Chapter 3

Digital signal Processing Method applied for Condition Monitoring of Transformer

3.1 Introduction

Reliability of diagnostic techniques plays a key role in quality assessment. With the development of new technology, possibilities to introduce new techniques are increased. On top of this, factors including electrical system reliability, cost reduction, environmental concerns and development of new materials, force to use the new techniques for diagnostic purposes.

Method should rely on detecting the effects of the resulting local change produced by a fault so that incipient fault in transformer can be located. For this purpose, frequency response measurement methods were vastly improved during the last two decades as a result of the improvements in electronics [39]. However, Frequency response measurements in wide bands of frequency and time were not used for diagnosis of high voltage insulations, until the recent past. Development of fast computers and digital signal processing technologies made a major break through for versatile use of the response measurement techniques both in the laboratory and in the field [40],[32].

Various methods are studied to diagnosis the incipient fault in transformer using advanced DSP techniques in this resarch work and described in next sections.

3.2 Detection of incipient turn to turn fault by wavelet analysis of impulse neutral current

Insulation failure is the major cause for most of the Power Transformers failing in the field. Hence, power utilities are more concerned about the reliable operation of the transformer to prevent the power outage due to insulation failure. To insure proper design and manufacturing techniques for providing adequate insulation in transformer, Standards (IEC:76, IS:2026)[24] give guidelines for conducting specific tests like Impulse, Partial discharge, High voltage test.

During impulse test, Impulse voltage is applied several number of times in each phase and the impulse voltage and neutral current waveform are recorded. According to standard, impulse voltage and neutral current should be compared visually after each test. During visual comparison, if no deviation in the shape of Impulse voltage and neutral current waveform is observed after each shot, transformer is considered to have conformed to the requirement of standard. Also, if there is a major failure, significant deviation in the shape of Impulse voltage and neutral current waveform will be observed and transformer is considered as not conforming to the requirement of standard .

But in case of minor deviation in the waveform, it becomes difficult to analyze the waveform in time domain only. For example, during the test if there is some insulation failure between coils for a few microseconds due to application of impulse voltage, it will be recorded as sudden small dip in voltage at that particular moment and same may be reflected in neutral current also in the form of leakage current or discharge. This weak point of insulation may be dangerous when transformer is installed in the field. Hence, to ensure proper insulation, this type of deviation should be analyzed in frequency domain with respect to time, which will be helpful in identifying the location of the fault and also type of fault[48].

Digital signal processing (DSP) techniques are being used for extraction of useful information from signals measured at the terminals of transformer[7]. In this context, signal can be any waveform like impulse voltage, neutral current, electrical and acoustic signal of partial discharge.

Wavelet analysis is one of such tools, being used in this area and other areas for this purpose. Impulse voltage and neutral currents are considered to be non-stationary signal, which can change in time axis depending upon severity of fault. And for analyzing non-stationary signal Wavelet analysis is best DSP tool[19]. By using discrete wavelet analysis, voltage and current waveforms can be subdivided into different frequency band. In each frequency band, these waveforms can be compared with respect to time.

3.2.1 The Discrete Wavelet Transform (DWT)

In the discrete wavelet, filters of different cutoff frequencies are used to analyze the signal at different scales. The signal is passed through a series of high pass filters to analyze the high frequencies, and it is passed through a series of low pass filters to analyze the low frequencies. A time-scale representation of a digital signal is obtained using digital filtering techniques like this.

The resolution of the signal, which is a measure of the amount of detail information in the signal, is changed by the filtering operations, and the scale is changed by upsampling and downsampling (subsampling) operations.

Subsampling a signal corresponds to reducing the sampling rate, or removing some of the samples of the signal. For example, subsampling by two refers to dropping every other sample of the signal. Subsampling by a factor n reduces the number of samples in the signal n times.

Upsampling a signal corresponds to increasing the sampling rate of a signal by adding new samples to the signal. For example, upsampling by two refers to adding a new sample, usually a zero or an interpolated value, between every two samples of the signal. Upsampling a signal by a factor of n increases the number of samples in the signal by a factor of n.

The DWT analyzes the signal at different frequency bands with different resolutions by decomposing the signal into a coarse approximation and detail information [26]. DWT employs two sets of functions, called scaling functions and wavelet functions, which are associated with low pass and highpass filters, respectively. The decomposition of the signal into different frequency bands is simply obtained by successive highpass and lowpass filtering of the time domain signal. The original signal x[n] is first passed through a halfband highpass filter g[n] and a lowpass filter h[n]. This constitutes one level of decomposition and can mathematically be expressed as follows:

$$y_{high}[k] = \sum_{n} x[n] - g[2k-n] \tag{3.1}$$

$$y_{low}[k] = \sum_{n} x[n] - h[2k - n] \tag{3.2}$$

where $y_{high}[k]$ and $y_{low}[k]$ are the outputs of the highpass and lowpass filters, respectively, after subsampling by 2.

The above procedure, which is also known as the subband coding, can be repeated for further decomposition [15]. At every level, the filtering and subsampling will result in half the number of samples (and hence half the time resolution) and half the frequency band spanned (and hence double the frequency resolution). Figure 3.1 illustrates this procedure, where x[n] is the original signal to be decomposed, and h[n] and g[n] are lowpass and highpass filters, respectively. The bandwidth of the signal at every level is marked on the Figure 3.1.

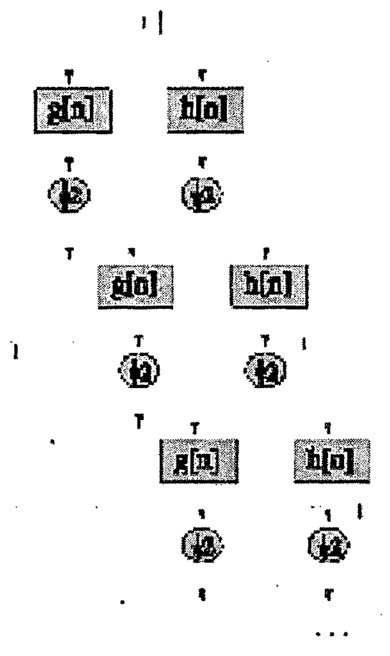

Figure 3.1: Signal stage Filtration by DWT

As an example, suppose that the original signal x[n] has 512 sample points. At the first decomposition level, the signal is passed through the highpass and lowpass filters, followed by subsampling by 2. These 256 samples constitute the first level of DWT coefficients.

This process continues until two samples are left. For this specific example there would be 8 levels of decomposition, each having half the number of samples of the previous level. The DWT of the original signal is then obtained by concatenating all coefficients starting from the last level of decomposition (remaining two samples, in this case). The DWT will then have the same number of coefficients as the original signal.

The frequencies that are most prominent in the original signal will appear as high amplitudes in that region of the DWT signal that includes those particular frequencies. The difference of this transform from the Fourier transform is that the time localization of these frequencies will not be lost. However, the time localization will have a resolution that depends on which level they appear. If the main information of the signal lies in the high frequencies, as happens most often, the time localization of these frequencies will be more precise, since they are characterized by more number of samples. If the main information lies only at very low frequencies, the time localization will not be very precise, since few samples are used to express signal at these frequencies. This procedure in effect offers a good time resolution at high frequencies, and good frequency resolution at low frequencies. Most practical signals encountered are of this type. The frequency bands that are not very prominent in the original.

3.2.2 DWT analysis of neutral current waveform

By using wavelet analysis, impulse voltage waveform of a healthy transformer and faulty transformer has been compared in frequency domain with respect to time. After comparing the two waveforms in high frequency domain, presence of high frequency component has been found in case of faulty transformer due to irregular shape of the waveform. Hence, if there is any dip in the voltage, due to some insulation failure between coils or any other reason, it can be traced very easily with the help of wavelet analysis [36].

Similarly by using wavelet analysis, neutral current waveform of a healthy transformer and a faulty transformer has been compared.

For a 50 MVA , 132/11 kV transformer, the neutral current waveform is analyzed by DWT which has deviation in wave shape from previous one . In DWT analysis of neutral current, after some time delay transient oscillatory signal has been found in a particular frequency band (approx. 35-8 MHz.) as shown in Figure 3.2. Presence of this signal at high frequency depicts capacitive current or leakage current through transformer, after the application of impulse voltage and that was confirmed as an incipient turn to turn fault in Partial discharge test.

This type of additional information can be obtained very easily and further work can be carried out in this area to identify the exact type of fault and its location, so that faulty transformer can be repaired fast and easily[30,31].

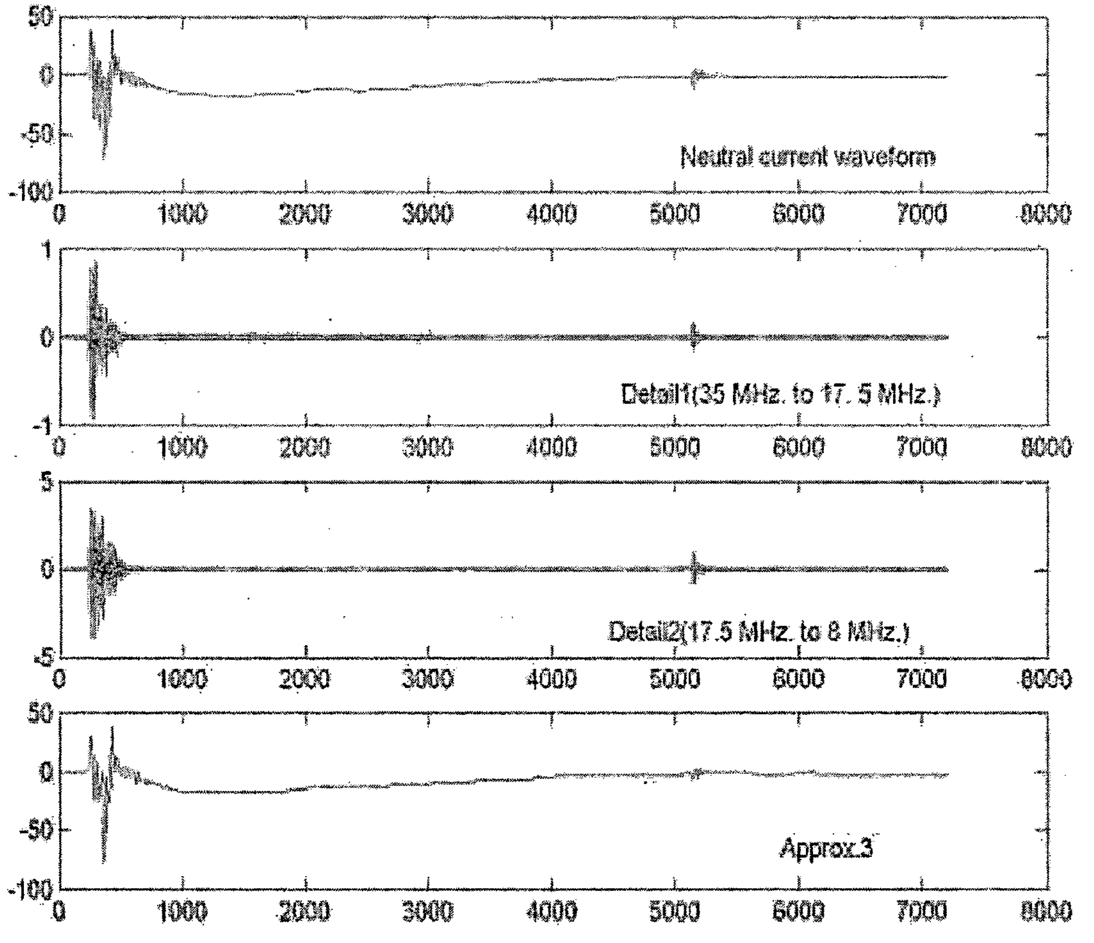

Figure 3.2: DWT of neutral current waveform

3.2.3 Finding from Analysis of waveform

1. DWT gives simultaneous information of both the time and frequency distribution of the input signal. Hence we can identify the frequency band of the minor fault for analysis. It has been applied to the neutral current for the detection of minor fault. In the above mentioned case, the 'db3' wavelet is used for the analysis.

2. From the above analysis as shown in Figure 3.2, it has been found that minor fault which started at 70 microsecond (confirmed by Partial discharge test) has frequency bandwidth of 35 MHz. to 8 MHz.

3. Also, it is very clear from analysis that neutral current has some high frequency component having frequency between 35 MHz. to 17.5 MHz. which is not very clear from the original neutral current waveform and it stared at 8 microsecond and continued up to 37 microsecond only, which indicate some incipient discharge due to poor quality of inter-turn insulation.

3.2.4 Limitation of the method

The analysis of turn to turn incipient fault was performed by DWT analysis of the neutral current signal obtained during impulse test and it is a very effective method for incipient fault detection in Transformer. The only limitation is that it is a laboratory method and can not be applied to aged transformer installed in the field.

3.3 Impedance measurement in frequency range from 10 kHz. up to 10 MHz.

Impedance measurement method for detecting very low order of winding deformation has been developed, which can be used for analysis having frequency range of 10 kHz. to 10 MHz in the field [40]. A high frequency sinusoidal signal (10 kHz to 10 MHz) is applied to one winding of transformer and the applied signal , the capacitive coupled current and inductive current in the winding are recorded as as per the experimental setup shown in Figure 3.3. Changes in capacitance and inductance of the winding as well as changes in the inter-turn winding capacitance and inductance, caused by winding movement will be reflected in the change of the amplitude of the current.

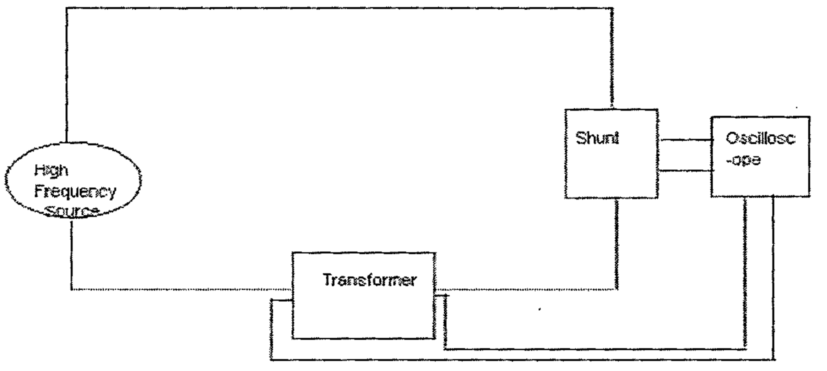

Figure 3.3: Experimental setup of Impedance Measurement

The voltage signal Vi is applied between the winding terminals at variable frequency (10 kHZ. to 10 MHz.) and current I is measured at each frequency. Hence, impedance Z (Vi/I) is measured for each frequency and a curve is obtained between impedance Z and frequency.

Such a Impedance versus Frequency curve for one of the high voltage (HV) windings of 500 kVA, 11000/433V, delta-star distribution transformer is shown in Figure 3.4.

3.3.1 Impedance measurement During short circuit test of transformer

During short circuit of distribution transformer, current flowing through each winding is 20 to 25 times of the rated current depending on percentage impedance value and forces on the winding during short circuit will be 400 to 625 times more than the normal force. To consider the effect of these forces on the displacement of winding, impedance versus frequency plot is obtained before and after the short circuit test as per the procedure mentioned in the previous section. Impedance versus frequency plot, before and after short circuit was compared for each phase individually. If, there is no significant change in winding configuration, both the plots was identical.

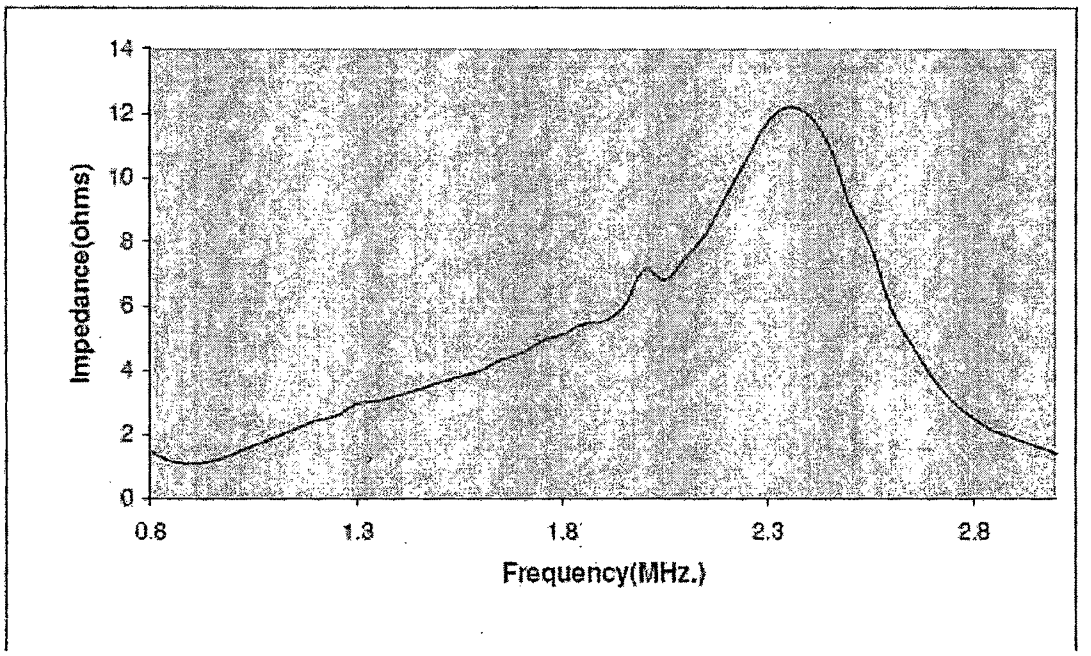

Figure 3.4: Impedance versus frequency plot of HV winding

3.3.2 Case Studies of faulty transformers after Short circuit test in Laboratory

A few cases of failure observed during the short circuit test of transformer and Impedance versus frequency plot analysis has been performed as mentioned below.

For, 500 KVA, 11/0.433 kV distribution transformer,dynamic ability to withstand short circuit test was conducted as per IS:2026-1977. During the test , nine times short circuit current is passed through transformer for 0.5 sec. duration each time. Transformer withstood all the shots and change in percentage reactance was within the limit of 2.0 percent as mentioned in standard.

After short circuit test , No load current and losses measurement was performed. The No load current observed abnormally high, 32.05 A at very low voltage 8.52 V, which indicates inter -turn fault in LV winding. Impedance versus frequency measurement was conducted on the transformer before and after short circuit test . The response curve was obtained for the low voltage (LV) windings for frequency range (10 kHz. to 10 MHz.) before and after short circuit. The variation is significant in middle phase LV winding as shown in Figure 3.5.

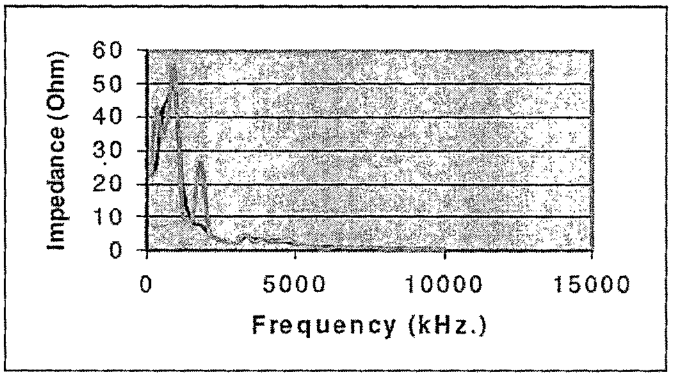

Figure 3.5: Impedance versus frequency plot of Y-phase , LV winding

It is clear from the Figure 3.5, that there is change in inter-turn capacitance and self inductance of the winding due to inter-turn insulation failure in that winding .The transformer was opened after the short circuit test and verified that it was turn to turn failure in LV winding.

3.3.3 Case studies of Aged Transformer in Feild

CASE 1: Measurement on Power transformer.

Test has been conducted on various transformers in a power generating station for the first time. Impedance plots of 100 MVA, 220 kV/7.0 kV, 3-phase Station transformer has been shown in the Figure 3.6 and 3.7, having two winding HV and LV.

Test has been carried out for all frequency range from 10 kHz. to 10 MHz. in three phases of LV winding. After plotting the graph Impedance versus frequency as shown in Figure 3.6, it has been found that resonance frequency of the winding for all three phases are in same range and also pattern of the plot is same i.e. r-n phase - 5.1 MHz, y-n phase - 4.9 MHz, b-n phase - 4.8 MHz.

Similarly, test has been carried out for all frequency range from 10 kHz. to 10 MHz. in three phases of HV winding as shown in Figure 3.7, the resonance frequency of the winding for all three phases are in same range also pattern of the plot is same i.e. R-N phase - 5.1 MHz. , Y-N phase - 5.1 MHz., B-N phase - 5.0 MHz.

From the comparison of three phases plots and their resonance frequencies, it is concluded that there is no such mechanical deformation in the winding and these plots can be taken as reference plot for comparison in future.

Any power transformer has its unique plot for Impedance in different frequency range having different resonance frequency. By experiment it have been concluded that in the range of 10 kHz. to 10 MHz. , we have found response, which is not prone to any noise, as we are doing direct measurement through oscilloscope suitable for high frequency measurement and waveforms are continuously monitored during measurement.

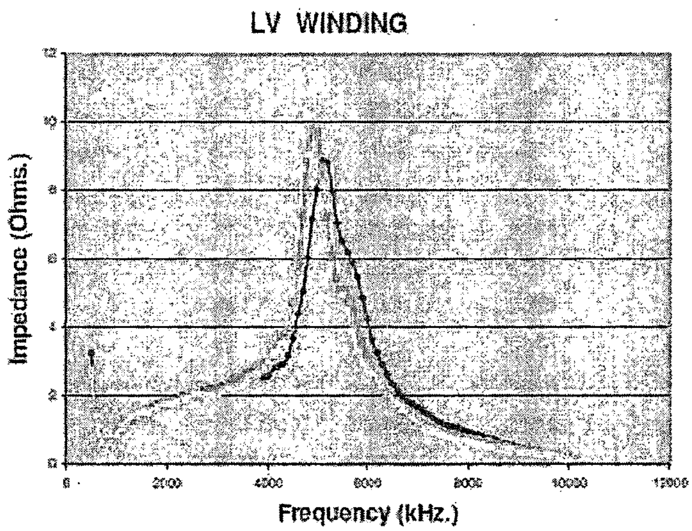

Figure 3.6: Impedance plot of LV winding

CASE 2: Measurement on Furnace transformer.

A three phase , 30 MVA Furnace Transformer having Voltage rating of 33 kV/280-202-150V, has experienced through severe short circuit during its normal operation and R- phase winding was damaged and it needs rewinding but other phases windings are healthy . Due to loss of production, enormous loss was there and utility planned to repair the transformer as quickly as possible, so they were willing to know whether they have to carry out rewinding of other two phases also. Hence , test was conducted on healthy windings and results are discussed below.

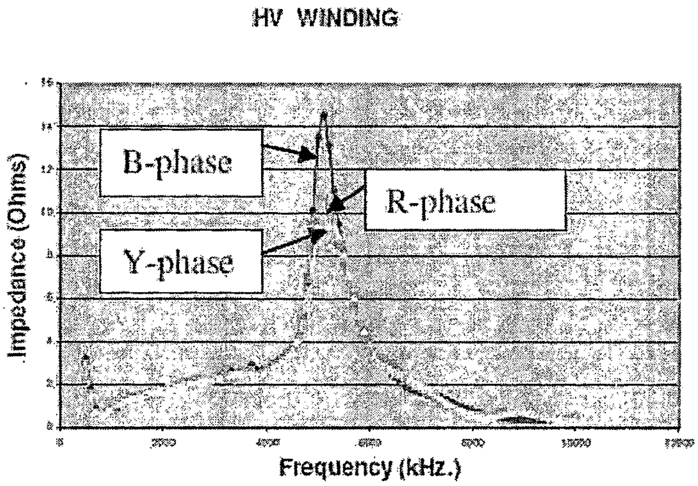

Figure 3.7: Impedance plot of HV winding

For HV and LV windings plots as shown in Figure 3.8and 3.9, it has been found that resonance frequency for two phases are in same range 1.2 MHz. Also, after plotting the graph Impedance versus frequency for HT-TAP winding it has been found that resonance frequency of the winding for two phases are in same range as shown in Figure 3.10. Hence, it was decided to repair only R-phase windings which was damaged during fault.

CASE 3: Condition assessment of Power transformer.

Impedance test has been conducted on 50 MVA, 220 kV/ 66 kV, 3-phase power transformer as shown in the Figure 3.11, 3.12 and 3.13 having three winding HV and LV1 and LV2. From LV1 windings plots as shown in Figure 3.11, it has been found that resonance frequency for three phases are in same range and also this winding was nearer to the core.

From LV2 windings plots as shown in Figure 3.13, it has been found that resonance frequency for three phases are in same range but individual winding's plots are not identical and this winding was after the LV1 winding.

From HV windings plots as shown in Figure 3.12, it has been found that resonance frequency for three phases are not in same range and also individual winding's plots are not identical and this winding was after the LV2 winding.

From utility it was the feedback that, this transformer had faced several times short circuit during its service life and on-site repair had been done. From the above result it

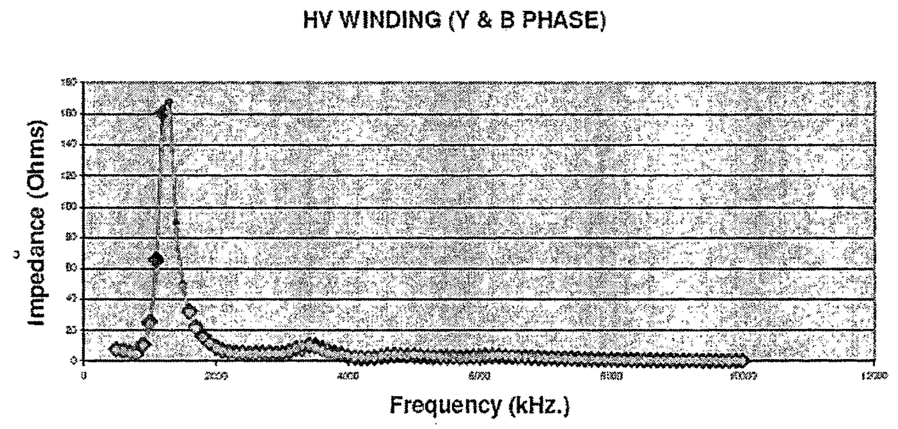

Figure 3.8: Impedance plot of HV winding

is concluded that due short circuit, severe radial forces was exerted on the three windings and HV winding had severe deformation being the outer winding.

The Impedance plot has been found to be adequate for the evaluation of possible displacements and deformation of the windings as well as detecting turn to turn failure in Transformers as it is obvious from the case study.

This type of condition assessment techniques have been proven to be sensitive, efficient and very reproducible. The main interpretation rule being by comparison of the plots in different span of life of transformer.

The experience has shown that in the evaluation of the Impedance versus frequency plots, the pattern of plot in the different ranges of frequencies must be considered.

1. Variation of the frequency response in the range up to 500 kHz. is linked with the radial relative geometrical movements between windings are evidenced.

2. Frequency ¿ 500 kHz. in this range axial deformations of each single winding are evidenced.

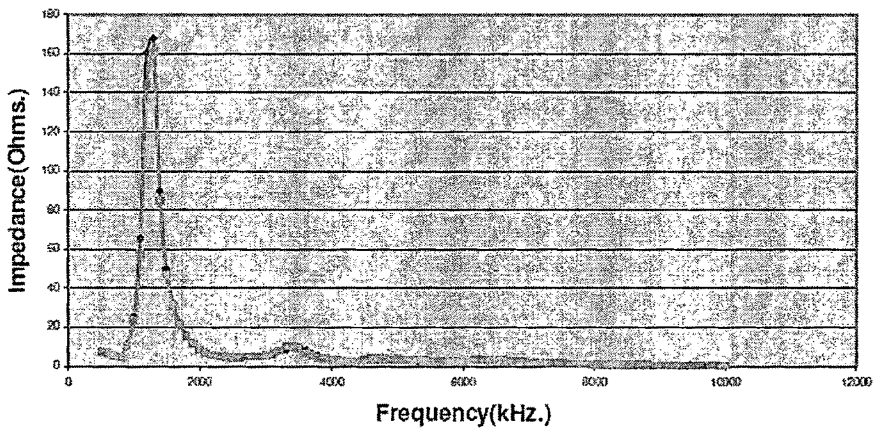

Figure 3.9: plot of LV winding

3.3.4 Limitation of the method

Repeatability and Cable Effects- The results seem to be repeatable up to 3 MHz for distribution transformer. The position of the noise floor may affect the repeatability of the measurements at high frequencies in some cases.

50 Ohm impedance matched test leads are used. Test leads are Coaxial cable with the shields grounded to the instrument chassis. The Impedance measurement requires a matched impedance signal cable, and performs a single-ended measurement, i.e., the signal with respect to the instrument ground. Thus, the shield of the signal cable is connected to the chassis of instrument. Practical field application, require the leads to be 60 ft. in length. This length has been selected as being the shortest to test the largest transformers from a location on the ground adjacent to the unit. Nevertheless, it is the lead length that determines the maximum effective frequency. At lengths of 60 ft., the cable approximates the wavelengths of the higher measurement frequencies, and there is probably little to be gained from the 2-10 MHz scan.

Earth lead and earth resistance effect is also a factor in limiting the repeatability at high frequencies. The winding nearest the tank (in this case the HV winding) is usually worst affected. Contact resistances can affect the repeatability of the measurements across

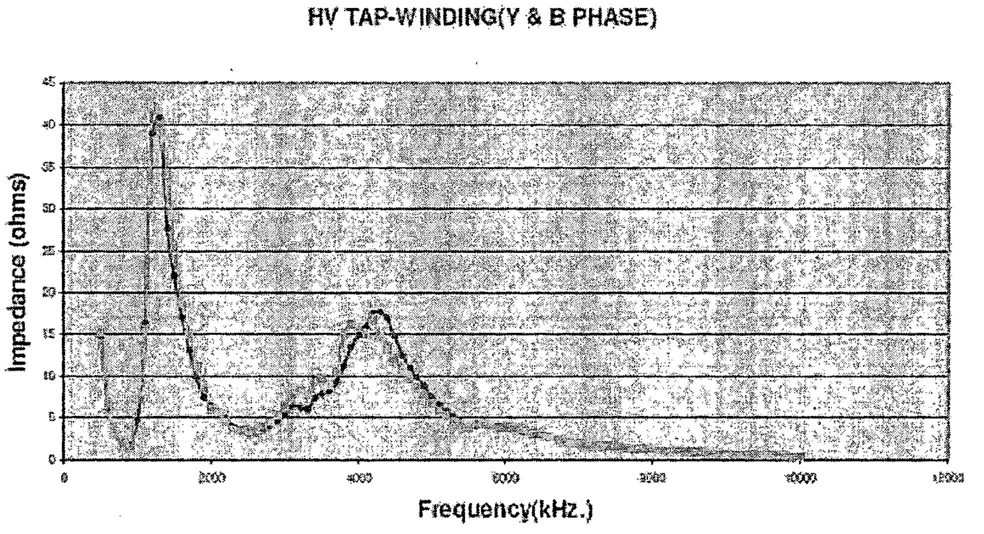

Figure 3.10: Impedance plot of HT-tap winding

the reproducible range. Low resistance windings are most likely to be affected, especially where there is a flat trend and the gain is close to zero. The main effects are a slightly reduced gain and a flattening of the response, which in some cases can result in the elimination of the more diffuse resonances.

3.4 Detection of Multiple faults in Transformer by SFRA

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

The comparison of results is usually made by plotting a graph of the modulus (or gain) of the winding against frequency for both sets of measurements [43]. An experienced observer then examines the two curves for any significant differences.

A transformer in general only possesses a limited number of major resonances which

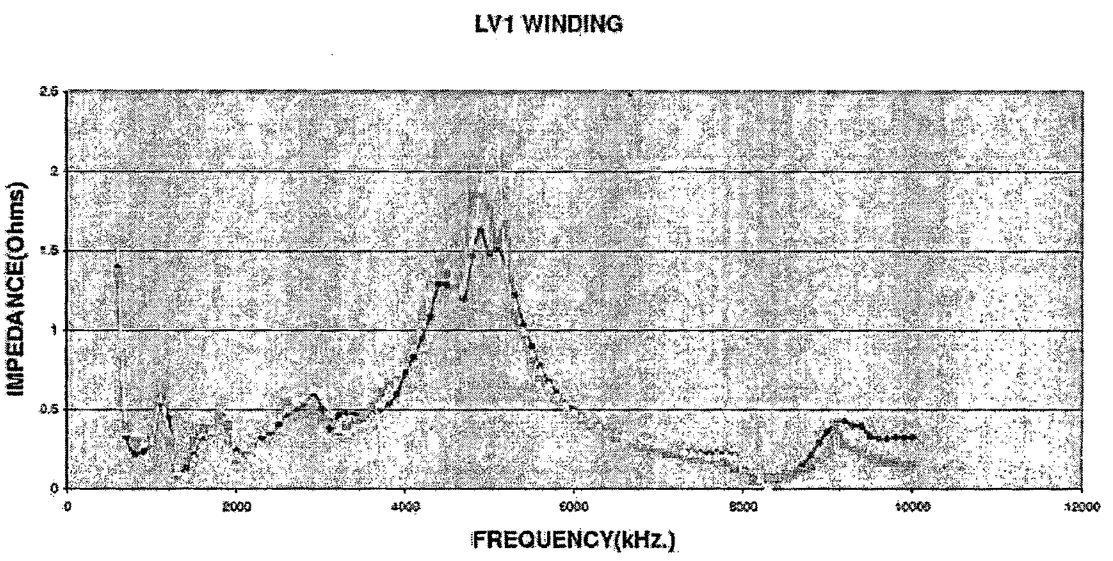

Figure 3.11: Impedance plot of LV1 winding

are governed by the winding construction as indicated in Figure 3.14. A transformer with a single layer winding and no tap-changer has fewer resonances than a transformer with a disk winding or equipped with a tap-changer and a large number of tap positions. It was found that the major transformer resonances are in the range from a few kHz to a few hundred kHz, depending on the size of the transformer. Bigger transformers in general show lower resonance frequencies than small transformers.

Sweep Frequency response analysis (SFRA) consists of measuring the frequency response of transformer windings over a wide range of frequencies and comparing the results of these measurements with a reference set. Differences may indicate damage to the transformer, which can be investigated further using other techniques or by an internal examination.

3.4.1 Failure of transformer detected by SFRA

Since opening the transformer for inspection is rather costly, the method should depend upon terminal measurements requiring a minimum of outage-time and resources. The SFRA method seems to fulfill these requirements and such issues of failure has been

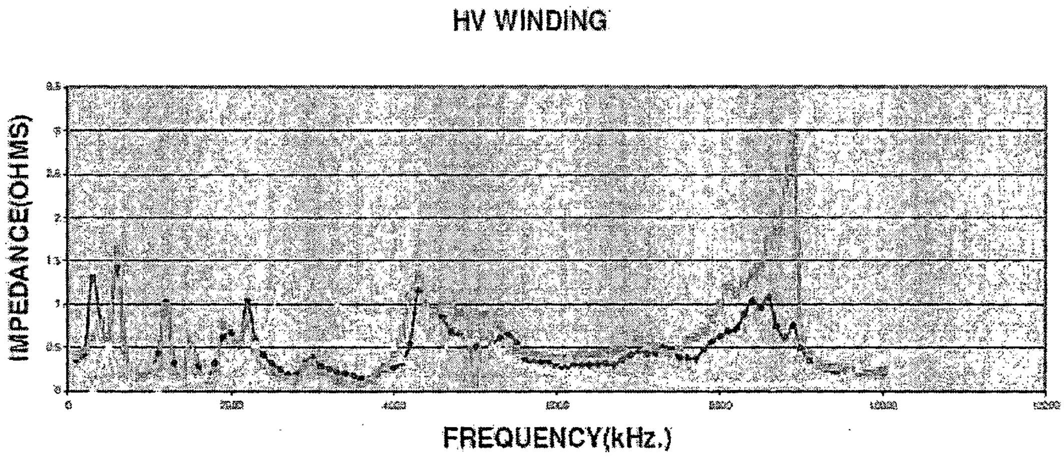

Figure 3.12: Impedance plot of HV winding

discussed in the following case study mentioned below requiring immediate attention after the tripping by protection relays.

CASE 1 - Confirmation of LV winding short circuit:

A three phase, two winding transformer having rating as mentioned below was tested for SFRA after it tripped on Overcurrent protection .

132 kV/11 kV, 10 MVA, 3-phase Transformer Winding configuration - HV(Star)/LV(Star) Year of manufacturing - 1979

The transformer had experienced several system faults since its commissioning in 1979 and had been operating with reduced mechanical strength due to its own natural aging. SFRA was conducted first time on the transformer after the over current tripping.

SFRA Data Analysis:

Data analysis is performed on three phase comparison basis and following points are observed:

1. Measured Open circuit frequency response of HV windings (132 kV , star) are shown in Figure 3.14. Response of B- phase (middle phase) is different than the Outer phases and they appear to be normal. In case of B-Phase winding the first resonance

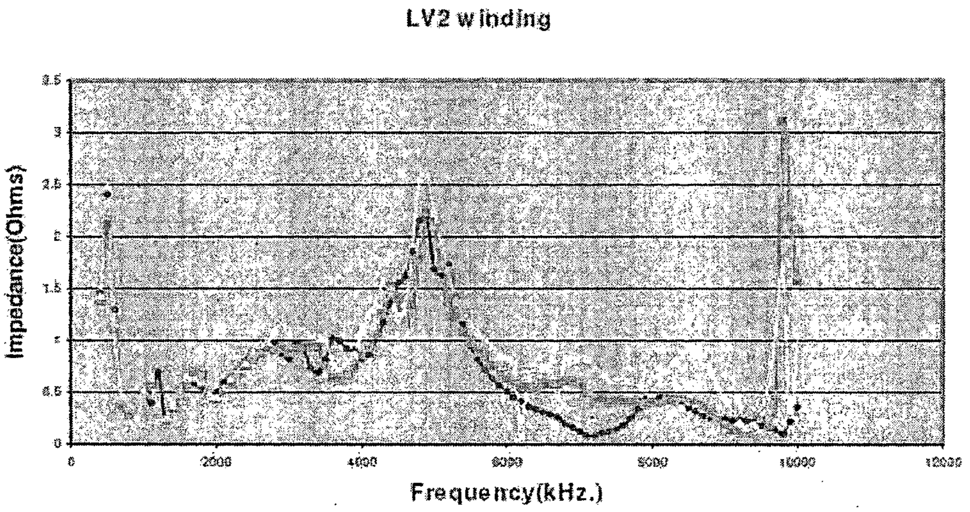

Figure 3.13: Impedance plot of LV2 winding

around 300 Hz. is absent . It can happen if the SFRA signal is getting internal short circuited path.

2. Measured Open circuit frequency response of LV windings (11 kV , star) are shown in Figure 3.15. Response of B- phase (middle phase) is different than the Outer phases which appears to be normal. In case of B-Phase winding the first resonance around 300 Hz. is absent as it was in case of HV winding. Main difference was the more flatness of B-phase LV winding plot in low frequency having very small response in dB compared to HV B-phase winding .

3. Short circuit plot of HV winding is shown in Figure 3.16 and Figure 3.17 in expanded view. At low frequency the difference in dB of B-phase winding is around 0.4 dB, which was not so critical .

Conclusion From Data Analysis:

Based on the above SFRA data analysis it is concluded that transformer has developed turn to turn fault and it is able to identify that turn to turn fault is in LV winding. It is possible to identify turn to turn fault by other conventional method like no load excitation current , turns ratio and magnetic balance test , but in which winding HV or LV winding

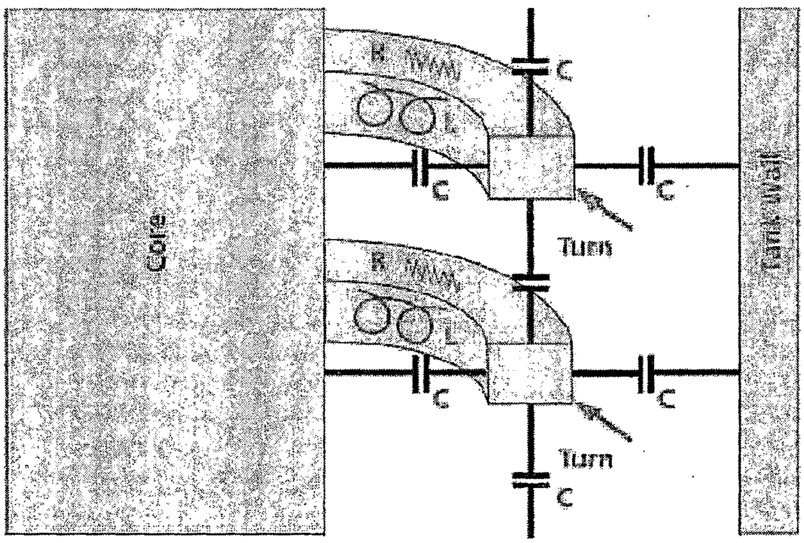

Figure 3.14: Equivalent Circuit for representation of individual capacitance and inductance of winding in Transformer

is a question mark. SFRA is the only test which can identify the winding and phase both, of the shorted turn fault if the analysis is done with proper knowledge and experience.

CASE 2 - Confirmation of Multiple Winding Fault:

A three phase, two winding transformer having rating as mentioned below was tested for SFRA after it tripped on Differential protection.

132 kV/11 kV, 16 MVA, 3-phase Transformer Winding configuration - HV(Star)/LV(Star) Year of manufacturing - 1976

SFRA was conducted second time on the transformer after the incident of fault and tripping. First base data of SFRA was available in the past record.

SFRA Data Analysis:

Data analysis is performed on per phase comparison basis as the base SFRA data was available and following points were observed:

1. Measured Open circuit frequency response of HV windings (132 kV, star) are shown in Figure 3.18and Figure 3.19 before and after fault. Response of H3-H0 phase is

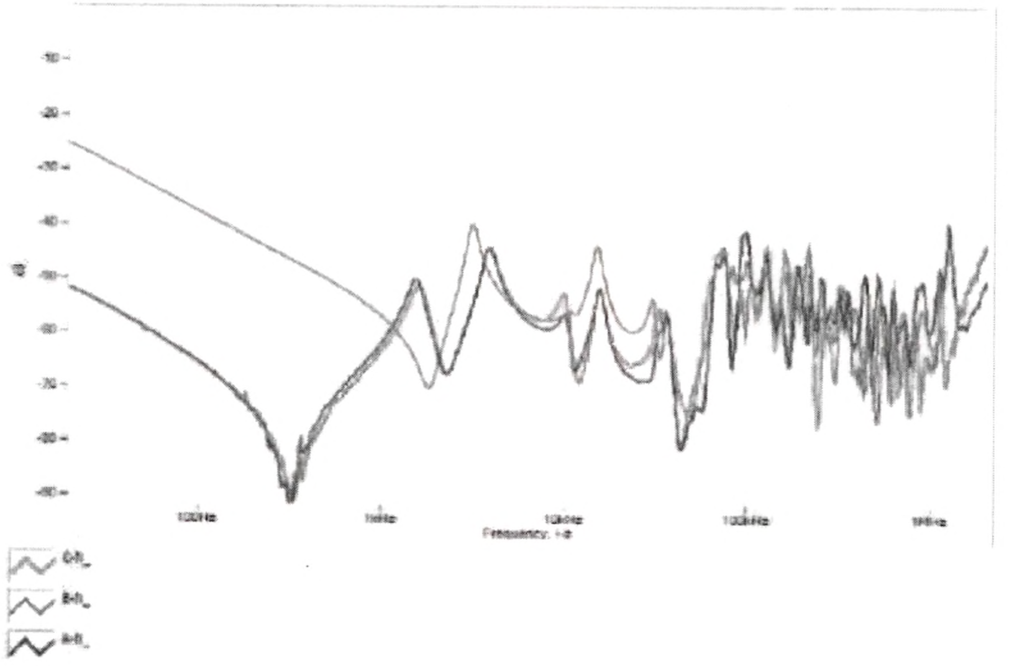

Figure 3.15: Open circuit Frequency Response of HV Winding

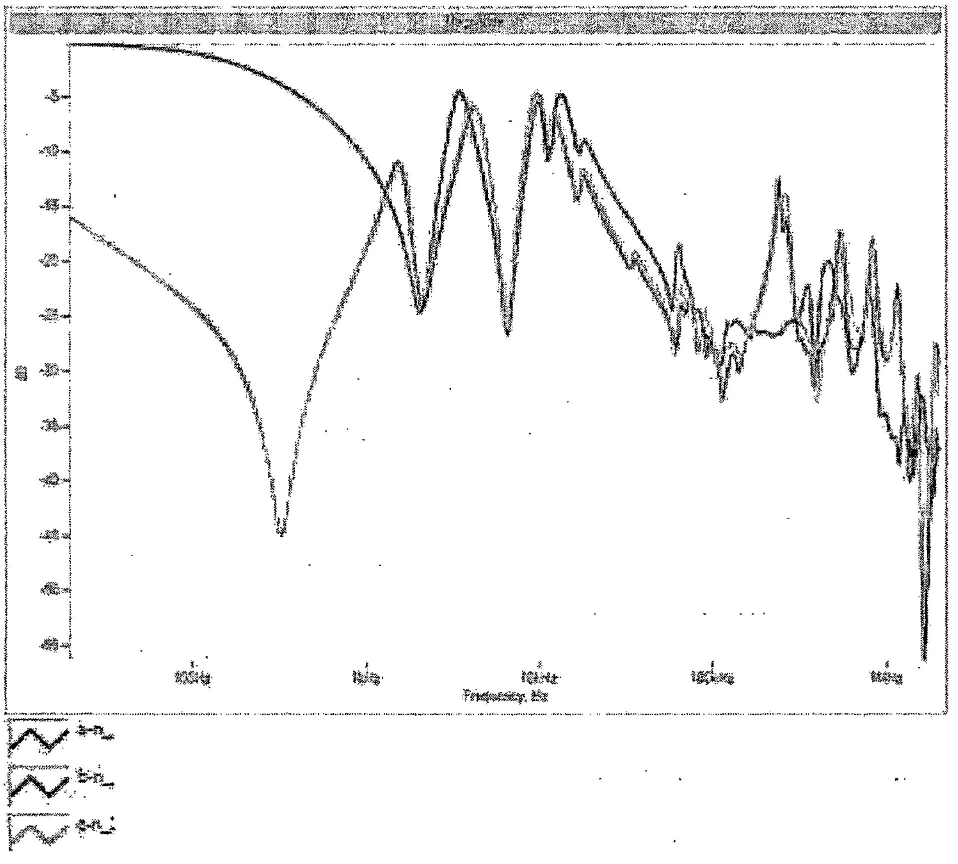

Figure 3.16: Open circuit Frequency Response of LV Winding

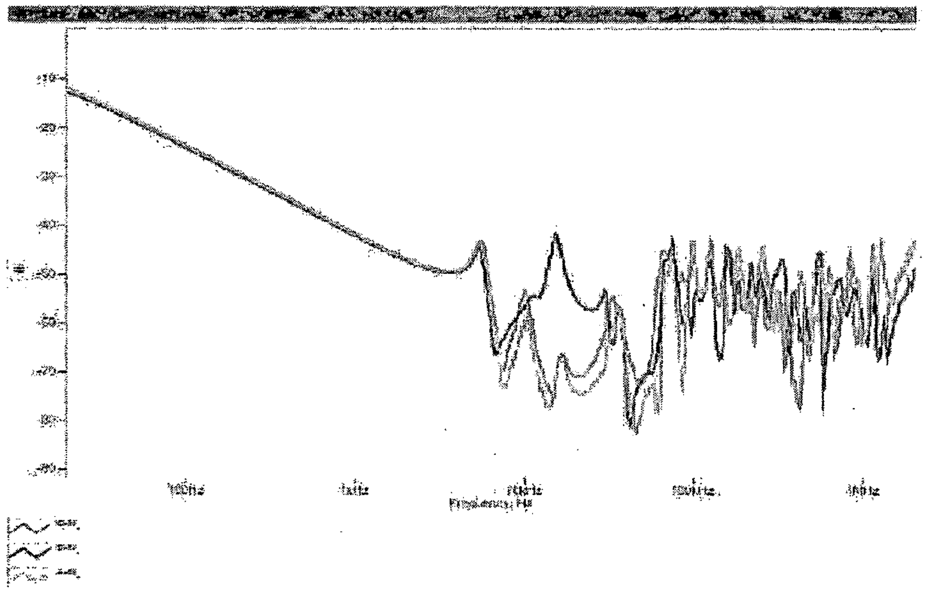

Figure 3.17: Short circuit Frequency Response of HV Winding

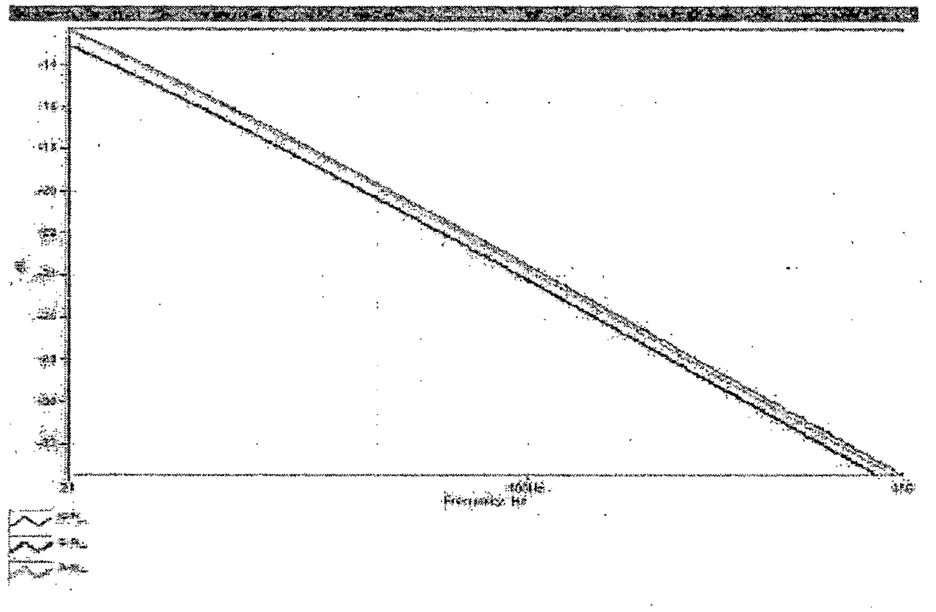

Figure 3.18: Expanded view of Short circuit Frequency Response of HV Winding

different than the other phases which appears to be normal. In case of H3-H0 phase winding the first resonance around 320 Hz. is absent. It can happen if the SFRA signal is getting internal short circuited path.

2. Measured Open circuit frequency response of LV windings (11 kV , star) are shown in Figure 3.20and Figure 3.21 before and after the fault . LV winding is worst affected again third phase i.e. (X3-X0) is different than other two phases. Overall LV winding is showing high impedance and since every plot is effected in same manner the chances of damage of LV neutral is there.

Conclusion from Data Analysis:

1. HV winding: Based on the above SFRA data analysis it is concluded that transformer has developed turn to turn fault in H3-H0 phase. It was confirmed in conventional ratio test also, where the ratio of H3-H0 was different than other two phases .

2. LV winding resistance is found to be 32 miliohms for all 3 phases instead of 12 miliohms (i.e. in healthy condition). Same was confirmed by SFRA also as all the three phase LV plot was showing high impedance of the winding at low frequency. On physical inspection damage of LV neutral connection inside the tank was found due to severe arcing on connecting joints. However, there is no damage to outside LV neutral bushing.

3. Based on the above SFRA data analysis it is concluded that transformer has developed multi type fault here i.e. turn to turn fault on HV winding and high impedance fault on LV neutral terminal. SFRA is able to identify both the faults very clearly which is not possible to achieve by only single test by any other method. Again. it is the experience and interpretation of SFRA results plays a major role in identify such multiple faults in Transformer.

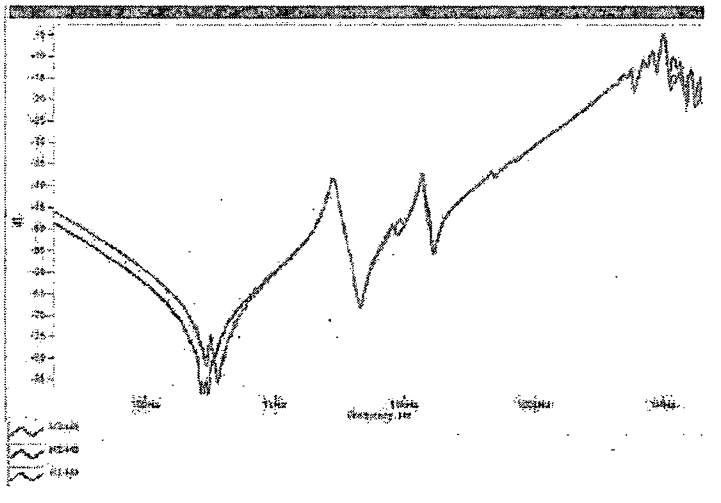

Figure 3.19: Open circuit Frequency Response of HV Winding before fault

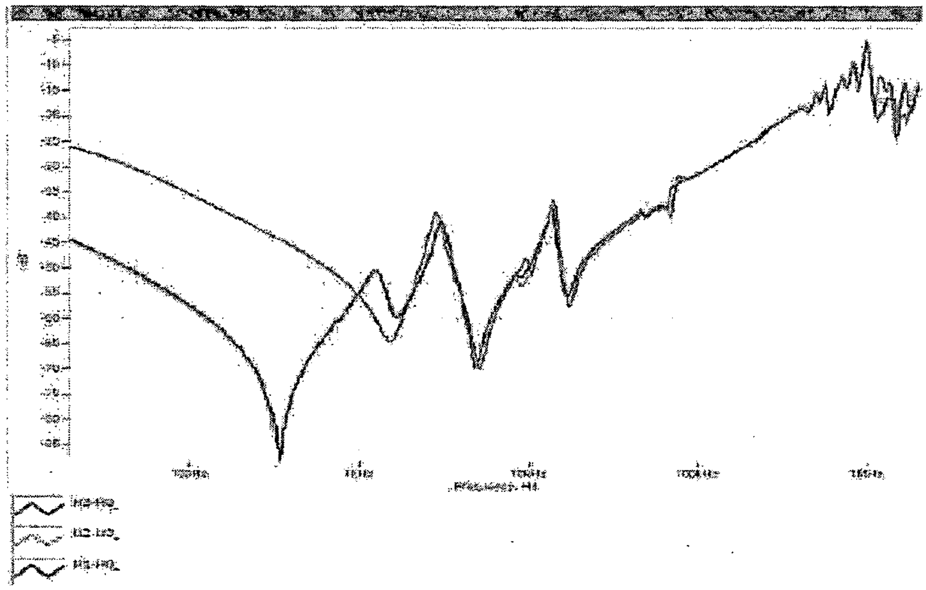

Figure 3.20: Open circuit Frequency Response of HV Winding after fault

3.4.2 SFRA History

Sweep Frequency Response Analysis method was invented by Dick and Erven at Ontario Hydro in Canada between 1975 and 1977. For some reason, their work was never taken up widely. The detail description of SFRA measurement and analysis was mentioned first time in the literature by Dick and Erven [3].

The Central Electricity Generating Board (CEGB) in the UK again started taking initiative in the SFRA the measurement technique in 1980's and applied it to the power transformer in their transmission network. Later on after the break up of the CEGB in the early 1990's, further research in developing SFRA method was taken up by National Grid in the UK and several papers were published in that era at various Conferences[21]. The technique has been discussed and developed further through conferences and client meetings and several utilities took up the technique.

Many early practitioners tried impulse systems[2] , and have continued to try them up to the present. Though appealing in terms of speed, it has not been able to match the range, resolution or repeatability of sweep methods. As the basic technique developed by early users required laboratory based equipment such as HP network analyzers, which

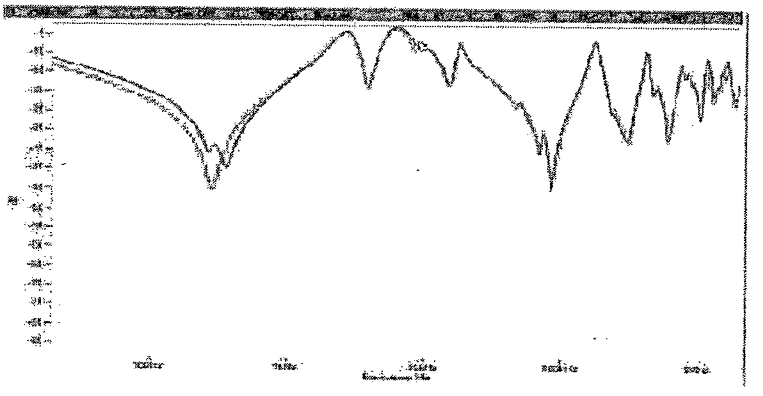

Figure 3.21: Open circuit Frequency Response of LV Winding before fault

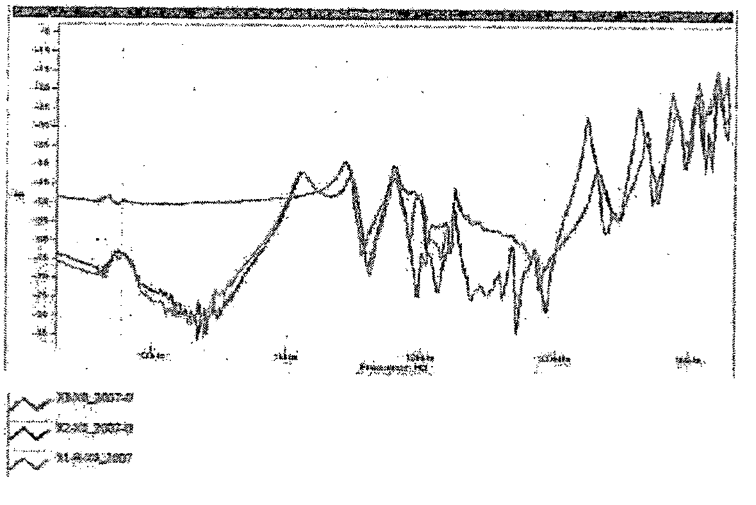

Figure 3.22: Open circuit Frequency Response of LV Winding after fault

were robust, but not field hardened, and required specialist operators.

Within international groups, such as CIGRE Study Committee 12 , there has been interest over the last ten years in developing method to focus upon mechanical problems[49].

3.5 Conclusion

The transformer is subjected to severe mechanical stress during the close-up secondary faults. Aged transformers have reduced short-circuit strength and are more likely to experience mechanical deformations. There are several outcomes from such faults: Severe deformations lead to an electrical fault which normally trip protection relays . Less severe deformations involve insulation rupture and partial discharges which after some time normally is discovered through oil analysis or tripping the bucholz relay. Minor deformations which show no significant change in the operational characteristics, where mechanical properties of the copper might be changed seriously risking rupture on next event. The impulse strength might also be reduced significantly due to damaged insulation and reduced distances.

The SFRA-method (Sweep Frequency Response Analysis) is one of the methods that seems promising because it appear to be sensitive in detecting mechanical deformation, electrical fault in core and in transformer windings [8].

The effects of test leads have been eliminated in SFRA measurements by the use of wide bandwidth leads whose characteristic impedance is matched to the input impedance of the measuring equipment so that reflections do not occur at the instrument end, with separate leads to apply and measure the signal at the input terminal. This has greatly improved the repeatability, sensitivity and reliability of the detection of winding movement. In this thesis a detailed study on application of SFRA for various fault detection in transformer is carried out and will be discussed in remaining chapters.