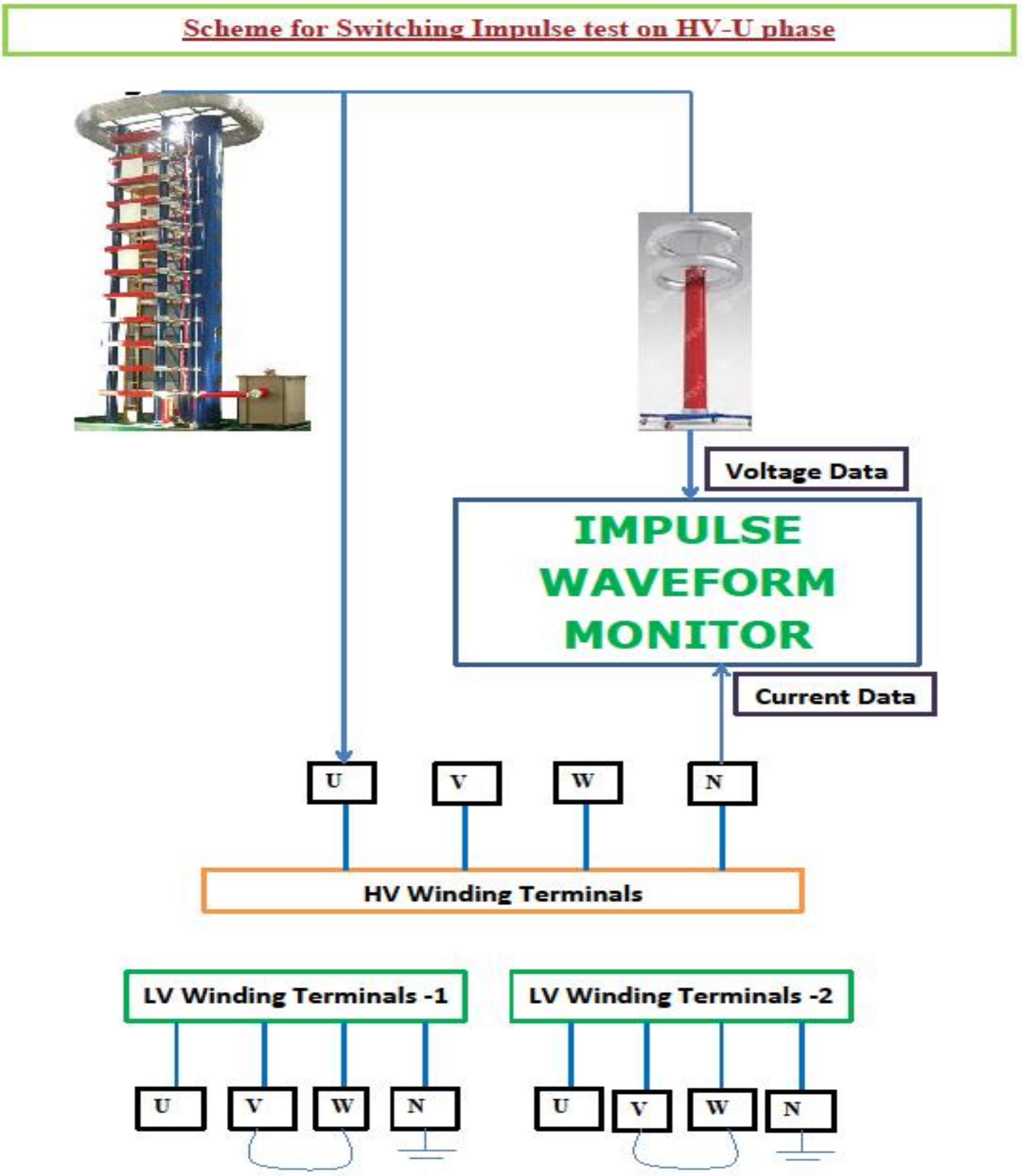


Fig. 3.3 Switching impulse diagram

Following the Subsequently Switching Impulse test (SI), successful testing was achieved on the 'V' and 'W' phase high-voltage (HV) terminals at the 100% test level of 1175 kVp. However, during the SI test on the HV 'U' phase, although the transformer endured the voltage at the 100% Basic Insulation Level (BIL) level, disruptions were observed in the current oscillogram. Interestingly, there were no distortions detected in the voltage waveform. While the test was successful on the 'V' and 'W' phase HV terminals at the 100% test level of 1175 kVp, the HV 'U' phase maintained the 100% BIL level without any distortion in the voltage trace. However, disturbances were observed in the current oscillograms for all three shots, particularly near the beginning and end of the current trace.

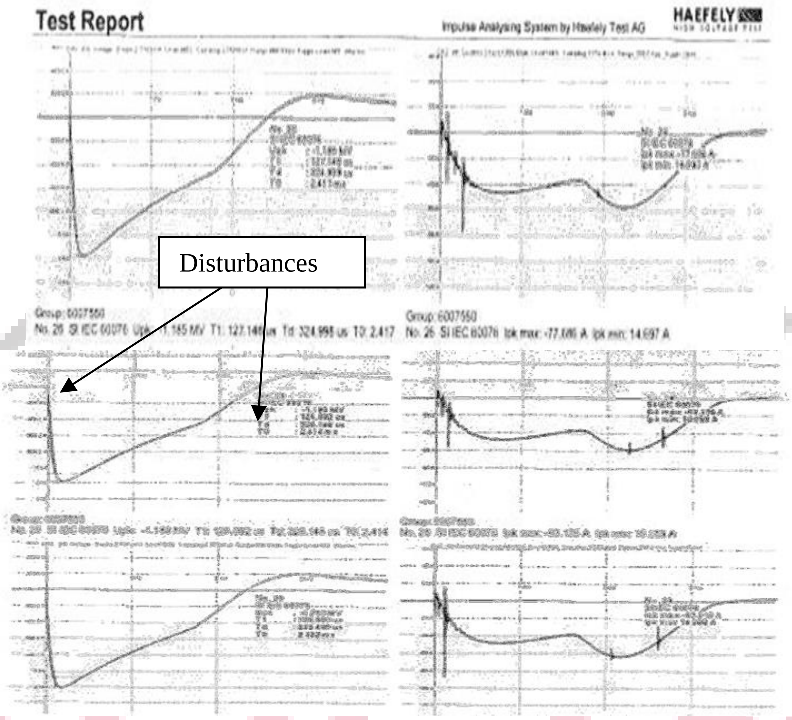


Fig. 3.4 Disturbances observed in current oscillogram

E. Problem Investigation

Transformer was withdrawn from testing for physical inspection and investigation.

Brainstorming

Brainstorming is a group creativity technique by which efforts are made to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed by its members.

In other words, brainstorming is a situation where a group of people meet to generate new ideas and solutions around a specific domain of interest by removing inhibitions. People are able to think more freely and they suggest as many spontaneous new ideas as possible. All the ideas are noted down without criticism and after the brainstorming session the ideas are evaluated. The term was popularized by Alex Faickney Osborn in the 1967 book Applied Imagination.


BRAINSTORMING

- *Brainstorming is the way of making of a group of people all think about something at same time, often in order to solve a problem or to create a good idea (oxford dictionary).*

Fig. 3.5 Concept and visualization of brainstorming

BRAINSTORMING FOR Possible reason - Joint team from NTPC and manufacturers-

- visual inspection of job after oil drain
- Investigation for failure analysis using RCA TOOL.
- Analysis based on the test details.

Visual inspection of job after oil drain by Joint team members;

Internal inspection of transformer was carried out with following observations

- Internal surface of tank was clear and there were no blackening marks.
- No abnormality noticed in the vicinity of any HV, LV or Tapping Leads. The OLTC was also clean and there was no abnormality.
- However Tracking/ treeing marks were observed on the outer surface of outer most pressboard barrier of U-phase coil (Pic.2). These marks were on diametrically opposite side of HV lead & approximately at centre location vertically. The progression of treeing/ tracking marks was in horizontal direction i.e. along horizontal periphery of outer surface of outermost barrier in the vicinity of high voltage discs.
- No abnormality was observed on inner surface of the outermost barrier

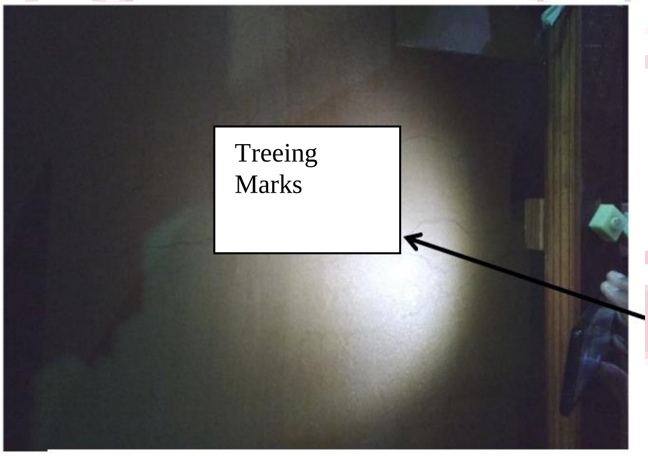


Fig. 3.6 Treeing marks outer surface of outer most pressboard barrier of U-phase coil

- Upon opening the remaining 5 pressboard barriers over the U-phase coil, no irregularities were detected.
- A thorough inspection of the U-phase high-voltage winding revealed no anomalies.
- No abnormalities were observed in the V and W phases or at any other site within the transformer.

F. Investigation for failure analysis using RCA TOOL

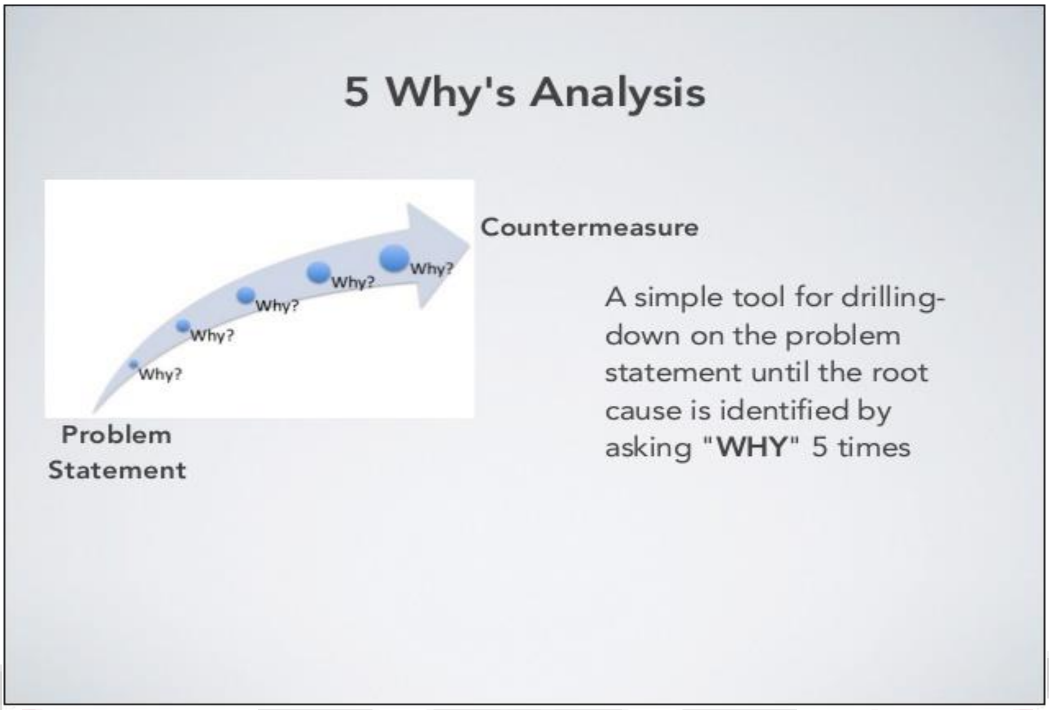
- Root cause analysis (RCA) entails the systematic examination of problems to pinpoint their underlying causes, facilitating the identification of effective solutions. This approach operates on the premise that addressing root causes is more impactful than merely treating surface-level symptoms.
- RCA encompasses a range of principles, techniques, and methodologies aimed at uncovering the fundamental reasons behind an event or trend. By delving deeper than superficial cause-and-effect relationships, RCA illuminates instances where processes or systems faltered, leading to the occurrence of an issue.

Goals and benefits

- The primary objective of root cause analysis is to uncover the fundamental cause behind a problem or event, aiming to delve beyond surface-level manifestations.
- Another key goal is to gain a comprehensive understanding of how to address, mitigate, or gain insights from the underlying issues identified within the root cause.
- Furthermore, the aim is to utilize the insights gained from the analysis to implement preventive measures systematically, thereby averting future occurrences of similar issues or replicating successful outcomes.

Rca Tool: Level 1

- WHY-WHY Analysis: The Why-Why analysis is a collaborative problem-solving method aimed at swiftly identifying the root cause of a problem. This approach entails the participation of technical experts who systematically analyze symptoms to pinpoint the underlying issue. The process involves asking "why" repeatedly in response to a problem, delving deeper with each iteration to unveil multiple layers of the issue. By continuously probing and examining the causal chain, the technique facilitates the discovery of the fundamental cause or causes behind the problem, enabling effective problem resolution.



5 Why's Analysis

Countermeasure

Problem Statement

A simple tool for drilling-down on the problem statement until the root cause is identified by asking "**WHY**" 5 times

Fig. 3.7 Understanding the 5 Whys Analysis: A Method for Root Cause Identification

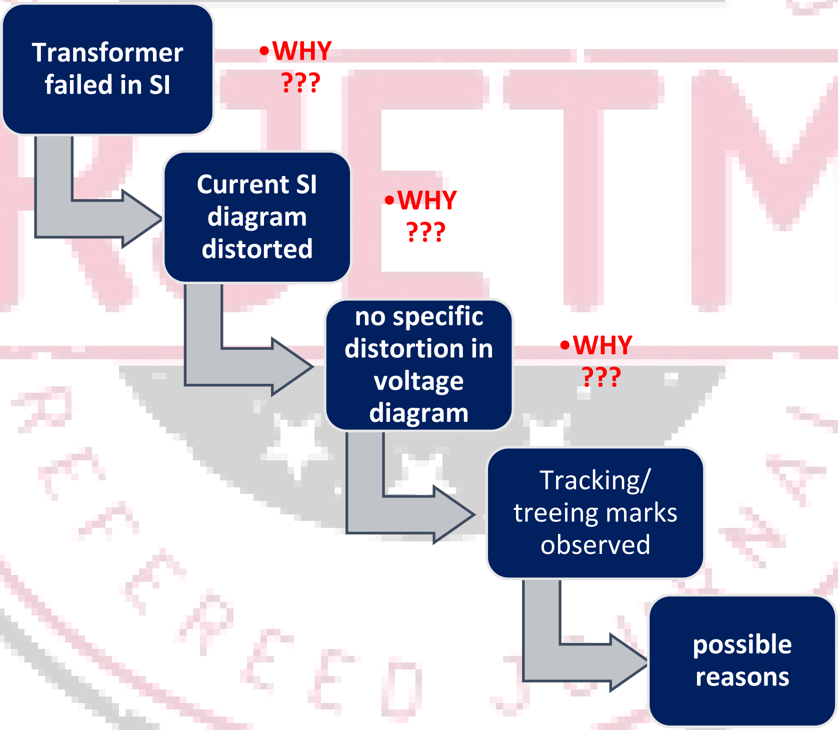


Fig. 3.8 Root Cause Analysis for Transformer Failure in Short Circuit Test Using the 5 Whys Method

WHY-WHY Analysis Result: The failure was a result of surface discharge phenomena i.e. treeing/ tracking on outer surface of outermost pressboard barrier.

A. Rca Tool Level 2

Various literatures related to this phenomena were studied and after analysis the phenomena, it emerged that fundamentally such treeing/tracking can be attributed to either of the following reasons:

- Quality of insulation item
- Quality of transformer oil
- Presence of high quantum of polar/ metallic contaminants
- Excessive moisture on the Pressboard surface

IV. CORRECTIVE & PREVENTIVE ACTION

A. Preventive Measures Implemented to Mitigate Such Issues

- It was communicated to manufacturer to measure the dew point of dry air before its application.
- A checkpoint in QAP to verify the due point of dry air was added.
- Although analysis indicates surface moisture ingress on outermost barrier as root cause, however as a precautionary measure and as advised by NTPC, all pressboard barriers over HV coil, between HV-LV & LV-Tap windings of U, V & W phases shall be replaced with new barriers.
- Transformer shall be reprocessed in VPD plant as per norms and made ready for testing after completion of processing
- Adequate care shall be taken during all stages of handling of transformer subsequent to processing so that transformer is not exposed to moisture or contaminants.
- The problem in dry air plant has already been rectified and with the installation of new Air drying system, there shall be no issue related to moisture in air.
- Now onwards, dew point of dry air shall be checked before use in the Transformer.

Fig. 4.1 Dew Point Measurement Display Showing Extremely Low Temperature

B. Validation of control action

All examinations will adhere strictly to the technical specifications outlined and will be conducted according to the approved test schedule provided. This meticulous approach ensures that each test is performed with precision and accuracy, meeting the specified criteria and standards set forth in the technical documentation. Following the designated test schedule guarantees that all required tests are completed efficiently and within the specified time frame, facilitating a comprehensive assessment of the equipment's performance and compliance with regulatory requirements.

Upon the successful completion of all prescribed tests and inspections, the transformer will be prepared for dispatch. This meticulous process ensures that the transformer meets all necessary quality and safety standards before it leaves the manufacturing facility. Each test is conducted with precision and thoroughness to verify the transformer's functionality, performance, and adherence to specifications. Once all tests are satisfactorily completed and documented, the transformer will be carefully packaged and prepared for transportation to its designated location. Only after confirming that all tests have been successfully passed will the transformer be dispatched, ensuring reliability and peace of mind for the end user.

C. Improvements

- A new checkpoint has been incorporated into the Quality Assurance Plan (QAP) to verify the dew point of the dry air used during the transformer manufacturing process, ensuring that moisture levels are within acceptable limits.
- To enhance oversight and quality control, NTPC representatives now conduct random visits to the dry air plant, ensuring compliance with moisture control procedures and standards.
- As an additional measure, a moisture or dew point meter has been installed along the dry air pipeline, providing real-time monitoring of moisture levels to further ensure the quality of the dry air used in the transformer manufacturing process.

V. CONCLUSION

The progression of power system grids has significantly impacted the efficiency, reliability, and sustainability of power supply. Enhancements in capacity, voltage capabilities, and smart grid functionalities have strengthened grid resilience against various disruptions. Power transformers, as critical components, require rigorous testing and maintenance protocols to ensure their longevity and reliability. The study identifies key factors contributing to transformer efficiency and proposes preventive measures to mitigate issues such as moisture ingress during manufacturing. Implementing improved quality assurance measures, such as monitoring the dew point of dry air and replacing susceptible components, has proven effective in enhancing transformer reliability. Additionally, the concept of power system resilience has been explored, highlighting its importance in maintaining uninterrupted power supply amid challenges. This research underscores the significance of continuous innovation and stringent quality controls in advancing power system grids and ensuring a sustainable and reliable power infrastructure.

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