



## DESIGN REVIEW AND FACTORY INSPECTIONS

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### ABSTRACT

This paper describes the summary aspects of performing design reviews and provides an experience based guide for performing factory inspections.

### INTRODUCTION

Large Power transformers represent a significant capital investment for any utility, industrial company, or other end user. The overall transformer cost of ownership can significantly exceed the initial purchase costs when the total costs involved in the procurement, installation, commissioning, maintenance, and operation are accounted for.

When something goes wrong with a transformer, either during the project phase or during in-service operations, significant budget over-runs or revenue loss can result. This is the primary reason that the significant majority of critical transformers receive some sort of additional surveillance by the end user, often in the form of design reviews and in-factory inspections. Design reviews are performed to ensure the transformer design is suitable for its intended service. Factory inspections are performed to demonstrate compliance with the customer specification and to assess the over-all quality (and indirectly the reliability) of the transformer under construction.

The benefits from factory inspections are difficult to quantify in terms of tangible dollars, but generally the avoided costs associated with the mitigation of potential problems that will surface during factory testing, installation, or operation are far greater than the relative minor expense incurred for the factory inspections.

### Design Review and Transformer Inspections

Transformers are designed and constructed to meet specific performance requirements, which are generally defined by the purchaser. These requirements are most commonly in the form of product specific technical specifications, or by reference to applicable industry standards. Factory inspections are performed to demonstrate the transformer is constructed as expected and the quality of the workmanship and material used in the construction are suitable to provide a trouble free transformer.

There are a significant number of customer or external inspections that are commonly performed at the manufacturer's factory. The more commonly performed inspections are:

- Vendor Qualification Inspection (Factory Evaluation)
- Comprehensive Factory Audit Inspection
- Quality Audit Inspection
- Transformer Design Review
- Coils and Core Inspection
- Post-Processing Inspection
- Pre-Tanking Inspection
- Acceptance Testing

Ensuring that a good quality product is manufactured and delivered successfully is difficult and the process should begin early in the procurement process by the proper selection of the manufacturer and by establishing the suitability of the proposed transformer design.



Vendor qualification begins by establishing qualified vendors from whom to solicit a proposal. It is extremely important to qualify only manufacturers with the appropriate design expertise, manufacturing capability and historical experience. If the request for a proposal is issued to a new vendor, an initial factory visit is highly recommended. The purpose of the initial visit is to evaluate the capability of the supplier's individual departments including; engineering, purchasing, quality assurance, production, testing and field service. A preliminary specification review during this initial factory visit is also highly desirable. The specification review will establish the proper interpretation of the purchaser's requirements and define the complexity of the required offer; avoiding interpretation errors and establishing a common base for bid evaluation.

Once an order for a transformer is awarded, it is important to perform a transformer design review. The design review is considered an integral part in the transformer procurement process. The design review is structured to source a quality product that conforms to the purchaser's specifications and operational parameters while ensuring long-term reliable service. This is accomplished by confirming the supplier's adherence to the buyer's technical specification and compliance with established industry standards. A proper design review contributes significantly to the successful long-term operation of a transformer.

In addition, a successful design review is mutually beneficial to both purchaser and supplier. The design review helps expedite a transformer design that is acceptable to both parties early in the procurement process. It also satisfies the Quality needs of both participants by confirming compliance, by defining the requirement of each subsequent inspection and by establishing a good working relationship.

It is to be noted that there are two guarded rules that must be adhered to during the design review:

First, the information made available for the design review is proprietary and confidential and should be respected. The inappropriate use or dissemination of this information will be detrimental to a good working relationship and will jeopardize the outcome of future design reviews.

Second, the methods of transformer construction found at a factory are a result of many years of experience and provide the historical lessons learned for that product. It is not advisable to request or specify the application of design and manufacturing methods utilized by other suppliers. The introduction of novel or unpracticed techniques will result in increased cost, delays and failure risk due to the lack of familiarity by the designers and manufacturing personnel.

There are many acceptable methods practiced to perform transformer design reviews. Most design reviews involve a technical presentation by the manufacturer followed by a discussion of each significant design category. In order to facilitate an open discussion process, it is important for the manufacturer to provide to the buyer's design review team the physical details of the proposed transformer construction in advance of the meeting. This will allow the purchaser's team time to thoroughly review the information and make the necessary preliminary calculations required of a comprehensive study.

It is best to perform the design review on location at the supplier's factory. This will make it easier to answer the technical issues that will arise during the meeting. This is aided in two ways; first, short factory visits can easily make evident construction details and features that are difficult to describe verbally or with drawings. Secondly, it allows immediate access to the suppliers' experts to clarify details as necessary.

The typical design review will scrutinize the more critical aspects of the transformer design. These are usually described by five general transformer design categories:

- Core and Winding Arrangement
- Type of Winding and Conductors
- Transformer Losses
- Short Circuit Forces and Stresses
- Thermal Design



There are other transformer design aspects that are important but sometimes deemed as secondary in the design review process. For example, the physical layout and control wiring requirements play a secondary role in determining the suitability of the transformer for its intended service.

The review of the transformer outline, control wiring schematics and physical drawings are best addressed by site engineers. Typically, site engineers have direct knowledge of the specific physical limitations and control and instrumentation needs at the transformer's final location; consequently it is extremely important to have the direct involvement of site engineers to address these design features.

## **Core and Winding Arrangement**

### **The Magnetic Circuit**

One of the first steps in the design review process is to evaluate the proposed core design. In the review of the core two main areas should be scrutinized. These areas are the core's induction levels and operating temperatures. These operating characteristics of the core are determined by the core's effective cross-sectional area, the core material properties and the core joint construction.

The calculated maximum core hot spot rises at specified excitation levels (as determined by the in-service operating conditions) must meet the required ultimate temperature levels found in the customer's specification or in applicable industry standards. These calculated results must provide adequate margin at all operating conditions without excessive heating that could lead to combustible gas generation.

The core temperature calculations should also include heating of the core's outer lamination packets under the different loading and excitation conditions possible in service.

Additional magnetic circuit aspects also evaluated during the design review can include unusual operating conditions such as the impact of geomagnetically induced currents (GICs) and core harmonic vibrations that may excite tank panel resonance.

### **Core Load Losses**

The performance characteristics guaranteed for the core are the no-load losses and excitation current. These calculated results are to meet the guarantee values supplied in the vendor's proposal. The no-load losses provided should be reasonable for a modern transformer core constructed with a highly permeable grade of steel and step-lap construction.

A concern that has surfaced with recent factory inspections is the method used to control the size of core lamination edge burr. The design review provides a forum to discuss how the burr size is controlled on the slit and punched laminations for the transformer core. The allowable maximum burr limit and the sampling frequency used to detect burrs are also established. It is imperative that the quality system at the factory can detect the burr dimension and frequency of occurrence with a high level of confidence.

### **Type of Winding and Conductors**

Analysis of the winding construction is a major component of a transformer design review. Windings are selected by voltage and current capacities. Some windings are better suited for high voltage and lower current applications while the opposite is true of other windings. The winding types and arrangements are selected to provide the best overall solution to the electrical, magnetic and thermal requirements expressed in the customer's specification or applicable industry standards.

Transformer windings must withstand the electrical stresses imposed upon them during factory testing and in service. In the design review, the manufacturer will provide the calculated voltage stress levels for the transformer



coils or windings. This summary is to include the following operational and testing requirements for each transformer design:

- Operating voltage
- Applied potential
- Long duration(1 hour) induced voltage
- Short duration(7200 cycles) induced voltage
- Switching impulse voltage
- Full wave lightning impulse voltage
- Chopped wave lightning impulse voltage

These results are typically obtained with manual closed form calculations for the operating, induced and switching surge conditions; however the impulse test conditions are best calculated with a transient voltage analysis program. It is extremely important that Extra-High Voltage (EHV) transformers are analyzed with transient analysis software. Closed formula or simple capacitive distribution calculations are not acceptable when calculating the impulse test voltage conditions for an EHV transformer.

The resulting voltage stress levels are coordinated with the physical insulation system proposed for the design. The physical distances used to separate the coil electrodes from each other and to insulate the conductors from ground must have adequate spacing and insulation to meet the design limits for all the aforementioned operational and testing conditions.

The insulation system of a transformer can be divided into two classes: (1) the major insulation or the insulation between windings and windings to ground, and (2) the minor insulation or the insulation used to insulate the conductors within a coil.

### **Major Insulation**

Modern transformer design utilizes high-density pressboard to create the major insulation structures within the transformer. Solid insulation that is dimensionally stable at high temperature allows the maintenance of oil spaces and control of the electric stresses across the entire insulation construction. Rigid barriers and contoured insulation should be used to appropriately subdivide the space within the transformer to judiciously distribute the electric stresses throughout the major insulation structure. The location and number of these barriers will have a great influence on the internal distribution of electrical stress. The ability to utilize formed parts from transformer board that are dimensionally stable provides added flexibility to the modern transformer designer to optimize each design based on customer requirements and established design practice.

The resulting electric field stresses can be analyzed with proprietary methods developed by the supplier or by methods that are more commonly available to the transformer industry. One of these methods is the use of the EHV-Weidmann Partial Discharge Inception curves with a suitable safety factor. The suitability of the safety factor is factory dependent in most cases. The nature is such that manufacturer's manufacturing capabilities, quality of workmanship and factory cleanliness must be considered in order to provide a suitable transformer. These factory conditions significantly contribute to the magnitude of the safety factor used in design. It is important to understand the method used to design the major insulation structure and how the proper safety factor for a given factory is determined.

During the design review, it is also prudent to request electric field plots of other critically stressed areas of the transformer. These areas may include high voltage line lead exits and high voltage bushing shields. Tools like Finite Element Analysis (FEA) are readily available to perform this analysis and many manufacturers have integrated the tools into their design process.

In summary, the information provided for the major insulation clearances and insulation construction must demonstrate that the insulation system is suitable for the given transformer application. The oil gap stresses



provided for the critical oil gaps and the tangential stress along the pressboard surfaces must be below the allowable limits defined in the purchaser's specification and the internal design limits established by the supplier.

### **Minor Insulation**

The manufacturer will also supply the calculated voltage distribution within coils and between coils under all operating and test conditions. The calculated voltages and resulting insulation stresses should be below allowable limits for each specific condition analyzed. In addition, there should be a general agreement that the allowable design voltage limits for the coil-to-coil voltage stress and conductor taping is comparable with industry norms and known dielectric physical principles as used for other large power transformers.

### **Transformer Losses**

Similar to dielectric analysis of the insulation design, FEA has become commonplace in transformer design in the areas of loss calculation, short circuit forces and thermal analysis. Most manufacturers of large power transformers today utilize either internally developed FEA tools or commercially available software to analyze the magnetic and thermal performance of a transformer design. These numerical analysis tools are used to calculate the transformer's real and apparent losses under load, the internal forces under different fault conditions, and the heating of a transformer's internal components.

### **Load Losses**

The manufacturer will provide the detailed breakdown of the load losses for the design review. These losses are to be supplied for different combinations of de-energized and on-load tap changer connections of the transformer; typically at the base and top ratings of the transformer.

The calculated loss values at the base rating are compared to the guarantee values stated in the vendor's proposal. The losses at the top rating are used to calculate the oil and winding temperature rises at the maximum loss position. This is also the position used for the temperature rise test.

The transformer ohmic losses are categorized according to how they are generated:

The calculated  $I^2R$  component of the losses is based on the conductor selection and geometry of the windings. This is the easiest component to calculate and very little deviation is expected during the factory tests.

The winding design and the selection of conductor sizes are important in reducing additional losses (eddy and circulating) in the windings. Therefore selection of the conductor size must carefully balance the conflicting requirements of withstanding the forces present during a fault and minimizing the eddy losses induced in sizable conductor strands.

The leakage field within a transformer is not uniformly distributed. In windings with multiple conductors in parallel it is important to utilize transposition techniques. Transposing is the method of making each conductor within an electrical turn occupy the same location within the leakage field. This placement of conductors equalizes the induced voltage among the parallel strands, consequently reducing the circulating current loss.

It is important to note that the calculation of the eddy and circulating losses within a transformer are dependant on the solution of the magnetic fields under loaded conditions. Therefore, the modeling method used in the magnetic field simulation could significantly impact the eddy and circulating loss calculations. The details of the numerical calculation should be discussed with the manufacturer to make sure that the proper analysis tools and detail were used to model the transformer geometry.

The stray losses are the most difficult component of the load losses to evaluate. The stray loss calculation method is usually empirically derived by the manufacturer for a given design family. The manufacturer's experience in designing a type of transformer is paramount in the calculation. It is very difficult to independently verify the stray loss component without detailed knowledge of the transformer design and the historical tested results for a given



design family. However, most manufacturers will provide a comparative analysis that demonstrates their ability to predict the total load losses typically to within 5 percent of the calculated loss values. This analysis will demonstrate the correlation between the calculated total losses and the tested results for similarly sized transformers of recent manufacture. The presentation should clearly demonstrate the supplier's historical ability to predict the total calculated losses with reasonable accuracy.

### *Impedance Calculations*

The impedance for transformers with simple geometries may be calculated using readily available closed form formulas with acceptable accuracy. Transformer designs with complicated geometries and inter-connected windings typically require FEA methods for more accurate results. If doubt persists regarding the accuracy of the impedance calculation, the manufacturer may be required to provide an analysis comparing the supplier's impedance calculation method with tested results. The typical expected deviation for this comparison should be no more than 3 percent.

The impedance calculation has a significant role in the overall design of the transformer. As a measure of leakage field strength it determines the magnitude of the eddy, circulating and stray losses. More importantly, the impedance limits the magnitude of the symmetrical current that will flow through the transformer windings under fault or short circuit conditions.

### **Short Circuit Forces and Stresses**

#### **Winding/Coils**

The review of the calculated short circuit forces is performed after a detailed summary of the current magnitudes is compiled for the different fault conditions that the transformer will experience in operation. Once the maximum winding currents are known, the short circuit forces for each winding can be calculated and compared to the allowable limits. The calculated short circuit forces should be reasonable in magnitude for a transformer of its capacity.

The allowable short circuit withstand limits are established by the physical and construction properties of the coils. The allowable limits should be congruent with best practices of the transformer industry and provide adequate margin to the material's strength characteristics.

Some of the more common modes of failure reviewed for core form transformers are circumferential stress, beam bending, spacer compression and conductor tipping.

The circumferential stress can be either compressive (typically for inner coils) or hoop stress on the outer coils. The compressive stress is calculated in two modes of buckling, forced and free buckling. The free buckling stress must be withstood only by the conductor material strength while forced buckling takes advantage of the supporting structures underneath the coil.

The strength of the conductor alone must be capable of withstanding the calculated hoop stress for outer coils. There should be an appropriate safety margin included in the conductor selection. When the physical properties of the coil conductor are insufficient to provide proper restraint under fault conditions, many manufacturers will utilize epoxy bonding of the individual conductor strands to meet the short circuit strength requirements of a design.

The beam bending stress developed under fault conditions must be withstood by the physical properties of the coil conductor and the span between adjacent supports or radial spacer columns.

Similarly, the maximum compressive stress developed on the insulating spacers by the vertical forces due to any fault condition should be less than the allowable limit for the spacer material.

#### **Clamping**



Clamping system designs vary widely among manufacturers. The clamping system provides four basic functions:

- Secure the core
- Clamp the windings
- Fasten the core and coils assembly to the transformer tank
- Facilitate lifting and handling of the core and coil assembly

In core form units, the clamping system is constructed with end-frames and lock-plates. The end-frames hold the core yokes together and provide a stable base for the windings. The lock-plates tie the top and bottom end-frames to one another providing the rigid restraint of the clamping system. The clamping structure with the use of high-density pressboard in the windings provides a properly balanced, high strength, securely clamped assembly that will resist short circuit forces.

While windings are designed to minimize axial and radial forces that a transformer will experience during a short circuit, not all the forces from the fault current can be eliminated. An allowance for the resulting vertical forces must be designed into the clamping structure of the transformer. During the design review the sizing and material properties of the tie-plates, end-frames and pressure ring must be evaluated to ensure that these components have sufficient strength during fault conditions and lifting operations.

### **Thermal Performance**

The winding temperature rise must not exceed the guaranteed levels. Loading the windings above the guaranteed values will cause overheating and accelerate the deterioration of the insulation. The active conductors within the windings are insulated with thermally up-rated cellulose paper for most transformer designs. This cellulose paper and pressboard insulation will degrade at elevated temperature. Degradation of the cellulose insulation materials results in the loss of mechanical strength. It is paramount that insulation maintains adequate mechanical strength so that it is able to withstand short circuit forces and other mechanical disturbances that it may experience throughout its lifetime.

The average winding temperature rise is the sum of two components, the average oil temperature rise and the average winding temperature gradient. The average oil temperature rise is the rise above the ambient temperature. The average winding gradient is the difference between the average oil temperature and average winding temperature.

The average oil temperature rise is a function of the transformer heating losses and the cooling equipment's ability to dissipate these losses. The cooling equipment most typically used to cool transformers are radiators, air blast fans or forced oil coolers.

In addition to the average winding temperature rise, the designer must also calculate the winding hot spot temperature rise. The hot spot temperature rise is the sum of the hot spot gradient and the top oil temperature rise. The hot spot gradient is based on the average winding gradient and a calculated hot spot multiplier. Most manufacturers will calculate the hot spot multiplier from the local conductor losses determined by finite element analysis. This approach can provide a relatively accurate calculation of localized heating.

It is important to review the heating of leads and structural parts of the transformer. This includes all cabled leads, especially high current carrying conductors. The heating of the low voltage high current leads is often a significant thermal concern.

Heating of the tank walls, low voltage bushing turrets, lock-plates and end-frames should be reviewed. In many complicated designs, it may be advisable to request that the manufacturer perform dimensional (3D) thermo-magnetic field analysis of these critical locations.



## Design Check Lists

The checklist is a simple but effective tool that has been used successfully to facilitate design reviews. A comprehensive check list, which is inclusive of the design review through the factory inspections, provides a systematic method to record all the critical design review items and verify their status during construction and testing. The check list can include technical requirements from the purchaser's specification and design related items from the design review.

## Factory Inspections

The initial or up-front verification process established with the factory qualification and design review is continued through the transformer acquisition process by maintaining proper vigilance during the construction phase. Factory inspections play a significant role in encouraging manufacturers to maintain high quality standards in their design and manufacturing processes.

Factory inspections are designed to augment the manufacturer's existing Quality Assurance or Quality Control processes at the factory. Factory inspections are not performed to replace or circumvent the internal processes established by the manufacturer, but rather these inspections are inserted into the normal and expected quality program to provide an independent verification and to establish that the supplier's quality system is functioning as designed. There should be no misunderstanding between the customer and the manufacturer in this regard.

Specific requirements of the technical specification can be confirmed during factory inspections. For example, it may be prudent to prohibit the use of solid wood support structures for high voltage leads, or in another example the use of specific metallic hardware for connections that carry high currents may be required. These special requirements can often be verified more easily during the construction process rather than after the transformer is completely assembled.

The factory qualification and design review inspections are typically performed during the procurement or before the manufacturing stages. However, four of these inspections are more routinely performed during construction; these are most often referred to as the factory inspections. They are listed as follows:

- Core & Coils
- Post-Processing
- Pre-Tanking inspections
- Witness of Acceptance Testing.

## Roles and Responsibilities for Factory Inspections

In order to establish a fair and consistent factory inspection process, it is important that the manufacturer and the inspector establish an understanding of the desired results from the inspection. To promote a positive outcome from the inspection process some basic rules and responsibilities need to be established. Each participant in this process has specific responsibilities:

### The Inspector

The inspector must be prepared for the inspection by being familiar with specifications, procurement contracts and specific project details. Competency with applicable standards is essential. In the United States, the most commonly referenced standard for power transformer testing and construction is the IEEE C57 collection. Two of the more significant documents within this collection that the inspector must be able to apply in practice are:

- IEEE Std C57.12.00, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers [1].



- IEEE Std C57.12.90, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers [2].

IEEE Std C57.12.00 defines general requirements for manufacturing, processing and testing power transformers. IEEE Std C57.12.90 defines how the specific acceptance tests must be performed on the transformer.

These industry standards outline the minimum requirements. The inspector must also be familiar with requirements stated in the customer's purchase order and technical specifications. It is very important that special design and performance characteristics be clearly identified early on so that the manufacturer has ample opportunity to comply with these uncommon requirements. Special construction features or requirements identified at the Design Review meeting must be clearly defined and included as part of the inspection's regimen.

The inspector must be flexible and accommodate the manufacturing schedule within reason. This may require long days and unusual working hours. It is important that the manufacturing process is not hampered. Delays in manufacturing at specific stages of construction can be magnified over time and result in shipping delays. Shipping delays will materially impact both the end-user and the manufacturer. This consideration becomes even more significant since the majority of large power transformers are now manufactured outside of the United States. Therefore, it is prudent to anticipate the additional burdens of oversea travel. These may include the procurement of special travel visas, required immunizations, confirming travel insurance and establishing emergency contacts.

The inspector must clearly define the inspection points required to fulfill the contract requirements established between the buyer and the supplier. The specific items of interest for each inspection should be clearly identified early on and communicated to the manufacturer. The condition of the inspection items or the transformer should be explicitly described. For example, if the coils are to be inspected, it is the responsibility of the inspector to define at what stage of the coil construction that the inspection will take place (i.e. each individual coil upon completion, marked and released into the assembly phase without the winding mold in place.)

### **The Manufacturer**

The manufacturer should properly notify the end-user or inspector well in advance of the inspection date and immediately inform them of any schedule changes. Last minute notices will undoubtedly necessitate unwanted compromises from the purchaser resulting in a poor working relationship between the two parties. Last minute schedule changes that are not properly communicated will result in increased travel costs.

The manufacturer should provide a dedicated private office during the inspection. This room should include as a minimum a work station, a phone and high-speed Internet connection. It is important that the inspector have a facility to communicate daily with other responsible parties with ownership in the project.

The manufacturer should also ensure that all inspection items are readily available at the inspection date and equipment needed for the inspection is operating properly. The inspection items should be easily accessible and unencumbered. It should not be required that the inspector unnecessarily be overexerted during the inspection to the point where injury may result.

The proper personnel responsible for each inspection point should be freely available; especially during late nights or after normal working hours. This will facilitate resolving any issue that may surface in an expedient manner and avoid possible delays.

### **The Coils and Core Inspection**

The Coils and Core inspection is performed on the coils and core once they are completed. This inspection takes place when the coils and the core have been released to the assembly stage; these parts are inspected prior to mating to ensure a thorough visual inspection that is not possible after assembly.

It is desirable for the manufacturer to coordinate the production schedule so that the core and the coils can be inspected at the same time.



The core inspection should be performed after the core has been up-righted with or without the top yoke installed. The core should be assembled with the bottom blocking mounted and leveled.

The following construction features of the core should be inspected:

- The fit of the core blocking for the bottom yoke and legs. The blocks should be properly landed and shimmed where necessary.
- The stack of the bottom yoke and legs. The core joints should be properly mated without large gaps.
- There should be very little variation in the bottom core joints.
- The core isolation method should be identified. The method used for electrically bonding structural members of the core clamp should be verified.
- The insulating material between the core and core clamp should be verified for suitability, especially in hot spot locations.
- Verify the fit of core bottom blocking. This is critical with designs with forced oil cooling of the core.
- Verify gasket locations for the forced oil cooling system.

Check the core stacking and construction logs:

- Check the core stacking dimension versus the design value.
- Check measured window opening against the design values.
- Verify the core steel has not been mixed and is of the same grade.
- Check that the core window and the core are square.
- Make sure the core limbs are plumb.

The coils should be inspected once they are finalized in the winding department. The coils should be up-right and released by the manufacturer's Quality department. The term "released" implies that the coils are ready for the next step in the construction process. Ideally, the winding form or cylinder is removed and the coil is placed on an elevated platform. This will allow for the most direct examination of the coils.

The following construction features of the coils should be witnessed:

- Verify alignment of spacer columns.
- Inspect the quality of cross-overs on disc coils. Make sure sections are not touching.
- Inspect the workmanship of transpositions.
- Check tightness of the disc sections especially if coils are interleaved or use a static shield.
- Make sure that the insulation on the coil conductor is not damaged.
- Verify that the coils are free of construction debris.
- Check the seating of the static rings. The static rings should be properly made to provide adequate coverage for the coil disc or section.
- Make sure that the columns are properly supported under the crossovers with solid insulation material.
- Verify that the cross-over span is no greater than that used in the short circuit calculations.
- Make sure that the proper coil materials are used in the construction.

Check the coil construction logs and documents:

- Review the coil sizing sheets. Verify that coil inner diameter, outer diameter and height are within manufacturing tolerance of the design.
- Review the coil sizing procedure to ensure the coils are properly stabilized.
- Review the copper test certificates to ensure the material meets the design specification.
- Visually inspect the coils for roundness. Eccentric coils can create problems further in the construction.
- Make sure each coil has been signed and released by the operator and by the section inspector.



Finally, review the Non-Conformance Report for the core, core parts and coils. If these documents are not available in English, request that the manufacturer translate these documents for review. Take note of any significant Non-Conformance written against the transformer and the resolution methods. The resolution techniques used to correct deficiencies must not compromise the transformer quality. A poor quality product will inevitably have problems in service.

### **The Post-Processing Inspection**

The Post-Processing inspection is performed after the active parts (core and coil assembly) of the transformer have been processed. Processing the transformer is drying of the insulation to remove moisture.

The following construction features of the core and coil assembly should be inspected during the Post-Processing Inspection:

- Verify that the core grounding system is complete.
- Inspect the core stack of the top yoke as it mates with the limbs. The core joints should be properly mated without large gaps.
- Verify the isolation system for the core clamp.
- Make sure the core and coil assembly is free of debris and contamination.
- Check the lead routing and construction. Verify lead, coil and tap-changer(s) clearance when applicable.
- Verify that the core steel is properly blocked on the top. The top yoke should be wave free and the top core clamp tight against the core insulation.
- Verify the tightness of the core ground connection, which is typically located on the top core yoke.

Check the construction logs:

- Check the final sizing sheets. Make sure the correct sizing pressure has been applied and the final coil sizes are within tolerance and uniform.

Once again, the Non-Conformance Report for the transformer should be reviewed. This allows a review of the construction history up to this point in the manufacturing process.

### **The Pre-Tanking Inspection**

The Pre-Tanking inspection is performed when the transformer is ready to be loaded into its tank or case. This is usually the last possible opportunity to inspect the transformer internal parts until the unit is received at the site.

The following construction features should be inspected:

- Check the cross tie bars for tightness.
- Is the Core & Coil bracing tight to tank wall?
- Verify the tightness of the coil clamping system.
- Check the leads for tightening marks. Make sure that all leads are properly restrained or braced.
- Verify lead clearances if needed.
- Inspect the entire assembly for debris or contamination.
- Check corona shield for tightness and correct orientation.
- Verify that the DETC makes proper contact and all connections are tight.
- Verify alignment of the DETC connections to the drive handles.

Check the transformer assemblies check sheets:

- Check the final assembly inspection check sheet.



- Check the final pressure sheets. Make sure pressure is correct per the design.
- Check the assembly test sheet. Verify post connection ratio and core isolation tests.

The Non-Conformance Report for the transformer should be reviewed. This should be the summary of all manufacturing problems up to the point of tanking.

### **Acceptance Testing**

A transformer that successfully passes testing at the factory will typically provide many years of service with limited or no troubles under the conditions that are prevalent in the modern electrical system. Consequently, the final proof required of the manufacturer is in the form of the factory acceptance tests. Factory acceptance tests are performed on a transformer to confirm:

- suitability for intended service
- accuracy of the design calculations
- guaranteed values.

The task of the inspector during the factory testing is to witness the test processes and ensure that the factory tests are performed according to the requirements of the applicable industry standards and the technical specification.

The first step in accomplishing this task is to review the calibration records and the traceability certificates to verify that they are current and certified by an independent auditor. This will ensure that the resulting test measurements are accurate and trustworthy.

The inspector must be also able to critically evaluate the test results to determine the acceptability of the measured values. Many times this is not easily accomplished, due to the nature of factory tests. The inspector should be sufficiently knowledgeable to expand the test regimen as required to determine with certainty that the transformer is acceptable to the end-user. A thorough understanding of testing standards similar to IEEE Std C57.12.90 is critical to accomplishing this goal. Further, a working knowledge of equipment used for each test will also benefit the inspector when modifying the test regimen to attain acceptable test results.

### **Non-Conformance Report Audit**

Most, if not all, manufacturers track various performance and quality metrics throughout the manufacturing processes. Typically, these records are used to drive internal process and product improvements. These measurements are an indication of how well a factory is performing relative to an established goal. More often than not, the goals are established internally to benchmark a specific factory with its peers within the corporation and to external competitors.

Some of the more common measured metrics are: re-work, through-put time, on-time shipments, test failures, warranty claims, non-conformance, etc. Although most manufacturers track and record these metrics, few make their performance history freely available. It is important to inquire about a factory's performance metrics and ask to review them. One of the more significant metrics that should be reviewed during the factory inspections is the Non-Conformance Reports.

The specific non-conformances written against the transformer being inspected provides a historical perspective on the overall quality of the manufacturing process and the unit under construction. The report provides insight on the overall factory quality but also allows the inspector to gauge how committed the factory is to providing a quality transformer. The more significant evaluations are of the resolutions adopted to rectify the non-conformances. Careful scrutiny of these corrections will provide significant insight on the "seriousness" of the factory in eliminating serious problems including sub-standard materials, marginal workmanship and inadequate sub-suppliers.

### **Quality Inspection or Over-sight**



Occasionally purchasers will request special quality oversight or inspections to demonstrate the transformer manufacturer's ability to comply with its own internal quality system and practices. Such inspections should be clearly identified at the initial order review stage to ensure the manufacturer is aware of the requirement and is capable of complying. Typically these inspections are performed concurrently with one of the aforementioned factory inspections and are different from an overall Quality Audit. The Quality Audit should be performed early on, ideally before the order is placed with a factory.

The quality inspection is critical since the factory inspections are designed to work with the suppliers own quality and inspection processes. A failure of the factory's quality system would seriously diminish the additional effort spent in performing the factory inspections.

It is important to evaluate each factory on its own established quality practices. Although a corporate quality program may exist for larger manufacturers, each factory is unique and has its own culture, training systems, manufacturing equipment, and quality processes.

The quality inspection process would select specific issues or historical problems and track their resolution throughout the factory's many departments to make sure they are correctly addressed per the requirements of the established quality system. These issues may include;

- adherence to a special technical requirement in the customer specification
- the selection criteria for critical components
- lessons learned from field and factory failures.

The most significant part of this inspection is to demonstrate that the established quality practices and systems are functioning as designed. In addition, it is important to verify that a closed loop process is adopted at each factory to drive continuous process and product improvement. Additionally, it is extremely important to verify that all documentations are up to date and properly authorized with signatures.

## CONCLUSION

Power transformers are a critical part of any electrical system. Factory inspections are used to demonstrate compliance with technical specifications and industry standards and to assess the over-all quality of a transformer. While no inspection can ensure the transformer will never have problems in service, the inspections described have proven to be reliable in ensuring that significant manufacturing defects are identified and resolved before the transformer is tested at the factory. A factory test failure could significantly impact delivery and accrue significant cost to the purchaser. A field failure could result in disastrous consequences involving significant revenue, production cost, environmental, safety, and public relations effects.

Factory inspections help to maintain a good working relationship between purchasers and suppliers, and are an essential part of a successful transformer purchase. Judicious vigilance by the end-user can ensure that a quality product is delivered on time with minimal concerns or defects.

## REFERENCES

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