

**CABLE SYSTEM
TRANSIENTS**

Theory, Modeling and Simulation

**AKIHIRO AMETANI
TERUO OHNO
NAOTO NAGAOKA**

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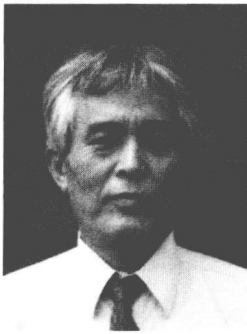
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CABLE SYSTEM TRANSIENTS

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Preface

Power transmission by cable is widely used in densely populated areas. Recently off-shore windfarms have become quite common, especially in Europe, and a number of off-shore windfarms are under construction and planned. Thus, a number of submarine cables have been installed and constructed. Submarine cables are also commonly used to connect an island to a mainland. Further, in Denmark all the overhead lines above 100 kV are replaced by underground cables. Thus, transients in cable systems become a very important subject, especially in long and complex cable systems.

The most significant difference of a cable from an overhead line is that a single-phase cable is composed of multi-conductors, that is, a core and a metallic sheath (shield), while a single overhead line is a single conductor. Thus, a three-phase cable (single-core coaxial cable) becomes a six conductor system. When the three-phase cable is enclosed in a conducting pipe, it becomes a seven conductor system. Therefore, an analysis of cable voltages and currents necessitates a theory of multi-conductors.

Another significant difference is that a cable is, in most cases, buried underground. This results in the propagation velocity of the earth-return mode along the cable being far smaller than that of an overhead line, which is nearly the velocity of light in free space. Also, the propagation velocity between a core and a metallic sheath (called “coaxial mode”) is determined by the relative permittivity ϵ_i of an insulator between the core and the sheath, which ranges from two to four, that is coaxial mode velocity $c_c = c_0/\sqrt{\epsilon_i}$, where $c_0 \cong 300$ m/ μ s (velocity of light).

There are various types and kinds of cables: (1) a power transmission cable, a communication cable and a control/single cable; (2) a directly buried or tunnel installed underground cable, a submarine cable and an overhead cable such as a gas-insulated bus; (3) a single-core coaxial (SC) cable, a multi-core cable, and a pipe-enclosed type (PT) cable; (4) circular or cylindrical, and flat-shaped cables; (5) normal-bonded and cross-bonded cables. This makes an analysis of cable voltages and currents far more complicated than that of an overhead line. As a matter of fact, the overhead line is categorized as just one of the cables, that is, a cable composed only of a core.

This book deals with transients in a power system cable. In Chapter 1, various cables manufactured and used in practice are described.

Chapter 2 explains the impedance and admittance formulas of typical cables, that is, an SC cable and a PT cable. Exact but complicated formulas for numerical calculations are described. Also simple but approximate formulas for a hand calculation are explained so readers understand the physical meaning of the formulas.

In Chapter 3, theories of wave propagation in various cables are described. Section 3.1 explains a basic theory to handle a multi-conductor system called “modal theory”. Then, wave propagation characteristics, which are the basis of a transient analysis, are investigated for an SC cable, a PT cable and a cross-bonded cable.

Chapter 4 discusses cable modeling for transient simulations by using well-known EMTP (electromagnetic transients program). A method of calculating the sequence impedances of a cable system is explained by using a lumped PI-circuit model. As the most conventional modeling method for a transient analysis, Dommel’s distributed line model is explained first. Then, Semlyen’s and Marti’s frequency-dependent line models are described. Also, frequency-dependent line models using vector fitting are explained.

In Chapter 5, transients in a single-phase cable are investigated based on experimental results and EMTP simulation results. Then, analytical calculations are carried out based on the theory explained in Chapter 3 so as to be able to understand the surge phenomena in a cable physically and theoretically.

Chapter 6 deals with field test results on various three-phase cables. A comparison with simulation results is carried out. Surge characteristics and the effect of various parameters are investigated based on the field test and simulations results. Also, EMTP simulation results by frequency-independent and -dependent line (cable) models prepared in the EMTP are discussed.

Chapter 7 explains abnormal transients in high voltage large cable systems where reactive power compensation is inherent. Because of a large capacitance due to a long cable and a large inductance of a shunt reactor, series and parallel resonance appears in the large cable systems. Also, system islanding, slow-front overvoltages, leading current interruption, zero missing phenomenon and cable discharge become significant problems. EMTP simulations are carried out, and the characteristics of the above mentioned transients are investigated based on the simulation result.

Chapter 8 describes transients in distributed generation systems where various cables are involved. Modeling of various components in a windfarm and a solar plant by the EMTP are explained. Handling EMTP simulations of transients in the windfarm and in the solar plant is explained, and the EMTP input data are described in detail.

Akihiro Ametani
March 2015

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