Chapter 10
Lightning Protection of Substations and the Effects of the Frequency-Dependent Surge Impedance of Transformers

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ABSTRACT
The reliability of electrical power transmission and distribution depends upon the progress in the insulation coordination, which results both from the improvement of overvoltage protection methods and new constructions of electrical power devices, and from the development of the surge exposures identification, affecting the insulating system. Owing to the technical, exploitation, and economic nature, the overvoltage risk in high and extra high voltage electrical power systems has been rarely investigated, and therefore the theoretical methods of analysis are intensely developed. This especially applies to lightning overvoltages, which are analyzed using mathematical modeling and computer calculation techniques. The chapter is dedicated to the problems of voltage transients generated by lightning overvoltages in high and extra high voltage electrical power systems. Such models of electrical power lines and substations in the conditions of lightning overvoltages enable the analysis of surge risks, being a result of direct lightning strokes to the tower, ground, and phase conductors. Those models also account for the impulse electric strength of the external insulation. On the basis of mathematical models, the results of numerical simulation of overvoltage risk in selected electrical power systems have been presented. Those examples also cover optimization of the surge arresters location in electrical power substations.
INTRODUCTION

Substations are nodes of a system for electrical energy distribution and transformation. They constitute a set of complex electrical devices disposed in one place or in a fenced area, or in a support construction. The basic elements of the substations are busbars with connected power lines of the same voltage and transformers, linking busbars of various rated voltages.

Transformers are very important elements of the electrical energy transmission systems. They enable adjusting parameters of electrical energy generated in power stations to the requirements of the end user. Owing to the specific character of electrical power system, transformers constitute a group of electrical devices which are vastly differentiated as far as their power and rated voltages are concerned.

Electrical power systems are exposed to various exploitation stresses. Especially important are overvoltages caused by various faults, taking place in electrical power systems. Their presence may result in failures in the insulation systems of the devices, and consequently lowering the reliability of electrical energy transmission and distribution. Those issues are a subject of insulation coordination to harmonize the following three elements:

- Overvoltage surges of insulation systems,
- Electric strength of insulation systems,
- Protection against surges.

The basic aim of insulation coordination is providing technically and economically optimum reliability level of electrical energy supply. The interrelation between elements of insulation coordination is characteristic, e.g. the level of overvoltage stresses depends not only on the applied protection but may also depend on the electric strength of the insulation. Especially the level of surges in electrical power stations, caused by lightning discharges to the lines, depends on stroke strength of the line’s insulation.

The frequency of lightning discharges to substations and lines is considerable owing to their height - the higher is the object, the higher is the frequency. Besides they are mostly localized in open areas far from other high buildings. In the lack of suitable protection lightning discharges would cause overvoltages of very high crest voltage, and consequently numerous failures of electrical power devices.

Two types of electrical power hazards can be distinguished:

- Direct lightning strokes,
- Overvoltages transmitted through the lines.

The protection against direct lightning strokes is used in substations with upper voltage over 100 kV and in medium voltage stations with high power transformers. This protection is realized with the use of lightning rods arrangement. The rods are connected to the station’s earthing system.

Protection against surges transmitted through overhead lines is realized though special devices, i.e. surge arresters. They are disposed as close as possible to the protected equipment, mainly transformers, and also in the place the overhead lines are connected to the electrical power stations. The surge arresters are supposed to lower the crest value of overvoltages below the level of electric strength of insulation in electrical power stations.

The surge hazards occurring in real electrical high and extra high voltage power systems are difficult to measure; the reasons of this state are of technological, operational, and economic character. This is why, currently, theoretical methods of analyzing overvoltages are dynamically developing, in particular in the domain of lightning surges. In those methods, there are applied mathematical models of physical phenomena to which computer-aided technologies and techniques are used.

While modeling and analyzing lightning surges, specific transient states are studied; such states are the effect of lightning strokes. Two effects have a significant impact on overvoltages