Transformer Diagnostics

For Fault Identification in the Winding

Introduction

To assess the condition of the winding of a high voltage power transformer, comparison of applied voltage and resultant neutral current signal will be used at reduced and full voltage levels. Any difference in the wave shape of the recorded neutral current and voltage signals at reduced and full voltage levels show the existence of fault in the transformer winding. Partial or complete failure of a transformer winding is reflected in the change of voltage or neutral current transient characteristics. The change in characteristics depends mainly on the extent of failure. A disc to disc failure in transformer winding may result in an instantaneous dip in the voltage and corresponding change in neutral current, whereas a winding failure may result in sudden collapse of voltage and abrupt rise in current. In order to detect such faults Transfer Function method is widely used which gives frequency response characteristics[2]. But determining the exact location of the type of fault is subject of detail research. Frequency response analysis has been used to detect the fault in the winding based on dominant frequencies in the recorded neutral current and to arrive a percentage change in dominant frequency with perspective fault locations[3]. The frequency response method is a comparative method in which the measured neutral currents for faulty winding and healthy winding are compared to quantify the deviation in the frequency characteristics. In the present investigation a low voltage impulse was applied from Recurrent Surge Generator (RSG) at one end of the high voltage winding and the transient neutral currents are recorded oscillographically across a 20Ω shunt for healthy as well as disc to disc short at various locations in the winding. The time domain input signals are converted into frequency domain using Fast Fourier Transform and the transfer function is obtained[4]. The investigation is carried out to study the frequency response behaviour for various disc faults created along the height of high voltage winding.

Fast Fourier Transform (FFT)

FFT is an algorithm that efficiently computes the Discrete Fourier Transform. The Fourier Integral is defined by the expression.

$$S(f) = \int_{-\infty}^{+\infty} s(t)\, e^{-j2\pi ft}\, dt$$

This method will isolate a peak at one particularly frequency of interest. But if the signal is built of two pure oscillations occurring in two adjacent intervals, two peaks are obtained without localization in time.

For the FFT analysis the Transfer Function of trans-admittance magnitude is obtained by dividing neutral current transform by the applied impulse voltage transform. This transfer function being the ratio and results obtained in frequency domain, characteristically define the transformer behaviour and thus is independent of the applied input signal.

$$\text{TF magnitude} = \frac{I\ (t)}{V\ (t)}$$

S (f) is the Fourier Transform of s (t)

Experimental Studies on Power Transformer

The details of the transformer used and experimental method adapted are described below:

Description of Transformer

The Generator Transformer and test setup used for experimentation is of power rating of 61 MVA and voltage rating 11.5/230 kV is shown in Fig 1.

Fig 1 Generator Transformer winding configuration

The High Voltage winding is of two-group construction with center entry type having a total of 112 discs. Due to symmetry only half of the winding is used for experimental studies.

Application of Recurrent Surge

A low-voltage impulse with peak magnitude 100 volts from RSG (type 481) is applied to the winding. The parameters of RSG are adjusted such that the required input wave shape of 1.2/50µs is achieved. The neutral end of the high voltage winding is connected to earth through a non inductive 20 Ω resistor shunt.

The input voltage and output neutral current are simultaneously measured using Nicollet make digital storage oscilloscope. In order to carryout experiment, the paper insulation from the outer turn of each disc in the winding is removed to have an access to the bare copper conductor of the discs. The bare portions of the conductors were physically stored to create the disc short and corresponding neutral currents were recorded.

The experimental recording of neutral current on CRO and disc faults created at different locations are shown in Fig 2.

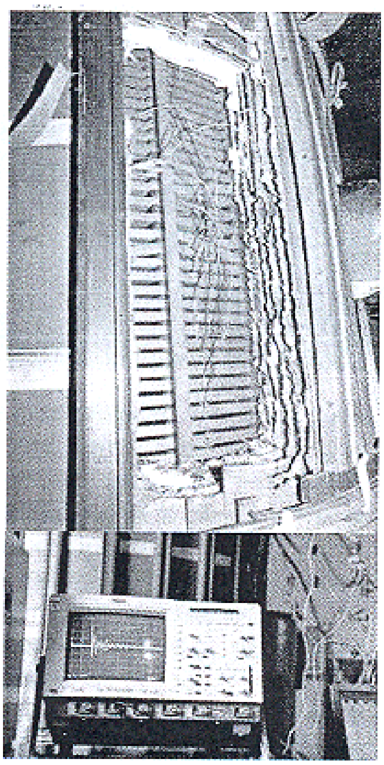

Fig 2 Test setup showing recording of neutral current on CRO

The schematic diagram of the test setup is shown in fig 3.

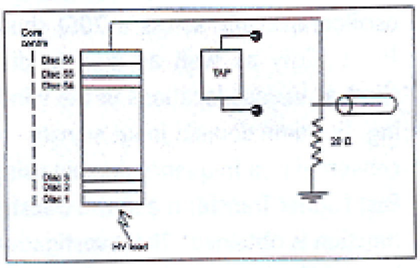

Fig 3 Schematic diagram of the test setup

A transformer winding can be modeled by sub-dividing windings into large number of sections, each section represented by self-inductance, mutual inductance and capacitance, parameters with all other sections of the same winding and also with other windings.

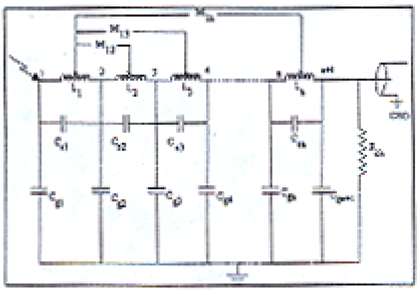

Fig 4 Equivalent electrical network of the winding

An equivalent electrical network showing the disc and node distribution along the height of the transformer winding is shown in Fig 4.

L_1, L_2 --------- L_n are self inductance of each section.

M_1, M_2 ---------M_n are mutual inductances.

C_{s1}, C_{s2} --------C_{sn} are series capacitances of the sections.

C_{g1}, C_{g2} --------C_{gn} are capacitances of the sections to ground.

R_{sh} ------ is shunt resistance for coupling neutral current.

The following cases were considered for recording neutral current for shorted discs.

* Healthy winding (without fault)
* 2-4 discs shorted
* 2-6 discs shorted
* 2-10 discs shorted
* 2-12 discs shorted
* 2-14 discs shorted
* 2-16 discs shorted

Results and Discussion

Changes in any one of the winding parameters will change the frequency response characteristics of the neutral currents. The typical neutral current wave forms for healthy and winding with 2-4 discs fault are shown in Fig 5(a) and 5(b).

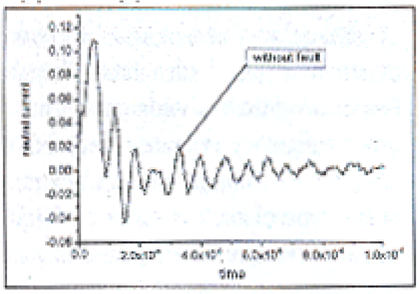

Fig 5 a Neutral current without fault

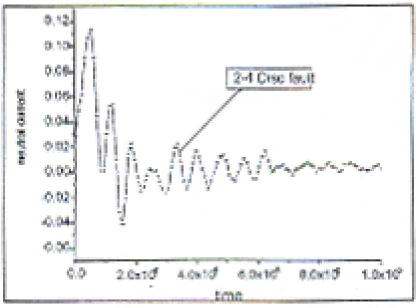

Fig 5 b Neutral current with 2-4 discs shorted

These recorded neutral currents are converted into ASCII data. The record length of the acquisition is maintained same throughout the experiment to obtain equal time intervals for comparision.

Fast Fourier Transform was calculated for the neutral currents for healthy winding and winding with faults to obtain dominant frequency peaks. A typical FFT waveform for healthy winding and winding with disc faults are given in Fig 6.

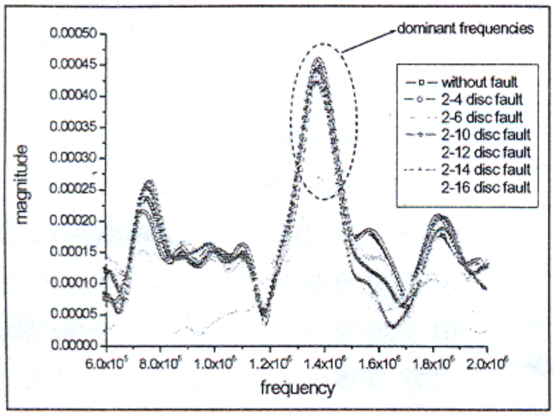

Fig 6 Comparative plot for frequencies

It is also observed that with respect to frequency shift, there is a specific trend related to length of the winding. The dominant frequencies and percentage change in individual frequency are given in Table I.

Table I Dominant frequencies and percentage change with different disc faults

Description of fault	Frequency (Hertz)	% Change in frequency
No fault	1396755	0.000
2 to 4	1394404	0.168
2 to 6	1394260	0.178
2 to 10	1393215	0.253

2 to 12	1389935	0.488
2 to 14	1387479	0.664
2 to 16	1385508	0.805

The shift in dominant frequencies for healthy winding and winding with different faults are shown in Fig 7.

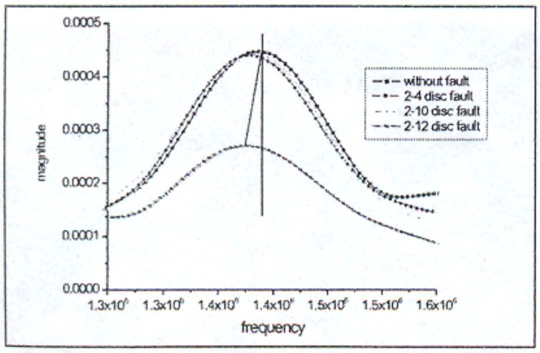

Fig 7 Dominant Frequency Pattern for Different Disc Faults

From the careful examination of the Table I reveals that there is a specific trend in percentage change in dominant frequencies with respective disc fault. The percentage change in frequency and length of the conductor with respective fault location are given in Table II.

The length of the conductor is calculated from the winding configuration. A characteristic curve has been derived between percentage change in frequency ~ percentage change in length as shown in Fig 8. From the figure, it is evident that percentage change in frequency is almost linear to the percentage change in length of the winding.

Table II Percentage change in frequency and length of conductor for different faults

Description of fault	Winding length	% Change in length	% Change in freq
56 discs (wf)	3094.784	0.00	0.000
2 discs	2984.256	3.57	0.168
4 discs	2873.728	7.14	0.178
6 discs	2763.200	10.71	0.194
8 discs	2652.672	14.29	0.253
10 discs	2542.144	17.86	0.488
12 discs	2431.616	21.43	0.664
14 discs	2321.088	25.00	0.805

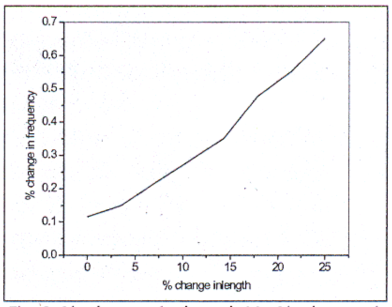

Fig 8 % change in length Vs % change in frequency

Conclusions

Fast Fourier Transform is a very good tool for neutral current analysis to obtain the dominant frequencies. FFT analysis reveals the shifting of frequency pattern if any fault occurs in the winding during impulse application. Minor faults like disc-disc in the winding of transformer can be detected using FFT. It is possible to correlate the percentage shift in dominant frequencies with respective fault location along the winding. Relation can also be established between percentage change in frequency and length of conductor, further work has to be carried out to establish the exact relationship.

REFERENCES

1. IEEE Guide for Transformer Impulse Tests IEEE std C57. 98-1993.
2. R Malewski and B. Poulin, Impulse Testing of Power Transformers using the Transfer Function Method, IEEE Transaction on Power Delivering Vol 5, No.2, 1990, pp. 1007-1012.
3. R Vanaja and K Udayakumar, Fault Location of power transformer during Impulse Test, IEEE Transaction on power delivery Vol 3, No. 2, 1998, pp 476-489.
4. V Jaya Shankar, R Vanaja Rajan, K Lokesh Babu, K N Prashant Kumar, P Pravin Kumar, Time Frequency analysis of Transient Signals, Fifth International Conference on Transformers, TRAFOTECH 1998.

Reference Book

IEEMA Journal
September 2006