Chapter 2
Basic Methods for Analysis of High Frequency Transients in Power Apparatus Windings

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ABSTRACT

Power apparatus windings are subjected to voltage surges arising from transient events in power systems. High frequency surges that reach windings can cause high voltage stresses, which are usually concentrated in the sections near to the line end, or produce part-winding resonance, which can create high oscillatory voltages. Determining the transient voltage response of power apparatus windings to high frequency surges is generally achieved by means of a model of the winding structure and some computer solution method. The accurate prediction of winding and coil response to steep-fronted voltage surges is a complex problem for several reasons: the form of excitation may greatly vary with the source of the transient, and the representation of the winding depends on the input frequency and its geometry. This chapter introduces the most basic models used to date for analyzing the response of power apparatus windings to steep-fronted voltage surges. These models can be broadly classified into two groups: (i) models for determining the internal voltage distribution and (ii) models for representing a power apparatus seen from its terminals.

INTRODUCTION

The voltages to which power apparatus terminals are subjected can be broadly classified as normal or steady state and abnormal or transient (Greenwood, 1991; Chowdhuri, 2004; Bewley, 1951; Heller & Veverka, 1968, Rudenberg, 1968; Degeneff, 2007). Most of the time, power apparatus operate under steady-state voltage; that is, the voltage is within +10% of nominal, and the frequency is within 1% of rated. All other voltage excitations may be seen as transients, which may

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arise from short-circuits, switching operations, lightning discharges, and from almost any change in the operating conditions of the system. There are exceptions, for instance, induction motors fed through PWM voltage source inverters, since these power converters produce steep voltage pulses which are applied repeatedly to motor terminals (Boldea & Nasar, 2010). The inverters may produce voltages with very short rise times, which in presence of long cables may cause strong winding insulation stresses and eventually lead to motor failures.

In general, abnormal or transient voltages dictate constraints for the insulation of the equipment. These constraints can have a significant effect on the design, performance and cost of power equipment. Standards classify the transient voltages that power equipment experiences into four groups, referred respectively to as low frequency, slow front (or switching), fast front and very fast front transients (IEC 60071-2, 1996; IEEE 1313.2, 1999):

- Low-frequency transients are oscillatory voltages (from power frequency to a few kHz), weakly damped and of relatively long duration (i.e., seconds, or even minutes).
- Slow front transients refer to the class of excitation caused by switching operations, fault initiation, or remote lightning strokes. They can be oscillatory (within a frequency range between power frequency and 20 kHz) or unidirectional (with a front time between 0.02 y 5 ms), highly damped, and of short-duration (i.e., in the order of milliseconds).
- Fast front transients are normally aperiodic waves, generally associated to lightning surges with a front time between 0.1 and 20 µs, although the current chopping of a vacuum breaker can produce transient periodic excitation whose frequency range may be included within this category.
- The term very fast front transient is used to refer surges usually encountered in gas insulated substations with rise times in the range of 50 to 100 nsec and frequencies from 0.5 to 30 MHz, although there are other switching transients with frequencies within this range.

Since transient voltages affect system reliability, and in turn system safety and economics, a full understanding of the transient characteristic of power equipment is required.

The capability of a winding to withstand transient voltages depends on the specific surge voltage shape, the winding geometry, the insulation material, the voltage-time withstand characteristic, and the past history of the winding (Greenwood, 1991; Chowdhuri, 2004; Bewley, 1951; Heller & Veverka, 1968, Rudenberg, 1968; Degeneff, 2007). The voltage stresses within the windings need to be determined to design winding insulation suitable for all kinds of overvoltages. During test voltages of power frequency, the voltage distribution is linear with respect to the number of turns and can be accurately calculated. High frequency surges that reach power apparatus windings can cause high voltage stresses, which are usually concentrated in the sections near to the line end.

The accurate prediction of the response of coils and windings to fast or very fast front voltage surges is a complex problem: the form of excitation may greatly vary and most large power apparatus are unique designs (e.g., each has its own impedance-frequency characteristic), so their transient response characteristic is also unique. Generally, the problem is addressed by building detailed models.

A model is a representation which can duplicate the response of a component under the stimulus of interest. The form of a model depends on how it is to be used, while the degree of detail in modelling depends on the type of disturbance and the position of the component with respect to the event that causes the disturbance (Greenwood,

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