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Passage of power Transformers High-Frequency Models and application top Q Analysis

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Abstract: We consider the possibility of proposed high-frequency (HF) models of transformers past power transformersforming part of an electrical grid. We first model a transformer, their application to power quality (PQ) studies. The models are classified according their structure, including its laminated core, toobtain asymptotic behavior of currents and voltages in the secondary circuit. we are able to determine the effects of different by-pass mechanisms which might be tried to getthe high-frequency signal from the primary to the secondary circuit. This research work is devoted to the comparisonof some proposed high-frequency (HF) models of transformers.

Keywords: high frequency transients, high frequency modelling.

INTRODUCTION

High-frequency modelling is essential during the design stage of power transformers in order to study the impulse voltage response, the winding integrity, power quality problems and also for insulation diagnosis. We use the results of the internal modelling in considering the current flow when a power supply is connected to the primary coil and a load is connected to the secondary. It is clear that, without any extra device linking the two sides of the transformer, there is negligible transmission of any high-frequency electromagnetic signal across the transformer. Connecting some sort of impedance (in the simplest cases, just a resistor, capacitor or inductor) across the transformer to link the primary and secondary circuits in such a way as not to change the performance at low, mains, frequencies, is seen not to significantly enhance the transmission of high frequencies.The possible changed internal behaviour of the transformer windings at high frequencies is briefly looked at in the Discussion, Section

THE TRANSFORMER MODEL

The experimental transformer model used was developed and manufactured by alstomand includes an interleaved disc winding and alpinism winding. It has been further developed by the Tony Davies High Voltage Laboratory at the University of South ampton. One of its main characteristics is that it can see high voltages of up to 30kVwithoutdischarging. The structure of experimental model has two types of winding (plain disc winding). The half cross section view of the two windings wrapped around a central iron core. The interleaved disc winding is above the plain disc Winding. The two windings have the same construction size and use identical materials. Every pairofdiscsofeitherwinding provides aterminalasa measurement point. A metal cylinder connected to earth is placed inside the windings to represent an iron core frequency domain. The procedure is based on a special measurement setup and rational approximation by the Vector Fitting approach.The approach is demonstrated for a 3 winding rectifier transformer, and for internal overvoltage calculation of a winding assembly. All measurements were performed during a 1-year visit at the University of Stuttgart, Germany.The age distribution of the Norwegian transformer population is entering a critical era. In a few years, 40% of the population will be older than 30 years. Most power transformers is operated well below nominal capacity and can, if maintained properly, stay in service for as much as 60-70 years (in some cases more). In practice the only reason for scrapping these units are due to upgrading of the network (for instance the voltage), or devaluating reliability due to age.

TEST OBJECT

The test object used in this thesis is a quite typical transformer for the Norwegian distribution network. It is manufactured in 1969 at one of the previous Norwegian transformer factories. The transformer is a 20MVA 66/6,6 kV YNyn0 transformerwith a 24-strand, 69 turns, double-start LV helical winding, a double-stranded continuously wound HV disc-winding with 564 turns, and an interleaved single layer regulating winding counting 110 turns. The magnetic circuit is a three legged stacked core. The test object is referenced by the cell-number and name of the substation: T3 Buran. T3 Buran was scrapped during autumn 2001 due to its age and a planned voltage upgrade in the network. Terminal measurements in all combinations (admittances and voltage ratios) were taken before disassembling the unit. The windings werethen removed from the core to be used in possible investigations later. The idea was to apply controlled deformations, for comparison to computermodels of the same winding. The effect of axial displacements without

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the core present, was studied by means of experiments. However, since the importance ofthe core is addressed later in this work, the experiments on these windings haveafterwards been considered to be of less importance than first assumed. The effect of radial displacements was not evaluated experimentally, since this is thoroughly studied by others.

FIGURE : DISASSEMBLING THE TEST OBJECT

BACKGROUND

Power transformers are the largest, heaviest, and often the most expensive singlepiece of equipment in a power system. Obviously appropriate care is necessary incommissioning, operation and maintenance of power transformers. It is the keycomponent in power networks. Since repair-time is considerable and backup-unitsare not always available, it is important to assess the condition of each and everyunit in the network. An international survey of CIGRE.on large powertransformers, show a failure rate of 1-2% per year. This is not much, but a singlefailure on a large transformer usually results in large expenses for the utility. Sincemany manufacturers are merging or shutting down, the repair costs will increasein future due to increasing distances of transport. This leads to a growingimportance of condition monitoring on power transformers, for early warning.

FRA is a fairly new diagnostic method for assessing mechanical integrity oftransformer windings. This method is based on comparing FRA signatures tobase-line measurements. Deviations may be attributed to mechanical deformations. In order to establish sensitivity guidelines for different mechanicalfaults, high frequency transformer modeling is utilized.

The transformer behaviour above operational frequencies has been subjected toresearch for nearly a hundred years, since the recognition of the capacitivebehaviour at impulses . Many different techniques of modeling have beendeveloped since then, depending on the application of the model. Experimentalwork was the basis during the first 50 years. The introduction of computers led topossibilities of solving complex problems such as internal voltages inside atransformer winding at high frequencies.

FRA (Frequency Response Analysis)

Deviations observed in FRA measurements can be related to actual winding deformations by means of a detailed high frequency model of the transformer.

A FRA-signature is generally a transfer function output/input as a function of frequency (50 Hz - 1 MHz), usually measured at very low voltages. Typicallywinding admittances, voltage ratio between windings, or the attenuation is measured. Measured signatures are compared to a reference. The reference is usually other phases (symmetric comparison), an earlier measurement (time-based comparison), or similar transformers (construction-based comparison). Assuming a detailed model based on constructional information is accurate, comparison would be possible also between model and measurement. Changes/differences are attributed to geometrical changes inside the winding.

HFMODELS

A. Physics-based models

This type of model is close to the real behavior of thereal transformer . The main drawback of this approachis the neccessity of information about the physicalstructure of the machine, including dimensions, materialsand geometry. The needed data is raraley provided by thetransformer manufacturer. Fig 1 shows a finite elementsmodel using the physical description of the machine.

B. Black-box models

Black-box models are suitable to obtain the HF behaviour of the transformer when it is difficult to obtain Information about machine. The basic idea is obtain the transfer function using transient information about voltage and current.

(a) Image of the real transformer

(b) Finite Elements model

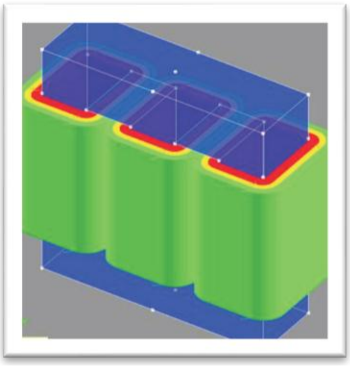

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Figure 1.Finite elements description of a laboratory transformer.

The admittance matrix is definedin the frequency domain in ranges that goes from 50 Hz to 1 MHz. Numerical models are introduced based on two-port network theory where its parameters are computed at different resonance frequencies which are experimentally measured.

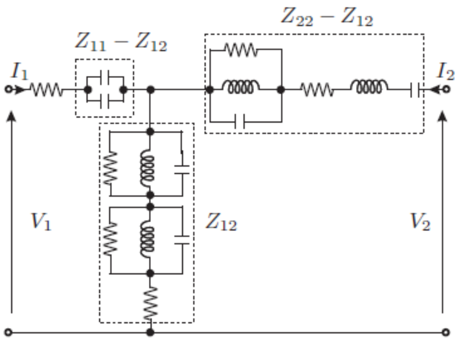


Figure 2. HF two-port description of a laboratory transformer [5].

MODEL COMPARISON

A set of different aspects are assessed regarding the applicability of FRA as adiagnostic method. Some of the most common fault-modes are simulated in orderto establish initial sensitivity guidelines for FRA interpretation. Since this work isfocused on one particular transformer rather than several different designs, theguidelines established here should not be generalized. It is therefore pointed outthat future investigations on other designs and types are important.model comparative has been made by introducing a setof basic parameters related with three key points. Model the type of model from the point of viewof their physical meaning. There are twomain sets:

i) Physical. The parameters ofthe model have a physical equivalent and

ii)Black-box. The parameters are computedusing a mathematical approach withoutconsidering their physical meaning.Frequency The range of frequency in which the modelis accurate enough. The frequency spectrumis partitioned in three bands.

i) dc -2.5 kHz
ii) 2.5 kHz - 1 MHz and
iii) 1MHz to ∞.

Data The theoretical or experimental approachfollowed to obtain the parameters:

i) Nameplatedata;
ii) Experimental high-frequency(HF) data;
iii) Experimental low-frequency(LF) data and
iv) Finite elements software.

Table I summarizes a comparison between models according to different criteria. The comparison includes information about the data source, the type of modelused and the experimental approach needed for parameter extraction.

There are mainly 3 types of faults considered in this thesis:

- Axial displacement
- Radial deformation (Buckling)
- Disc-to-disc short-circuit

The first are mechanical faults and the last being an electrical fault.

P-Q REQUIREMENTS

The standard IEEE Std. 1159 provides a detailed description of each disturbance in terms of their typical spectral content, duration and magnitude. The summary provided by table II can be used as a reference point in order to define the models in terms of frequency spectrum and amplitude. The amplitude is also important because the saturation problem. At low frequencies (between 50-60 Hz and 3 kHz) it is expected that classic models could be extended to consider harmonic losses and additional saturation.

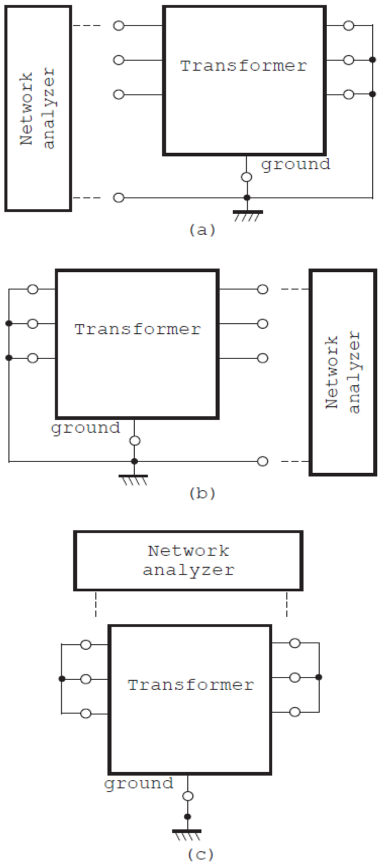
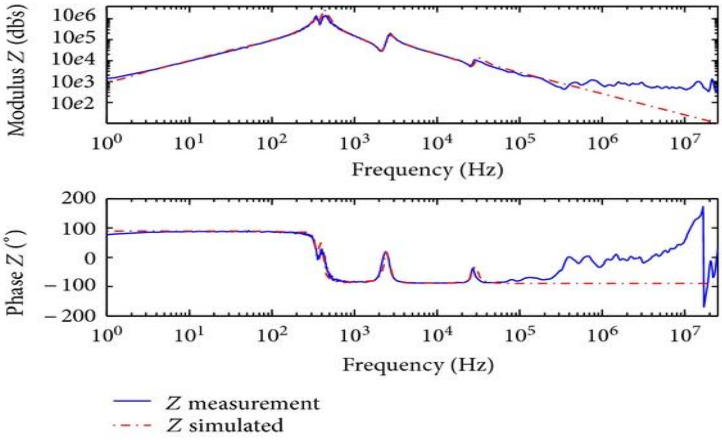


Figure 3. Transformer connection for the capacitance measurement.

It shows an inter-phase comparison with deviations in a verylocalisedfrequency range (10-100 kHz). The difference at 15kHz is very interesting: Theouter phases have quite identical traces with two small peaks, while the centrephase has only one distinct peak. There also seem to be some disagreement justabove 100kHz. This can probably be attributed to the influence of the tapchangeras described in fig. It is also interesting to note the consistency of the measurements up to 7 MHz,which indicates that inter-phase comparison of admittances can be used foradmittance up to this frequency for this transformer size. The resemblance between the phases is very high from 200 kHz to 7MHz. Since mechanical damages usually influence on the FRA signature in this frequency-range, an interphasecomparison will supply a sufficient sensitivity.



COMPARISON BETWEEN DIFFERENT TRANSFORMER HF MODELS.

COMPARISON BETWEEN DIFFERENT TRANSFORMER HF MODELS.

		Model				
		Abed [1]	Sabiha [5]	Gustavsen [4]	Zhongyuan [7]	Abeywickrama [3]
Model	Physical	✓				✓
	Black-box		✓	✓	✓	
Frequency	$f \leq 2.5$ kHz					
	2.5 kHz $< f \leq$ 1 MHz	✓		✓		✓
	$f >$ 1 MHz		✓		✓	
Data	Nameplate					
	Experimental HF		✓	✓	✓	
	Experimental LF					
	Finite elements	✓				✓

CATEGORIES AND TYPICAL CHARACTERISTICS OF POWER SYSTEM ELECTROMAGNETIC PHENOMENA AS DEFINED IN IEEE STD. 1159 [9] VS SIMULATION MODEL.

Categories	Typical spectral content	Typical duration	Typical voltage magnitude	model
1.0 Transients	5 ns rise 0.55 MHz	< 50 ns	0 8 pu	Sabiha [5] and Zhongyuan [7]
2.0 Short-duration root-mean-square (rms) variations		Between 0.5 cycles and 1 min	0.1 - 1.8 pu	Classic models
3.0 Long duration rms variations		> 1 min	0 - 1.2 pu	Classic models
4.0 Imbalance		steady state	0.5 - 30 %	Classic models
5.0 Waveform distortion	09 kHz and broadband	steady state	0 - 20 %	Abed [1], Gustavsen [4] and Abeywickrama [3]
6.0 Voltage fluctuations	< 25 Hz	intermittent	0.1 - 7 %	Classic models
7.0 Power frequency variations		< 10 s	± 0.10 Hz	Classic models

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Set-up :-The set-up facility allows us to obtain the parameters of the model. It is necessary to carry out three different sets of measurements:
1) open-circuit.
2) short-circuit.
3) capacitance measurement.

The connections used for open-circuit and short-circuit follow the classical approach that is used at nominal frequency (50 or 60 Hz). For the measurement of capacitances it has been proposed three configurations. summarizes the three configuration needed for the

- capacitance measurements:
- Input capacitance. Fig. a shows the configuration for the measurement of the input capacitance.

- Output capacitance. Fig. shows the configuration for the measurement of the output capacitance.

I-O capacitance.Fig.shows the configuration for

- the measurement of the input to output capacitance.

CONCLUSIONS

This research work establishes a comparison between different models that can be used for high-frequency modeling. The comparison includes different criteria like the type of model and the experimental methodology and set-up. In a future work the models will be evaluated in a experimental way in order to compare their accuracy.

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