CHAPTER 1

1.1 INTRODUCTION

The reliability of a complex system such as a power network is contingent on the proper functioning of the constituent individual apparatus. Amongst these, the power transformer occupies a pre-eminent place. With ratings up to 800 MVA, 400 kV, three phase, as in a generator transformer, it probably forms the most ubiquitous power apparatus. This wide range calls for varying engineering and manufacturing skills. Be that as it may, it is in the fitness of things that the quality of any finished product be certified by the manufacturer prior to despatch. A system of routine and type tests have hence been designed by international agencies such as the IEC for each apparatus. Dielectric tests constitute one important aspect of quality assurance. The lightning impulse test on a power transformer is done in order to assess its dielectric integrity when exposed to overvoltages of atmospheric origin. Its importance can be gauged from the fact that it forms a routine test for transformers with rated voltages above 300 kV. Of equal concern is a demonstration of the ability to carry short time currents.

1.2 IMPULSE TEST ON A POWER TRANSFORMER

The shape of the voltages, their magnitudes and the sequence of application that constitutes a proof test are covered by standards such as the IEC-76, 1980. The generally recommended order of the different impulse applications is:

- one reduced full impulse
- one 100% full impulse
In addition to the record of the applied voltage, it is mandatory to observe another waveform during a test (IEC 722). This transient could be one of the following:

a) the neutral current;

b) the winding current;

c) the current transferred to an adjacent winding;

d) the tank current;

e) the voltage transferred to a non-tested winding.

In its simplest form, a test arrangement conforming to IEC 60, would consist of a Marx generator with an arrangement for conducting an impulse test chopped on the tail, a voltage divider, a current shunt and measuring cables that connect to a recording device (oscilloscope). Traditionally, the voltage and supplementary oscillograms have been recorded on analog impulse oscilloscopes whose specifications are laid down in IEC 790. In principle, the absence of significant differences between voltage and current transients recorded at reduced voltage and those recorded at full test voltage constitutes evidence that the insulation has withstood the test.

This form of testing has a fairly long history. Hagenguth (1944) was the first to suggest the neutral current method. Significant contributions were also made by Stewart and Holcomb (1945), Rippon and Hickling (1949), Lengnick and Foster (1957) and Aicher (1961). In spite of their long usage, traditional methods utilising analog oscilloscopes suffer from certain drawbacks. To appreciate this fact it is sufficient to recall that the IEC 722
acknowledges the recognition of failure during impulse tests to be a skilled task. It also concedes that a comparison of the current records during chopped tests is not possible unless the instants of chopping are almost identical.

To elaborate these ideas consider Figure 1.1 which shows a failure during a lightning impulse where the small change in the form of the current at BIL is reason enough for a disqualification of the test object. In contrast, a similar statement cannot be made regarding the successive chopped waves of Figure 1.2. Further, minor changes in the applied voltage can make the comparison an arduous proposition even for the standard lightning wave. A distinction between a partial discharge and a minor breakdown within a winding is not discernible. Finally, the subjective nature of the interpretation leaves much to be desired. Digital techniques using signal processing are being increasingly used to eliminate some of these drawbacks. Of these, the transfer function method has gained some acceptance during the past few years (Malewski et al, 1992).

1.3 TRANSFER FUNCTION ANALYSIS

A summary of the results using digital techniques for high voltage measurements has been published by McComb et al (1991). Maier and Schwab (1983) are probably the pioneers of the field. In addition to using time-domain records for assessment, Malewski and Poulin (1985) proposed an approach in the frequency domain. This was the first use of transfer function method as a tool for certifying insulation integrity. The transfer function (Tf) can be defined as

\[ Tf = \frac{\text{FFT}(i)}{\text{FFT}(v)}. \]
Figure 1.1 Lightning Impulse - Full Wave (LI-FW) failure of a 33kV Transformer

Figure 1.2 Chopped Lightning Impulse (CLI) effect of difference in times to chopping when testing a 33kV transformer
where FFT(i) and FFT(v) refer to the Fourier transforms of the digitised values of the current through the winding and the applied voltage respectively. The hardware requirements for this method involve accurate digitisers with high sampling rates and a provision for long record lengths. In addition, Fast Fourier transform (FFT) algorithms and some form of digital filtering software are necessary (Malewski and Poulin, 1988, Leibfried and Feser 1991). The advantages claimed for the method are a consistent interpretation of the chopped test, an immunity to minor deviations in the applied voltage and a possible recognition of partial discharge from failure (Malewski and Poulin 1988, Malewski et al, 1992). A synthesis of the long experience based on analog measurements and the newer convenient digital techniques could yield better insight into transformer behaviour, resulting in reliable fault diagnosis.

1.4 SCOPE OF THE PRESENT WORK

In this thesis, we are principally interested in developing objective criteria for failure identification in transformers using signal processing methods. Fertile areas in the domain of electrical engineering viz., network analysis, linear systems, (continuous and discrete time) and signal processing in the time and frequency domains, form the bedrock of these methods. A paramount task is also to underpin failure identification procedures to breakdown phenomena. Advances in condensed matter theory (Forster 1990), discharge simulation in gases (Christophorou and Pinnduwage, 1990) have hence been invoked in formulating models. One redeeming and unanimous observation has been that every breakdown event, quintessentially involves the creation of a conducting path in an otherwise insulating region (Dissado and Fothergill, 1989).
The common aims of much of the reported work concerning digital techniques are the characterisation of digitisers (McComb et al 1990, Malewski et al, 1983) and techniques for reducing noise in the high voltage environment (Leibfried and Feser, 1992). We essay to stress aspects concerning the recognition of catastrophic events. In a narrow context, the work focusses on the recognition of failures during an impulse test. However, in general, we seek to identify a breakdown occurring in a winding when energised by any arbitrary aperiodic wave. It is also necessary to demonstrate that any perceived defect is indeed related to a failure of insulation within the transformer. This paradigm shift places a far greater onus on the testing authority who is the protagonist. In simpler parlance, we assume a case of 'innocent unless found guilty'.

In proposing newer methods for fault identification we had to base ourselves on various sources of experimental data. A major portion of these stem from our simulations. In addition, we had the opportunity of analysing records of over a thousand transformers (of rating upto 132 kV, 16 MVA) using conventional analog oscilloscopes. We hence considered it necessary that the failure records from these tests be studied carefully and interpreted using the newer methods. Some of these records are included to facilitate comparisons. As far as practical impulse testing based on digital measuring systems (and transfer function analysis) is concerned, experience is lesser and would be of the order of a hundred and fifty power transformers. A few relevant results with this method are also included.
1.5 ORGANISATION OF THE THESIS

In Chapter 2, results pertaining to experimental simulations on breakdown across lumped parameter elements are reported. A model for the observed data is also proposed.

The utility of a frequency domain approach to characterise linear systems forms the crux of the Chapter 3. Issues germane to the computation of Fourier transforms are also addressed here.

Chapter 4 concerns the impulse testing of transformers based on the transfer function method.

Objective criteria for failure identification utilising filtering techniques in the time and frequency domains are developed in Chapter 5.

In Chapter 6 a different approach is relied upon. Additional voltages superimposed on the power frequency voltage are needed here.

An order of magnitude calculations of axial forces in a current transformer is presented in Chapter 7. It is shown that coil deformations within transformers can also be detected using the transfer function method.

Chapter 8 concludes the work with a recognition of limitations and suggestions for further work.