Power System Transient Analysis

Theory and Practice using Simulation Programs (ATP-EMTP)

Eiichi Haginomori • Tadashi Koshiduka
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POWER SYSTEM TRANSIENT ANALYSIS

Preface

The development of the EMTP (Electro-Magnetic Transient Program) has contributed to a revolution in analysis of switching phenomena and insulation coordination, which are critical issues in modern electric power systems. The authors of this book have been engaged in the development of Japan's electric power system, which is one of the most reliable in the world, as engineers of research and development and in universities for 30–50 years. In their careers, they have used EMTP for solving problems. The contents of this book come from their experiences. Although fundamental examples are displayed, they will definitely be practical for existing power systems.

Some of the contents of the book have been used to teach students in universities and engineers in industry. Those students and engineers all gained a splendid skill that proved useful in their jobs. Electric supply companies and manufacturers need skilled engineers; without them, the modern electric power system cannot operate reliably and safely.

The electric power system is changing rapidly and will change in the future both to cope with the growth of electricity demand and to keep the sustainability of modern society. Designers of today's complicated system configurations and operations need the knowledge in this book more than ever before.

The authors strongly hope that young engineers in the field study this book and use it to contribute to society's future.

Contents

Part I

Standard Course-Fundamentals and Typical Phenomena

1

Fundamentals of EMTP

The Electromagnetic Transients Program (EMTP) is a powerful analysis tool for circuit phenomena in power systems. Both steady state voltage and current distribution in the fundamental frequency and surge phenomena in a high-frequency region can be solved using EMTP. Selection of suitable models and appropriate parameters is required for getting correct results. Many comparisons of calculation results and actual recorded data are carried out, and accuracy of EMTP is discussed. Through such applications, EMTP is used widely in the world. EMTP can treat not only main equipment but also control functions. ATP-EMTP is a program that came from EMTP. After ATPDraw (which provides an easy, simple, and powerful graphical user interface) was developed, ATP-EMTP was able to expand its user ability.

1.1 Function and Composition of EMTP

Built-in models in EMTP are listed in Tables 1.1 and 1.2. Table 1.1 shows a main circuit model and Table 1.2 shows a control model. There are two ways to simulate control; one is TACS (Transient Analysis of Control Systems) and the other is MODELS. MODELS is a flexible modeling language and permits more complex calculations than TACS. All statements in MODELS must be written by the user. MODELS is not covered in this book, but TACS is explained for representing control.

1.1.1 Lumped Parameter RLC

The Series RLC Branch model is prepared for representing power system circuits. Load, shunt reactor, shunt capacitor, filter, and other lumped parameter components are represented using this model.

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Table 1.1 Main circuit model.

Main Circuit Equipment	Built-in Model
Lumped parameter RLC	Series RLC branch
Transmission line, cable	Mutually coupled RLC element, Multiphase PI equivalent (Type 1, 2, 3)
	Distributed parameter line with lumped R (Type-1, -2, -3)
	Frequency dependent distributed parameter line, JMARTI (Type-1, -2, -3)
	Frequency dependent distributed parameter line, SEMLYEN (Type-1)
Transformer	Single-phase saturable transformer
	Three-phase saturable transformer
	Three-phase three-leg core-type transformer
	Mutually coupled RL element (Type 51, 52)
Nonlinear element	Multiphase time varying resistance (Type 91)
	True nonlinear inductance (Type 93)
	Pseudo nonlinear hysteretic inductor (Type 96)
	Staircase time varying resistance (Type 97)
	Pseudo nonlinear inductor (Type 98)
	Pseudo nonlinear resistance (Type 99)
	TACS controlled resistance for arc model (Type 91)
Arrester	Multiphase time-varying resistance (Type 91)
	Exponential ZnO (Type 92)
	Multiphase piecewise linear resistance with flashover (Type 92)
Switch	Time-controlled switch
	Voltage-controlled switch
	Statistical switch
	Measuring switch
TACS controlled switch	Diode, thyristor (Type 11)
	Purely TACS-controlled switch (Type 13)
Voltage source, current source	Empirical data source (Type 1–9)
	Step function (Type 11)
	Ramp function (Type 12)
	Two slopes ramp function (Type 13)
	Sinusoidal function (Type 14)
	CIGRE surge model (Type 15)
	Simplified HVDC converter (Type 16)
	Ungrounded voltage source (Type 18)
	TACS controlled source (Type 60)
Generator	Three-phase synchronous machine (Type 58, 59)
	Universal machine module (Type 19)
Rotating machine	Universal machine module (Type 19)
Control	TACS
	MODELS

1.1.2 Transmission Line

The multiphase PI-equivalent circuit model, Type 1, 2, and 3, is used as a simple line model. It has mutual coupling inductors and is applicable to a transposed or nontransposed three-phase transmission line.

Table 1.2 Control model.

Control Element	Built-in Function in TACS
Transfer function	$\frac{K}{s}, Ks, \frac{K}{1+Ts}, \frac{Ks}{1+Ts},$
	$G\frac{1+N_1s+N_2s^2+\cdots+N_7s^7}{1+D_1s+D_2s^2+\cdots+D_7s^7}$
Devices	Frequency sensor (50)
	Relay operated switch (51)
	Level triggered switch (52)
	Transport delay (53)
	Pulse transport delay (54)
	Digitizer (55)
	Point-by-point nonlinear (56)
	Time sequence switch (57)
	Controlled integrator (58)
	Simple derivative (59)
	Input-If selector (60)
	Signal selector (61)
	Sample and track (62)
	Instantaneous min/max (63)
	Min/max tracking (64)
	Accumulator and counter (65)
	RMS meter (66)
Algebraic and logical expression	+, −, *, /, AND, OR, NOT, EQ, GE, SIN, COS, TAN, ASIN, ACOS, ATAN, LOG, LOG10, EXP, SQRT, ABS
	Free format FORTRAN
Signal source	DC level (Type 11)
	Sinusoidal signal (Type 14)
	Pulse (Type 23)
	Ramp (Type 24)
Input signal from main circuit	Node voltage (Type 90)
	Switch current (Type 91)
	Synchronous machine internal signal (Type 92)
	Switch state (Type 93)
Output signal to main circuit	On/off signal for TACS-controlled switch
	Signal for TACS-controlled source
	Torque and field voltage signals for synchronous machine

The distributed parameter line model with lumped resistance, Type-1, -2, and -3, consists of a lossless distributed parameter line model and constant resistances. The resistance is inserted into the lossless line in the mode. Normally the resistance corresponding to the fundamental frequency is used, then this model is applicable to phenomena from the fundamental frequency to the harmonic frequency, in the 1–2 kHz region.

The frequency-dependent distributed parameter line model developed by J. Marti, Semlyen, takes into account line losses at high frequency, even in an untransposed line. It enables the production of detailed and precise simulation for surge analysis. The required data for use of the model can be obtained using support routine Line Constants or Cable Constants, explained later. Height of transmission line tower, conductor configuration, and necessary data are inputted to the support routine, and the input data for EMTP are calculated by the support routine. Both cables and overhead lines are treated by these support routines.

1.1.3 Transformer

A single-phase saturable transformer model is a basic component that permits a multiwinding configuration. The two- or three-winding model is used in many study cases. A pseudo nonlinear inductor is included in this model for saturation characteristics. Input data are resistance and inductance of each winding. A three-phase saturable transformer model also is prepared. The three-phase three-leg transformer is applied for a core type transformer that has a path for air gap flux generated by a zero sequence component. When a hysteresis characteristic is desired, the pseudo nonlinear hysteretic inductor, Type 96, should be used instead of the incorporated pseudo nonlinear inductor. In such a case, the Type 96 branch will be connected outside of the transformer model. The mutually coupled RL element is used for representing a multiwinding transformer; however, self and mutual inductances of all windings are required for input data. This is used for transition voltage analysis in the transformer, which requires a multiwinding model.

1.1.4 Nonlinear Element

True nonlinear inductance, Type 93, has a limit on the number of elements one circuit can hold. When the true nonlinear is included, an iterative convergence calculation is carried out at each time step. Therefore, one element is permitted in one circuit. If more than two elements are needed, these elements must be in separate circuits or be separated by a distributed parameter line. The distributed parameter line separates the network internally as explained in the next section; it is a marked advantage of the EMTP calculation algorithm.

Pseudo-nonlinear elements are prepared that can be used without such constraints. An iterative convergence calculation is not applied for the pseudo nonlinear element, but a simple method is applied. That is, after one time step is calculated, a new value on the nonlinear characteristic curve is adopted for the next time step. Then if the pseudo-nonlinear element is used, a small time step must be selected, suppressing a larger change of voltage or current in the circuit during one time step. The pseudo-nonlinear reactor, Type 98, is the same as the element included in the saturable transformer model. A residual flux in an iron core is simulated by use of the pseudo-nonlinear hysteretic inductor, Type 96.

For use of TACS controlled resistance for the arc model, Type 91, the arc equation must be composed by TACS functions.

1.1.5 Arrester

In the model Type 92, two models are available: one is the exponential ZnO and the other is the multiphase piecewise linear resistance with flashover. The pseudo-nonlinear resistance is also used as an arrester.