

# Chapter 11

## Transformer Insulation Design Based on the Analysis of Impulse Voltage Distribution

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### ABSTRACT

*In this chapter, the calculation of transient voltages over and between winding parts of a large power transformer, and the influence on the design of the insulation is treated. The insulation is grouped into two types; minor insulation, which means the insulation within the windings, and major insulation, which means the insulation build-up between the windings and from the windings to grounded surfaces. For illustration purposes, the core form transformer type with circular windings around a quasi-circular core is assumed. The insulation system is assumed to be comprised of mineral insulating oil, oil-impregnated paper and pressboard. Other insulation media have different transient voltage withstand capabilities. The results of impulse voltage distribution calculations along and between the winding parts have to be checked against the withstand capabilities of the physical structure of the windings in a winding phase assembly. Attention is paid to major transformer components outside the winding set, like active part leads and cleats and various types of tap changers.*

### INTRODUCTION

Reliable and cost effective insulation design is a key element in the capability of a transformer to fulfill its function in an electric grid. For large power transformers with high voltages, the insulation medium consists predominantly of mineral oil and oil impregnated cellulose products, like kraft

paper, pressboards and other natural materials of a wood-like nature.

The insulation performance for over-voltages of a transient nature is verified through the application of impulse voltages on the transformer terminals, according to international standards. The design process for insulation structures includes an analysis for the transient voltages between conductors of a winding, between winding parts in a winding phase assembly, and from winding

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parts to grounded surfaces. The impulse voltage distribution is usually calculated for one wound leg only, which is assumed to be representative of all phases. The design procedure described in this chapter is illustrated on a large core type power transformer with circular windings around a quasi-circular core, but can also be applied to other types of power transformers.

**ESTIMATION OF IMPULSE VOLTAGE DISTRIBUTION VIA WINDING RATIO AND OSCILLATING FACTOR METHOD**

The winding system of a power transformer consists generally of a minimum of two windings of different nominal voltage levels. The simplest example is a two-winding transformer with a fixed ratio, with (per phase) only one winding (in one part) for the LV winding and one winding (in one part) for the HV winding. Most of the time however, one of the two windings (usually the HV winding), has more than one part, because it needs to be adjustable in voltage. This means that

a winding will have a discontinuity in electrical properties in the connection point between the two parts.

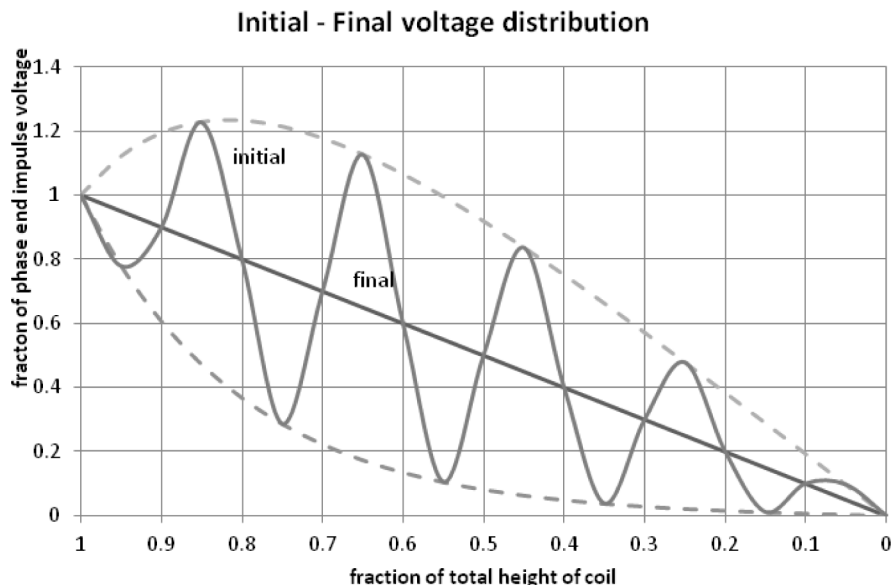
The impulse voltage distribution along a winding is usually not divided linearly according to the turns ratio, which is in contrast to the voltages at nominal frequency. The initial distribution is determined more by the series capacitances of the winding parts. The voltages tend to oscillate with a level that is approximately proportional to the difference between the initial capacitive voltage distribution and the final inductive voltage distribution, as shown in Figure 1.

For estimation purposes, and for a quick check of the correct behaviour of a transient model, a simple rule of thumb for the amplitude (peak-peak) of the oscillating voltage is assuming a multiplication factor of two, two times the nominal voltage.

The first winding type where this rule is applied is a layer winding. We take an example where the layer winding consists of six layers (of equal turns). See Figure 2.

Nominal or induced voltages between the layer ends are:  $(100\% / 6) \times 2 \text{ layers} = 33\%$ .

*Figure 1. Initial-final transient voltage distribution along the height of a homogenous coil*



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