CHAPTER 1

1.1 INTRODUCTION

The reliability and safe operation of all electrical equipment depend on the integrity of its insulation. A routine test such as the power frequency test is performed on every unit to verify the dielectric strength. A type test such as an impulse voltage test is done to assess the withstand capacity of insulation to over voltages. The dielectric strength test is the deliberate application to the equipment, of an impulse voltage higher than its normal working voltage, for a specific period of time to discover if the insulation withstands or breakdown under that voltage called the basic insulation level voltage (BIL).

The impulse voltage tests reveal internal insulation faults caused by design or manufacturing flaws. This test is very important and is a routine test for transformers rated higher than 230kV.

1.2 IMPULSE TEST ON POWER TRANSFORMER

Power transformers are usually tested with the standard 1.2/50 μs lightning impulse test (LI) voltage at the BIL. The shape of voltages, their magnitude and sequence of application that constitute a proof test are covered by standards such as IEC 76 (1980) and IEC 722 (1982).
To ensure that any untested winding is not damaged by a transferred surge, its terminals are either earthed directly or through resistors of very high value to limit the transferred voltage to less than 75% of the test value. The sequences of application for impulse test are

- one reduced full voltage
- one 100% full voltage
- two reduced chopped impulse waves
- one 100% chopped wave
- two full wave

The detection of failure is based on comparison of the impulse voltage and neutral terminal current oscillograms taken at full and reduced test voltage levels, respectively. A minor difference between the compared oscillograms can be indicative of a winding fault. In addition to these records the IEC 722 (1982) standard recommends the observation of waveforms from other non tested terminals of the test object, namely:

- winding current
- current transferred to an adjacent untested winding called capacitively transferred surge current
- tank current
- voltage transferred to a non-tested winding called transferred surge voltage.

The test arrangement is done as recommended by IEC 60 (1992). The impulse test is done using a Marx generator with an arrangement for conducting the impulse or chopped impulse test, a voltage divider, a current shunt, and measuring cables that connect to a recording device (oscilloscope). IEC 790 (1984) specifies on the oscilloscopes and peak voltmeters for impulse test.
The identification of failure during dielectric test is conventionally performed on analog oscilloscopes. With the advent of technology new types of digitising oscilloscopes have been developed with in-built features like

- higher speed of acquisition
- higher vertical resolution
- larger memories
- integrated mathematical functions, and
- programmability.

The analysis of impulse signals, hence, can be done with more convenience with digitiser scopes. To mention one feature- it is now possible to determine the difference between the recorded signals by using the mathematical function, namely difference between channels as an instrument analysis rather than the traditional way of determining signal variation as a skilled task.

1.3 LITERATURE SURVEY

A great quantum of work is done for development of dielectric testing techniques for high voltage equipment by researchers.

Hagenguth J.H (1944) was the first to suggest neutral current method followed by Lengnick G.W, and Foster S.L (1957), Aicher L.C (1961) for testing of transformers.

Rudenburg R (1940), Stewert H.C and Holcomb J.E (1945), Rippon E.C and Hickling G.H (1968) analysed on the use of oscillographic methods of winding failure during impulse test on transformer and suggested that alternative positions could be adopted for the current shunt. Some information on detection of breakdown has been provided by Miki A et al (1978) and Grundmark B.L (1980).


The Cigre working group (1979, 1984) has approached various aspects of performance of high voltage transformers. They worked on dielectric testing techniques and on the analysis of transformer failure modes and causes.


James R.E, Phung B.T and Su.Q (1989) have discussed on the transformer winding behaviour in three different frequency ranges. They have shown that the
trans-admittance spectrum of windings can be marked using a sinusoidal voltage source as the travelling wave region (up to 0.05 MHz); range of frequency components within (0.08 MHz to 0.8 MHz) as the capacitive network region; and within (0.06 MHz to 0.6 MHz) as the critical frequency region of windings.


Many researchers have debated on the limitations of the present trend of dielectric testing and have put forward a few questions for open discussions. Zaengel W.S and Lehmann K (1993) says, though IEC standards specify procedure for fault analysis of test object using impulse voltage, yet it would be appropriate to develop methods to acquire complete knowledge of insulation with detecting its weak points, and assessing its evolution in time.


McComb T.R (1990) rightly points that multiple fold magnification of signal traces is required to zoom the difference between records of current oscillograms at reduced and full voltage for detection of discharges. This limitation is attributed to the limited sampling rate of the digitiser at a time when high frequency components of considerable amplitude are present at the front of the wave.

James R.E et al (1986,1989) have worked on interpreting partial discharge measurement and location in power transformers.

Bartnikas R, and Novak J.P (1993), Su. Q, James R.E (1992) comment that in order to prevent aliasing, the sampling rates had to be sufficiently high to accommodate all the frequency components of the signal. Due to limitation in sampling rates available, they suggest the use of active filters for partial discharge distribution analysis.

Malewski R et al (1983, 1985, 1992), McComb (1992) appreciate the introduction of digital recording techniques as it opens new evaluation possible as a complement to the conventional analog voltage and current records since records are in digital form.

Malewski R and Poulin B (1985) propose the deconvolution of transfer function from digitised records of neutral current and applied voltage as a supplement to the present methods of impulse analysis for better interpretation of test results. This is a unique method that could compare records of reduced and full level and records obtained during variable time to chop during the impulse testing.

Many researchers like Shinichi Menju (1988) have questioned the influence of nonlinear zinc oxide arrester in the winding on the evaluation of transfer function.

Leibfried T and Feser K (1991,1992), Hanique E (1994) comment that transfer function analysis had to be tested for its full capabilities to monitor power transformers in service and to utilise it for location of faults in windings.
Hanique E (1994), reports on the identification of discharge as an attenuation of resonant frequency pole height during the transfer function analysis. But here the limitation is that changes in signal could also be caused by other components in the circuit like variation in impulse generator test setup.

Jayashankar V (1994) has developed an algorithm for winding failure detection during full and chopped lightning impulse tests using digital signal processing methods.


Among signal analysis methods, the time-frequency analysis techniques like.

- short-time Fourier transform analysis (STFT)
- wavelet transform analysis (WT)
- Wigner Ville distribution analysis (WVD)

are gaining importance for applications related to analysis of non-stationary signal with continuous and transient nature.

Michael R Portnoff (1980) has discussed on the application and implementation of short-time Fourier transform analysis (STFT) to analyse digital signals and systems. The limitation in signal resolution due to the STFT analysis is overcome by implementing wavelet transform.
A great quantum of research and development is in progress to improve the algorithm, implementation and application of wavelet transforms to analyse non-stationary real-time signals.


Patrick Flandrin and Bernard Escudie (1984), Glorie Foye Boudreaux Bartls and Thomas Parks W (1986) have elaborated the properties and interpretation of WVD for signal analysis. David Waldo and Prabhar Rao Chitrapu (1991) discussed the WVD of finite duration signal. The WVD has been exhaustively used in speech signal analysis.


The choice of Kernels is based on the signal characteristics as given by Moeness G Amin and William J Williams (1998). The problems on aliasing and the approaches on reduction of aliasing during signal estimation with time-frequency methods are discussed by Theo A.C.M Claesen et al (1983), L Jubisa Stankovic and


Their simpler approaches have been exhaustively analysed for fault analysis in transformers during the low voltage sweep signal analysis and impulse test analysis of signals, as a new contribution in this thesis.

Igor Djurovic and Ljubisa Stankovic (1999) discussed on the implementation of Virtual Instrumentation for time-frequency analysis.

The utility of the new signal analysis techniques like time-frequency methods is a new attempt for analysing failures in transformers, and this forms one more important contribution in this thesis.

1.4 SCOPE OF PRESENT WORK

From literature survey it has been proposed to extend analysis of some of the unanswered features in the existing impulse analysis technique. This is an outcome of a few questions raised by James R.E. et al (1989), Hanique E (1994), Bartnikas R and Novak J.P (1993), Peter Marshius et al (1997). Some of the problems chosen for discussion are the following:
• Whether transformers experience higher internal stress for some different possible signal pulse shapes.

• Whether proper recognition has been given to the effect of internal resonances to locate faults in transformer winding.

• On the application of new signal processing methods to overcome the limitations of the existing trends.

• Whether it is possible to identify the nature of winding failure and estimate its extent of defect using the existing methods of dielectric testing.

• Whether it is possible to isolate non-linearities in winding response like an arrester conduction from that of faults, and discharges within winding.

• On the limitations of present day instrumentation to be accounted for impulse testing.

An efficient instrumentation must record the following data on signals captured during occurrence of faults and discharges. The requirements are:

• Identifying the nature of winding fault by characterising the signal recorded using signal analysis techniques.

• Determining the time of occurrence of discharge.

• Finding the maximum of the discharge pulse

• Evaluating the frequency components of the fault and discharge signal.

• Isolating the bands of frequency components using filtering techniques.

In this thesis, we are principally interested in developing an objective criterion for failure identification in transformers using signal processing methods. Analysing many records of signal it has been shown that it is possible to identify breakdown failure from a discharge and demarcate an arrester response. It is further
shown possible to identify winding response from the neutral current using time, 
frequency, and time-frequency analyses, and transfer function analysis.

The simultaneous plotting of instances of fault and their corresponding 
frequency components is proposed using the time – frequency analysis techniques, 
namely, the short time Fourier transform (STFT) and wavelet transform (WT). The 
limitation of time – frequency resolution in STFT due to use of windows of uniform 
bandwidth is overcome by incorporating the application of Wavelet transforms for 
impulse analysis of winding faults.

The variation in the energy density spectrum of the signals caused by 
insulation faults is well depicted with suitable examples of real power transformer. 
For this test, the records from the transformers are analysed with the time – frequency 
plot using the Wigner Ville Distribution (WVD) method. This thesis proposes this 
technique for the first time as a new and better method for the winding failure 
analysis. This can be also utilised to analyse sweep signal response as a post signal 
analysis method to confirm the occurrence of fault.

Signal analysis is done on records from analytical simulation on an Abetti 
coil model and on an experimental layer-winding model with 20-section specially 
constructed. These results have been confirmed with signal analysis on a large 
number of transformer test reports. The new impulse analysis technique proposed in 
this thesis is further validated with signal analysis on IEC 722 (1982) digitised data.

The detection of occurrence of faults, identification of type of winding fault 
and location of site of fault is been presented in sequel in the following chapters of 
the thesis.
1.5 ORGANISATION OF THE THESIS

In Chapter 2, results pertaining to the new impulse analysis method using digital filters with different frequency bands are reported. The application of transfer function method to identity arrester characteristic is also proposed.

The utility of the Wavelet Transform to isolate the instance of occurrence of discharges forms the crux of the Chapter 3. Issues germane to the computation of the Fourier transforms and short time Fourier transforms are also addressed here.

Chapter 4 presents the determination of location of faults to as low as 5% of the winding length using frequency response analysis. Method of determining extent of failure is also addressed.

In Chapter 5 the objective criteria for failure identification is well established using the Wigner Ville distribution analysis. This method has been suggested as a supplementary to confirm the occurrence of fault and to locate the site of section to section failure. The confirmation on location of failure is addressed by using the low voltage sweep signal analysis characteristic as a different and new approach.

Chapter 6 presents results from additional experiments as a case study enumerating the sequential steps for winding failure analysis with impulse test records.

Chapter 7 concludes the work by proposing the time-frequency techniques to be an improvement over the existing methods of failure diagnosis. In this chapter, the limitations in the proposed trend for transformer failure analysis and suggestions for future work are also presented.