Simulation and predictive analysis of phenomena accompanying the load variation of power transformer

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Abstract– *The study of the transformer in disturbed working mode and the identification of these disturbances and their origins have a particular importance for the choice and the dimensioning of the transformer; and even for the optimization of the exploitation of the electrical energy placed at the disposal of the consumer.*

The aim of this paper is to study the behavior of the power transformers following brutal load variations by simulating the different electric parameters of the transformer during the increase or the reduction in power required by the receivers.

This study permits to identify and analyze the phenomena accompanying the change of operating condition in order to be considered in the selection of transformers characteristics in the event that these maneuvers will likely happen.

Key words– *simulation, power transformer, disturbed mode, loads variation.*

I. Introduction

In our modern world we use more and more technology in our everyday life, to the point where we have become completely dependent on electric power, both in our personal life and for our commercial and industrial activities.

The electric power required by consumers varies with time due to various factors:

- Climate: seasons sucsusion, presence or absence of sunlight in the day ....
- Sociological: weekly or annual vacancy ....
- Cultural: with television shows in the evening (football matchs, special event .... In July 1969, landing a man on the moon during the night, triggered in Europe a high demand of electrical power in a less time.
- Economics:
  - in long-term industrial development, recession.
  - in short-term startup and shutdown of industries, and the connection \disconnection of electrical machines (motors, pumps ....).

It is for this latter type of variation in power demand and its influence on the power transformer that we have interested in this article.

Firstly, we give some definitions of terms that will be used in the interpreting of the simulation results.

Then, we discuss the simulation of a power transformer in the case of sudden changes in load.

II. Definitions and Terminology

II.1. Power variation

The variation of the required power may be due to the change in the number of loads supplied simultaneously or to the increase or reduction of the power absorbed by one or more loads.

II.2. Overvoltage

One qualifies an overvoltage as any time function voltage that exceeds the peak voltage of the steady mode at its maximum tolerance.

There are basically, by their origins:

- The atmospheric overvoltages: direct or induced lightning strike.
- The operational overvoltages.

II.3. Overcurrents:

All current that exceeds the nominal current of service is considered as an overcurrent.

In general, overcurrents are classified into two categories:

- Temporary or transient overcurrents.
- Abnormal overcurrents due to overload and short circuit.

II.4. Harmonics:

It is the alteration of the sinusoidal waveform of the current and / or voltage generated by non-linear electrical systems.

The distorted signal can be decomposed into a sum of sinusoid with frequency (*n. f*) where $n \in \mathbb{N}$ and *f* is the frequency of the signal (Fourier series expansion).

II.5. Transient mode

The transient mode refers to the behavior during the transition between two stationary states.

III. Effect of load variation on the power transformer

The study of the transformer in disturbed mode and the identification of these disturbances and their origins are particularly important for the selection and sizing of the transformer and even help to optimize the exploitation of the electrical energy available to the consumer.

The phenomena which arise due to these load variations are difficult to predetermine. We know beforehand that it can create over-voltages and over-currents, but the propagation in time and the shape of these quantities with exactitude remain very difficult to determine. That's why the use of specialized software is required to observe, analyze and evaluate the actual behavior of the power transformer versus this change in operating parameters.

The over-voltages generated following the power variations can involve a dielectric stress on the transformer. This stress results in premature aging, or even by an insulation fault between turns or to ground.

In general, one can classify internal failures caused by over-voltages as follows:

- Insulation faults between turns of the same winding (the most common case),
- Faults between windings,
- Insulation faults between the involved winding and a neighboring conductor (other winding, core or tank).
- The combination of these three categories of faults.

For the immersed transformers, the external isolations are largely dimensioned and, consequently, the occurrence probability of an external dielectric failure rests very weak, except for certain cases of transformers of overhead grids in zone particularly polluted. Also, the dry transformers types can be affected by the external dielectric failures in the event of insulating surfaces pollution.

IV. Simulated system

The simulations presented in this paper were performed on a step-down three-phase power transformer S = 4500KVA; the primary and the secondary line to line voltages were 30kV \ 0.4kV respectively.

As shown in Figure 1, the transformer supplies initially a load S1 which represents 30% of its rated power. At a given time an additional load S2, equal to 20% of the rated power of the transformer will be connected.

Simulations were carried out using Matlab \ Simulink software package.

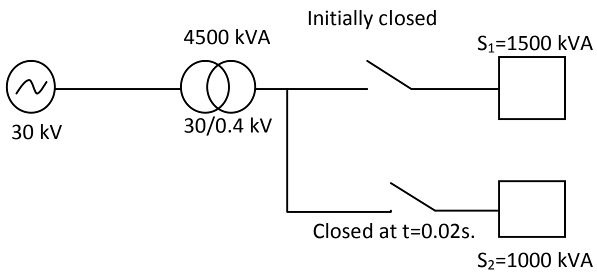

Figure 1 : principle scheme.

V. Results of Simulation & Discussions

The results of simulations of different electrical parameters of power transformer, during this switching of load, are shown in the figures hereafter (Fig. 2, 3, 4 and 5)

At the connection instant of the additional load (t = 0.02 s) There is a voltage drop followed by an immediate surge of about 1.5 V_{Rated}.

These surges, even with relatively low amplitudes (compared to the atmospheric over-voltages), can cause internal over-voltages in the transformer by the coincidence of its frequency with that of the excitation frequency. Moreover, they can create micro-dielectric breakdown of insulation without visible influence in the short term, but in long-term; the frequent exposition to these constraints can be one of the main causes of the decrease in the lifetime of power transformers. The insulation level of the transformer must be increased to cover the internal stresses waited in the event of resonance.

It should be noted also the deformation of signals (primary and secondary voltages) for about twenty milliseconds after the connection of the load S2 (see Fig. 2 & 3).

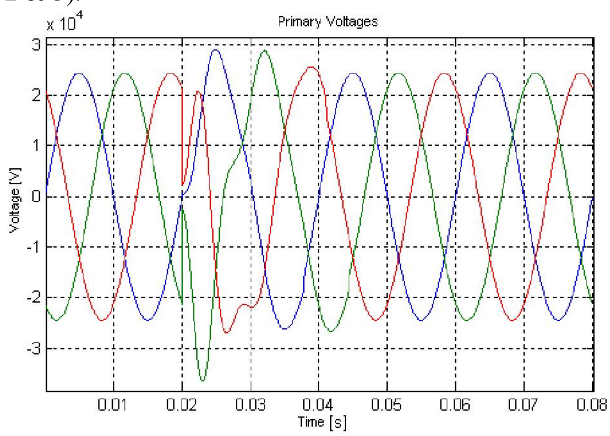

Figure 2: The primary voltages (connection of the additional load at t = 0.02 s)

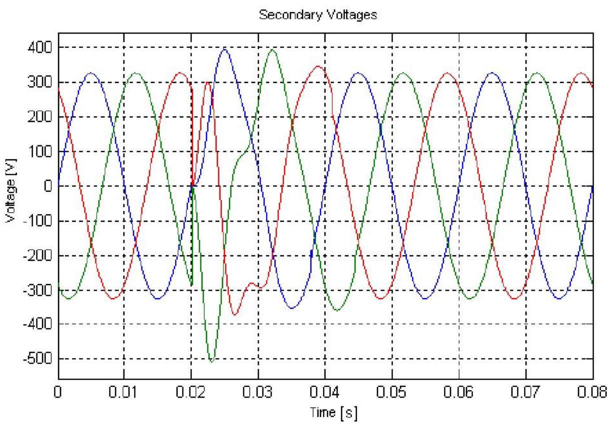

Figure 3: The secondary voltages (connection of the additional load at t = 0.02 s)

For primary and secondary currents, we see that the connection of the additional load generated considerable over-currents in the transformer windings

These overcurrents are of passengers types and last only a few milliseconds.

Peak values may reach several times the load rated current (4.I_{load} in this example).

From the Viewpoint of heating, and in general, the transient nature of these over-currents and the important thermal inertia of the transformer, especially for immersed type, allows to withstand these values without any problem; except if these operations are of repetitive type in very short intervals of time to the point where the thermal process becomes adiabatic. In this case the accumulation of the heating, due to the intermittent operations, may become dangerous for the transformer.

Also, these simulations show the not sinusoidality of the primary and the secondary currents during the transient period due to the existence of harmonics, which are the result of the nonlinear behavior of the magnetic circuit of the transformer. When we speak of the existence of harmonics, it means that the signal frequency is affected, and therefore the quality of the electrical energy will be degraded.

These harmonics are harmful not only for sensitive equipment but also for the power grid to which the transformer is connected.

Another important incidence of harmonics on power transformer is that may cause mal tripping of protective devices, especially for the differential protection.

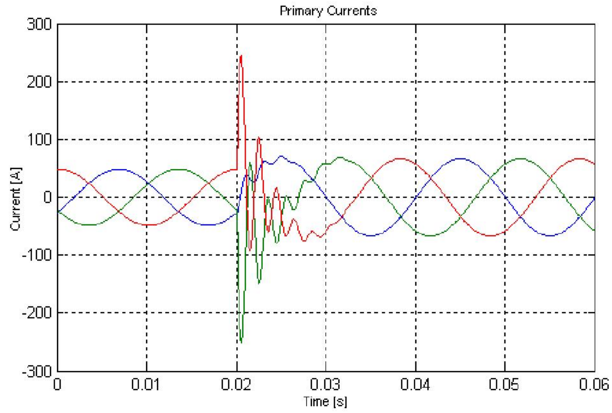

Figure 4: The primary currents (connection of the additional load at t = 0.02 s)

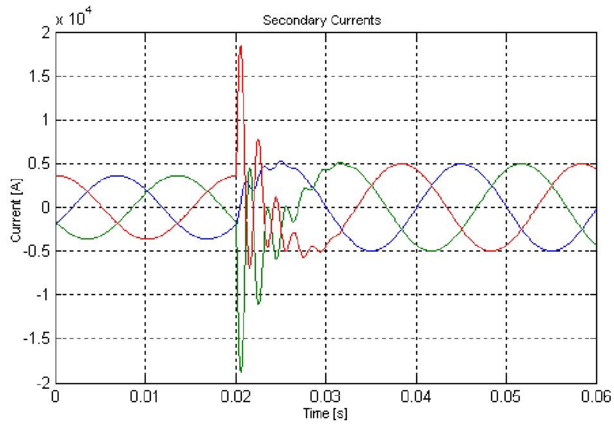

Figure 5: The secondary currents (connection of the additional load at t = 0.02 s)

The reduction of the effects of harmonic, frequency variations and overvoltage is carried out by the introduction of equipment suitable for each case. Their sizing and selection of their connection points and the optimization of operational procedures of electrical energy under these conditions are subject to detailed studies beyond the scope of this document.

The selection and sizing of the power transformer must consider the worst case of these phenomena.

When sizing the transformer for supplying residential users, this study does not seem necessary given the limits of the fluctuation of the power required.

However, this study constitutes a primordial stage for the choice and dimensioning transformers feeding the industrial factories which undergo abrupt and fast variations in power consumption during startups and shutdowns of large motors and electrical machinery, and the connecting or disconnecting workshops and industrial production lines.

VI. Conclusion

This paper aimed to study the behavior of transformers during the fluctuations in the required power.

The obtained results of simulation allow to identify and analyze the phenomena accompanying the change in the working mode of power transformer caused by the change in the supplied load.

This paper demonstrates also the value of simulation as a tool for sizing and transformer characteristics preselection so that it will be able to withstand the stresses imposed by the load variations.

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