Electrical Power and Energy Systems 43 (2012) 358–363

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Transformer diagnosis based on two low frequencies waveforms

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ARTICLE INFO

Article history:
Received 6 May 2010
Received in revised form 13 May 2012
Accepted 14 May 2012
Available online 30 June 2012

Keywords:
Diagnostic
Coupled circuit method
FRA
Transformer faults

ABSTRACT

The health of power transformer is important for the reliability of electrical power grid. There are various methods of evaluating the frequency spectrum to confirm the presence of an incipient fault. So, the accuracy of FRA method suggested by many researchers for predictive defections, has been discussed; and the robustness (efficiency, simplicity and fast diagnosis) of the proposed 2LFW as a substitution diagnostic process has been detailed and proved. It should be noted that the proposal is general and can be applied to different transformer, without any comparison to a reference signal. Furthermore the diagnosis can be done even for transformers in operation mode (in service), thus avoiding economical losses.

1. Introduction

Transformers are valuable equipment which makes a major contribution to the supply security of a power system. Protective devices are an important part for detecting fault conditions in a power system. The appropriate protection scheme must be selected to ensure the safety of power apparatus and reliability of the system. Generally, power transformers can be protected by over-current relays, differential relays depending on purposes. The differential protection is aimed at detecting internal faults in transformer windings after an important defection.

So the diagnostic methods are systematically being improved and extended due to growing requirements for reliability of power systems in terms of uninterrupted power supply and avoidance of blackouts. Hence, the detection of winding faults in transformers, during exploitation is an important aspect of power transformer failure prevention.

If a transformer is inflicted by a fault and based on these warnings, necessary actions like preventing maintenance could be taken. Before an unplanned outage of a power transformer can cause a very important socio-economical prejudice.

Consequently, it is of great importance to minimize the frequency and duration of unwanted outages of power transformers. The transformer defects are of various natures; this paper interests to electric types.

The investigations show that transformer failures are meanly caused by internal winding short-circuits faults [1] (e.g. winding erosion and conductor insulation due to vibrations initiated by the electromechanical forces).

In the majority of the cases, transformer is disconnected by its protection systems, which react only if the transformer undergoes a serious incident, such as; transformer differential protection witch contains a number of additional functions (matching to transformation ratio and vector group, restraint against inrush currents and over-excitation). Therefore it requires some fundamental consideration for configuration and selection of the setting values. Optimum design of the transformer protection ensures that any faults that may occur are cleared quickly so that possible consequential damage is minimized.

2. Transformer faults detection

The partial internal winding short-circuit faults leads to overcurrent in windings that result terrible damages [2] such as severe hot-spots, oil heating, winding deformation, damage to the clamping structure, core damage, and even explosion of transformer.

The ideas is to detect faults at there embryonic states. And, is conditioned neither by the transformer Plug off (disconnection) nor by its operation mode. So, Frequency Response Analysis (FRA) is found to be a useful tool for reliable detection of incipient fault in a transformer [3], by finding winding or core defects. It is a powerful and sensitive method to evaluate the mechanical integrity of core, windings and clamping structures within power transformers by measuring their electrical parameters in a wide frequency range. Thus, contribute to maximum supply security, and to avoid expensive unexpected outages. Unfortunately, this technique engages very complex procedures, with a preliminary knowledge of all defects to be inspected, in addition to a very

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http://dx.doi.org/10.1016/j.ijepes.2012.05.021

Nomenclatures

$L_1^p; L_1^s$	self inductance of coil 1 of respectively primary and secondary winding
L^p; L^s	self inductance of respectively primary and secondary winding
L_{p-cc}^p	self inductance of short circuited coils1 primary and winding
$M_{1-n}^p; M_{1-n}^s$	mutual inductance between of coil 1 and n of the same winding
$M_{1-m}^{p,s}$	mutual inductance between of coil 1 and m of primary and secondary winding
$M^{p,s}$	mutual inductance between of primary and secondary winding
$M_{p-cc}^{p,p}$	mutual inductance between of short circuited coils the same winding
$M_{p-cc}^{p,s}$	mutual inductance between of short circuited coils of primary and secondary windings
$\psi_1^p; \psi_1^s$	electromagnetic field of coil 1 of respectively primary and secondary winding
ψ^p; ψ^s	electromagnetic field of respectively primary and secondary winding
M; N	coils number of respectively primary and secondary windings
Kp; Ks	short circuited coils index of respectively primary and secondary windings
Mp; Ns	short circuited coils number of respectively primary and secondary windings
I^p; I^s	primary and secondary current respectively
γ, λ	unbalance ratio at the window frequency of respectively primary and secondary currents
PWM	pulse width modulation
Fm	modulation frequency (simple frequency)

qualified operator. Moreover, the detailed *R–L–M–C* model must be valid for the frequency range of 10 kHz to a few MHz, so, inclusion of hysteresis and skin effect are necessary to have a more realistic response [4]. This point only adds the complexity of solution method.

In fact, the FRA is a comparative method, i.e. an evaluation of the transformer condition is done by comparing an actual set of FRA results to reference results. Three methods are commonly used to assess the measured traces:

1. FRA results will be compared to previous results of the same unit.
2. FRA of one transformer will be compared to a type-equal one.
3. FRA results of one phase will be compared to the results of the other phases of the same transformer.

The proposal described in this article, in addition to its simplicity and fast diagnosis, requires neither preliminary knowledge, nor qualified operator.

3. Coupled circuit method

The windings belong to the active part of a transformer, and their function is to carry current. They are arranged as cylindrical shells around the core limb. It is considered that the electromagnetic coupling of each phase winding is perfect, and strongly tight one with the other; consequently, they make an equality approximation between self and mutual inductance unit.

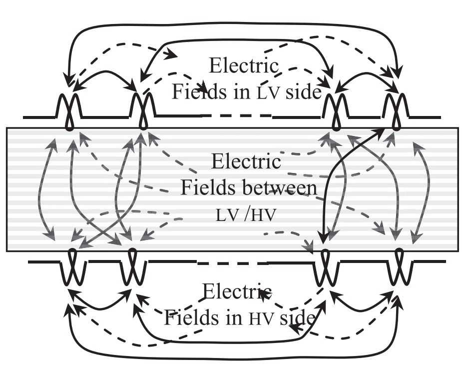

Fig. 1. Internal interactions of coils in the transformers.

Spectral analysis method is based on a closely perfect modeling of the transformers by taking in account electromagnetic and electrostatic fields (electric fields) Fig. 1. The analysis and the detection of faults are based on the comparison to the reference data and harmonics signature. Therefore, the transformer is divided into several portions of windings (coils); considered as several circuits in interactions [5]. Each element in defect found its own harmonic signature; this means the recorded signals must be pre-processed for noise suppression before they can be used for faults localization and the reading and analysis defects became more complex; generally require artificial intelligence [6], such as the neuron networks [7] or fuzzy logic [8].

The elements which make the study more complex is the relationship between *L–M–C*, created by the electric fields. The annular distribution of the current inside the wire influences negatively its own resistance and inductance in the case of the high frequencies. The effects of skin and proximity [9] are the consequences of fields induced in a coil by itself or by the nearest coils Fig. 2. This effect can be expressed in the form of self and mutual inductances [10].

Then magnetic flux ψ_1 created by coil 1 is expressed as:

$$\psi_1 = L_1 i_1 + M i_2 \tag{1}$$

where L_1 and M are respectively, self and mutual inductance.

If a coil in addition to its owner field, is surrounded by other coils [11] Fig. 1, in this case they interact through inductances so called as mutual ($M_{k,j} = M_{j,k}$). This interaction can be put in equation thanks to several theories such as the finite element method and fuzzy logic [12,13] but, the coupled circuits method [14] offers an analytical development Moreover, it gives most possible exhaustive modeling of transformers.

Electro-magnetic fluxes of all coils in primary and secondary side of transformer Ψ vs. current relationship are given by (2).

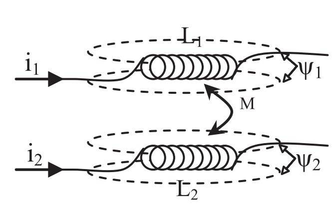

Fig. 2. Effect of self and mutual inductances.