Long-term reliability and good performance in service is expected for power transformer because of time cost replacement of a failed unit. Main insulation design is one very important topic to assure that.

Voltage Stresses on Solid-Liquid Insulation of Large Power Transformers

Influence of dielectric tests on main insulation design

ABSTRACT

Due to the time cost replacement of a failed large power transformer, reliability and good performance in service are fundamentals for long-term operation.
Insulation coordination studies are the base to evaluate the occurrence of the most important transients like overvoltages, system disturbances, lightning discharges and switching operations which reach the transformer terminals connected to the system.
A set of dielectric tests are required to be performed at the manufacturer facilities as a function of the transformer insulation level according to the standards.
Such dielectric tests are mandatory to define the main insulation transformer design such clearances between windings, windings to core and leads as well.
Therefore it is very important to understand how and where the voltages are distributed within the transformer during the dielectric tests.
This article presents an overview about the voltage distribution of the main dielectric tests within the winding assembly of a three phase 40 MVA 138/13,8kV wye-delta regulating transformer.

Keywords:

insulation design, dielectric test, main gap, fieldplot

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Different types of dielectric tests are required to be carried out on transformers as per standards at manufacturers facilities to check the transformer design.

INTRODUCTION

Power transformers are required to be designed for long term operation with good performance and reliability as they are one of the most important pieces of equipment in a power system. Therefore they should be designed to withstand all types of transients during their life in service. Most transients are caused by natural phenomena like lightning atmospheric discharge or caused by the system switching operations or disturbances.

It is much too complicated and complex to represent such stresses by tests as the transients are basically dependent on system characteristics and the geographic conditions where the transformer is connected and installed.

International committees have established workgroups consisting of Manufactures, Utilities, Generators and Academic Societies. These workgroups have published standards e.g. IEEE and IEC to provide a standardised testing methodology.

These documents describe the controlled conditions to be simulated at manufacturer's test field. They specify which tests must be performed on the transformer and the conditions for acceptance. They are known as dielectric tests.

The type and level of the test is a function of the insulation level of the transformer specified by the customer.

The dielectric tests and the application of appropriate protection devices defined by insulation coordination study have the aim to assure a reliable operation of the transformer without failure during its life in service.

Therefore the transformer's insulation design like core and coil assembly and leads are submitted to Final Acceptance Tests at manufactures facilities to prove its ability to withstand different kinds of dielectric stresses. Once approved, the transformer is expected to operate in service with reliability for the long-term withstanding possible transients from the system.

This article presents an overview about the dielectric stresses on the main insulation of medium power transformers of 40 MVA designed with solid-liquid insulation. The insulation levels are given in the Table 1.

	Primary Wye connection		Secondary Delta connection
	Phase	Neutral	Phase
Rated Voltage	138	-	13,8
Applied Voltage	230	230	34
Induced Voltage	230		
Lightning Impulse	550	550	110

Table 1 – insulation level of the transformer with full insulated neutral in kV

Separate AC source withstand voltage test (Applied Voltage Test)

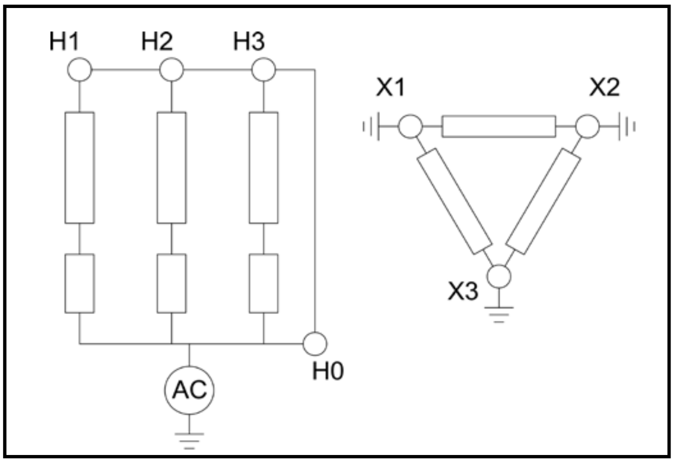
The main proposal of this test is to check the major insulation between windings and each winding to ground. Each circuit is tested separately. For a two winding transformer, two tests are required.

When the voltage source is connected to primary windings, the secondary windings are grounded and the tank as well. Then the test is performed on secondary windings with the voltage source connected and the primary windings grounded.

During this test an AC source is applied with approximately 2 times the rated voltage of on the transformer under test. Primary and secondary transformer voltage circuit is tested separately.

When tested, all bushings of the same circuit (primary or secondary) are connected together including neutral in a wye connection. The bushings from the other circuit are directly grounded.

The Figure 1. shows the equipotential lines during an applied voltage test of 230kV on the primary windings (high voltage)of a three phase wye-delta regulating transformer as an example.



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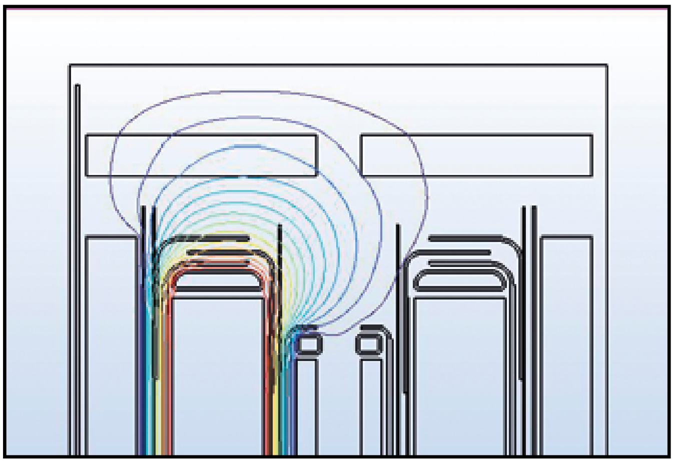

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Figure 1: Applied voltage test on high voltage, wye connection

Applied voltage test is an AC voltage test either on primary or secondary of the transformer. Higher voltage gradients appear typically between primary and secondary circuits.

Lightning Impulse Test

Impulse test system is necessary to produce the wave shape 1.2/50 µs as required by the standards. The generator is a very large piece of equipment composed by an RLC circuit in modular stages. The impulse generator is set up in various series and parallel configurations to achieve the wave form 1.2/50 µs and the required impulse voltage level.

The test is applied individually to all terminals of the transformers. When one terminal is tested, the other bushings are solid grounded, grounded via resistances or grounded via a shunt for fault detection purposes. This is done for each terminal with the specified lightning impulse level.

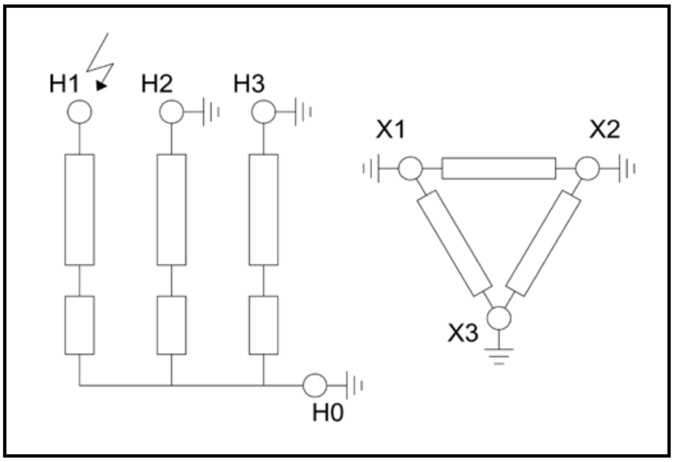
The Figure 2. shows the equipotential lines distribution during a lightning voltage test on high voltage terminal of a three phase wye-delta regulating transformer, same example of the Figure 1.

As the neutral bushing is grounded and connected directly on regulating winding, the regulating winding assumes the potential zero.

The Figure 2b shows the voltage distribution at the peak of the voltage. Observe that the equipotential lines have a different distribution in comparison with the applied voltage test. Now the stress between the HV and R windings are higher.

During the lightning impulse test, transient voltages appear within the windings but this is not addressed in this article.

Lightning impulse test is a unipolar wave shape applied individually on each terminal of the transformer. Voltage distribution is different from applied voltage test.



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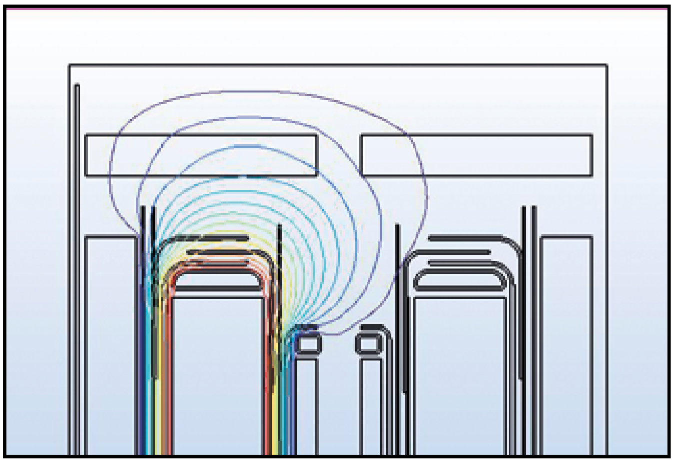

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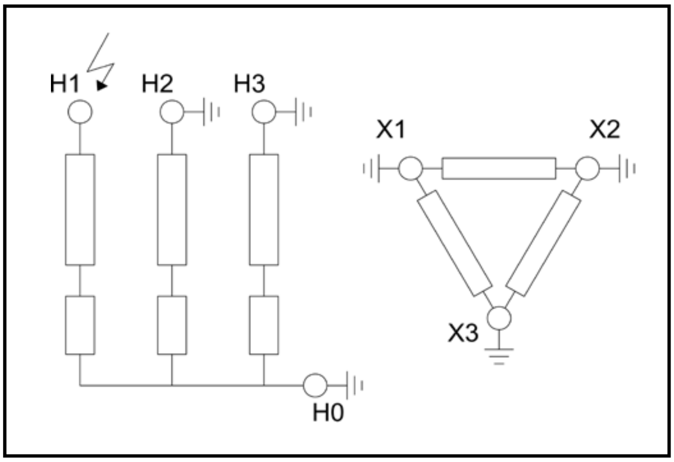
Figure 2: Lightning Impulse test in a wye-delta transformer



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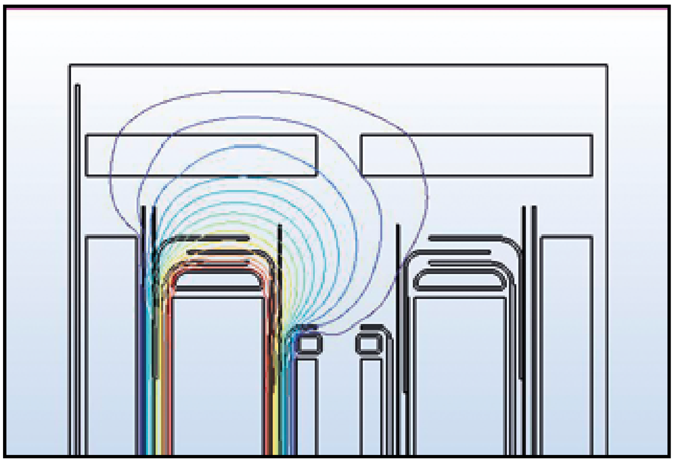

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Figure 3: Induced voltage test in a wye-delta transformer

Induced voltage test

During this test an AC voltage source is connected on the transformer under test.
Depending on the highest voltage of equipment under test, *Um*, it is required by the standards a single or three phase test.

The Figure 3. shows as example a single phase induced voltage test in a three phase wye-delta regulating transformer, same example of the Figure 1.

During the single phase induced voltage test, the neutral terminal is enhanced to 1/3 of the required voltage on line terminal to ground. This means that the voltage distribution is different from the applied and lightning impulse tests. The neutral has 33% of the potential of the voltage applied.

Induced voltage test is another AC voltage test with belonging test circuit and voltage distribution

FOTO: Johnny Chan LinkedIn


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Applied voltage test is an AC voltage test either on primary or secondary of the transformer. Higher voltage gradients appear typically between primary and secondary circuits.

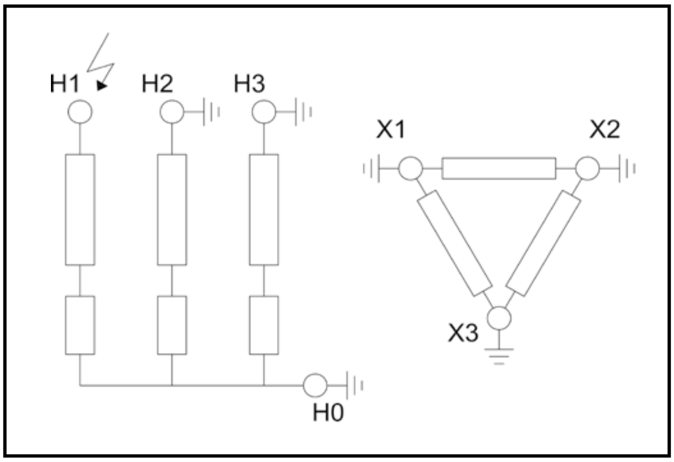
AC Design

To determine the AC dielectric stress in a solid-liquid structure of a large power transformer it is very important to know the voltage distribution within the windings. This depends on the way the windings are connected into the test circuit.

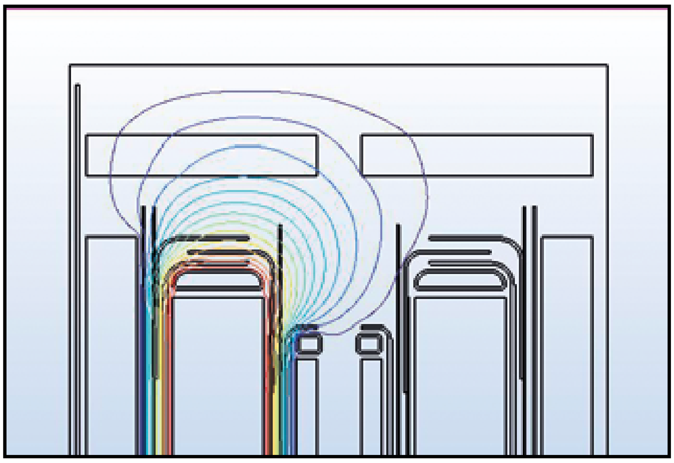
It is also important to define the clearances between the windings and the windings and core.

The state-of-art for Large Power Transformers design for AC system is composed by solid-liquid insulation. For transformers filled with mineral oil, the permittivity ratio between mineral oil and the pressboard is in the range of (ξóil: ξpsp = 1:2). This results in a higher electrical field in the oil gaps for AC stresses.

For tests like switching and lightning impulse tests, the evaluation of the equipotential lines distribution is performed consi-



Streamlines



Equipotential lines

Figure 4 – AC field plot in a core window section

dering those wave shapes as an AC equivalent stress by using conversion factors.

The Figure 4. shows one simulation for AC distribution between Low and High voltage windings in a core window section.

The equipotential lines are the lines where the charges are under the same potential. The electrical field intensity is proportional to the potential gradient.

The streamlines are perpendicular to the potential lines and show the path and direction of the forces of the electrical field over the charges.

Induced voltage test is another AC voltage test with belonging test circuit and voltage distribution

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Juliano MONTANHA holds a degree in Electrical Engineering from University of São Paulo – Brazil from 1998 when he started working at Siemens Power Transformer factory in Jundiai - Brazil. Juliano has been working with insulation technology regarding main insulation design up to 800 kV, including leads design and winding assembly. He was responsible for winding assembly standardisation for local market in 2000. Juliano is a high voltage expert at Siemens Transformer Group and has participated on a worldwide R&D research with the Siemens transformers factories. Between 2011 and 2013, he was responsible for insulation design group at Jundiai Siemens factory. He was also responsible for implementation of 500 kV electrode in Jundiai factory as well as transient studies for Power Transformers design like VFT studies and failure investigations. Juliano technically supported the manufacturing process of HVDC units at Siemens factory in Jundiai and Siemens factory in México in 2010. He has been a member of IEEE since 2014.