SOLUTION TECHNIQUES FOR ELECTROMAGNETIC TRANSIENTS IN POWER SYSTEMS

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Summary

This chapter presents numerical methods used in computer programs for the simulation of electromagnetic transients in power systems. The simulation of modern power systems requires advanced numerical tools capable of calculating steady-state conditions and perturbed states with highest accuracy. Electromagnetic transients are calculated at the circuit level and modeling methods must always attempt to reduce approximations. A complete computational environment includes load-flow, steady-state, initialization and time-domain modules. These modules are presented with related formulation methods. Specific aspects, such as control systems and nonlinear components are also considered. The emphasis is on network formulation and solution methods for off-line applications. The computer programs used for electromagnetic transients are capable of delivering power system studies from slow to fast and very fast

transients. The numerous application fields are summarized in this chapter with typical examples.

1. Introduction to Power System Analysis Methods

Modern power systems are complex and require advanced mathematical analysis methods for design and operation. Numerical techniques can be used to simulate and analyze power systems. These techniques are programmed in specialized computer software packages. The power system simulation and analysis tools can be subdivided into the following main categories: steady-state, electromechanical transients and electromagnetic transients.

The computation of a power system load-flow falls into the steady-state category. It is often based on the positive sequence approximation of the studied network. The positive sequence approximation uses the balanced network assumption: balanced loads and continuously transposed transmission lines. It is an acceptable approximation mainly for transmission systems. Distribution systems are not balanced by nature and require multiphase and unbalanced load-flow calculation methods. The load-flow solution is the first initialization stage of a power system. It determines all voltage phasors in the studied system and establishes all initial conditions.

The load-flow solution of a power system is a nonlinear problem that must be solved using an iterative method. When all load-flow constraints are converted into lumped branch equivalent models, it is possible to achieve a linear steady-state solution without iterations.

Electromechanical transient analysis methods assume low frequency perturbations and can be solved using the positive sequence network approximation. The power system is assumed to remain in steady-state, whereas the generating units (synchronous or asynchronous machines) are solved using differential equations in time-domain. Such methods can be efficiently used to simulate and study very large scale systems for rotor angle stability problems including large disturbances and small-signal stability problems.

The category of electromagnetic transients is designed to avoid approximations and for the widest range of frequencies. Studied phenomenon signals are visualized in time-domain and can contain frequencies from 0 Hz to 1 MHz and more. Using such a wideband of frequencies requires circuit-based detailed calculation methods and models. The modeling sophistication is linked to the frequency content. Electromagnetic transients include electromechanical transients. Due to the detailed representation of circuit components and increased precision, the computation of electromagnetic transients requires more computing resources and consequently much more computing time.

Software packages and methods used for computing electromagnetic transients are called EMT (Electromagnetic Transients) type tools.

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2. EMT-Type Simulation Methods

EMT-type simulation methods are classified into two main categories: off-line and real-time. The purpose of an off-line simulation tool is to conduct simulations on a generic computer. Off-line tools are designed for high efficiency using powerful graphical user interfaces, numerical methods and programming techniques. Such tools do not have any computing time constraints and can be made as precise as possible within the available data, models and related mathematics.

Real-time simulation tools are capable of generating results in synchronism with a real-time clock. Such tools are capable of interfacing with physical devices and maintaining data exchanges within the real-time clock. The capability to compute and interface within real-time, imposes important restrictions on the design of such tools. Computing technologies and numerical methods are however, evolving rapidly and the gap between real-time and off-line methods is constantly reducing.

This chapter targets only off-line solution methods and tools. The objective is to provide an overview on off-line simulation tools and methods for the computation and analysis of electromagnetic transients. This chapter focuses on the most widely recognized and available groups of methods applied in industrial grade computer software packages. The document follows the initial work presented by Mahseredjian, Naredo, Karaagac, & Martinez-Velasco (2010), Mahseredjian, Dinavahi, & Martinez (2009), Mahseredjian (2007), Mahseredjian, Dinavahi, & Martinez (2007).

3. Application Fields for the Computation of Electromagnetic Transients

The initial application of EMT-type tools was the computation of overvoltages in power systems. There are four main categories of overvoltages: very fast front, fast front, slow front and temporary. The very fast front category is related mainly to restrikes in gas insulated substations. The frequencies range from 100 kHz to 50 MHz. The lightning overvoltages fall into the fast front category, their typical frequency content is from 10 kHz to 3 MHz. The switching overvoltages fall into the slow front category with the frequencies ranging from fundamental frequency to 20 kHz. Switching events are internal controlled or uncontrolled events. For example, controlled events are line switching actions. Faults on buses or in transmission lines fall into the list of uncontrolled events. As for the temporary overvoltages, the typical causes for such overvoltages are: single-line-to-ground faults causing overvoltages on live phases, open line energization and load-shedding. In some cases temporary overvoltages are combined with ferro-resonance. The frequency content for temporary overvoltages is typically from 0.1 Hz to 1 kHz.

Frequencies above the fundamental frequency usually involve electromagnetic phenomena. Frequencies below the fundamental frequency may also include electromechanical modes (synchronous or asynchronous machines).

The above categories can be expanded to list specific important study topics in power systems:

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- switchgear, TRV, shunt compensation, current chopping, delayed-current zero conditions;
- insulation coordination;
- saturation and surge arrester influences;
- harmonic propagation, power quality;
- interaction between compensation and control;
- wind generation, distributed generation;
- precise determination of short-circuit currents;
- detailed behavior of synchronous machines and related controls, auto-excitation, sub-synchronous resonance, power oscillations;
- protection systems;
- HVDC systems, power electronics, FACTS and Custom Power controllers.

These applications are in a wideband range of frequencies, from dc to 50 MHz. EMT-type methods are also applicable to the simulation and analysis of electromechanical transients. EMT-type programs can produce more precise simulation results for such studies due to inherent modeling capabilities to account for network nonlinearities and unbalanced conditions. Frequency dependent and voltage dependent load models can be also incorporated.

Since EMT-type programs are able to represent the actual circuit of a power network, they are more general than traditional power system analysis tools. EMT-type methods constitute the precision reference for power system analysis.

4. Computational Methods

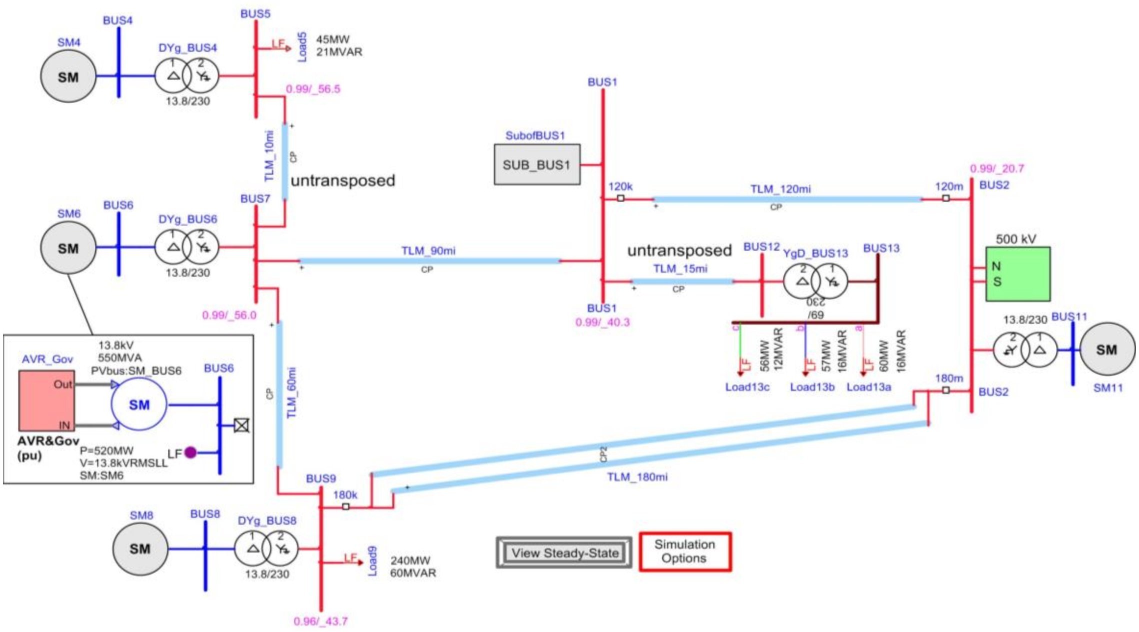

Figure 1. Sample 230 kV network study case.

The first input level for an EMT-type simulation is normally a Graphical User Interface

(GUI). A typical example is presented in Figure 1. This example uses a single-wire diagram representation combined with unbalanced load representation. Sub-networks are used to evacuate design details. The transformer sub-networks contain detailed circuits for the transformer models. The Synchronous Machine (SM) sub-network contains the actual generator symbol and data with the generator control systems. In EMT-type methods control systems are represented using block diagrams. The block diagram of a generator governor/turbine model is shown in Figure 2.

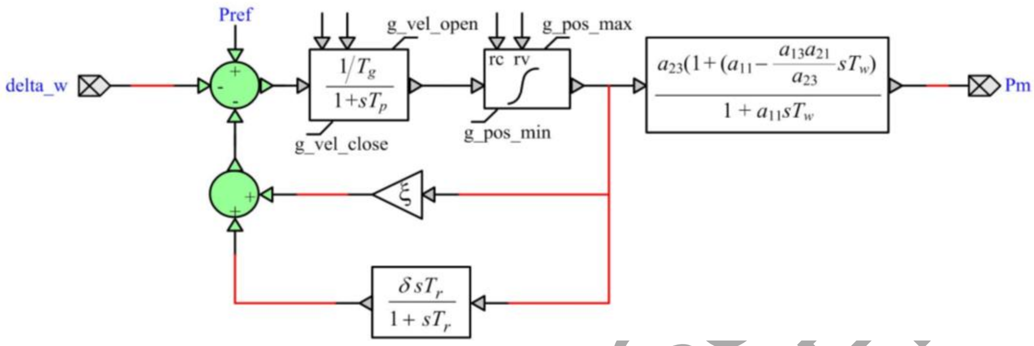

Figure 2. Synchronous generator governor/turbine model using block diagram representation.

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Biographical Sketch

Jean Mahseredjian received the M.A.Sc. and Ph.D. degrees from the École Polytechnique de Montréal, Montréal, QC, Canada, in 1985 and 1991, respectively. From 1987 to 2004, he was with IREQ (Hydro-Québec) working on research and development activities related to the simulation and analysis of electromagnetic transients. In December 2004, he joined the Faculty of Electrical Engineering at École Polytechnique de Montréal.