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Simulation of Power System Conditions for Relay Protection and Automation Tasks

Goda S. NUDELMAN, Olga A. ONISOVA, Alexander A. NAVOLOCHNY
VNIIR
Russia
onisova@vniir.ru

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1 INTRODUCTION

Development of power system significantly affects functionality of relay protection and automation systems. Modern protective relays are complex multi-function microprocessor-based “Intelligent Electronic Devices” (IED) which are able to perform the most advanced protection and automation algorithms. Future innovations in electrical engineering associated with Smart Grid technologies in combination with increasing complexity of relay hardware and software require new approaches to relay protection and automation tasks.

2 RELAYPROTECTION TASKS AND POWER SYSTEM MODELS

Let us consider the following major tasks of relay protection and automation:

- selecting relay protection functions and protection equipments;
- configuring relays, relay setting;
- estimating efficiency of relay protection and automation functions;
- development of new relay protection and automation algorithms, development of new methods for calculation of relay protection and automation settings.

Modern approach to relay protection and automation tasks requires wide use of digital simulation technologies. Depending on the considered task appropriate power system model should be chosen. Figure 1 shows classification of power system models based on simulation techniques applied.

For relay protection and automation tasks it is necessary to deal both with possible steady-state modes and with wide range of transients [1] characterized by the time frame from microseconds to several seconds. Figure 2 shows typical time frames for power system transients.

The two basic theories for power system modeling are field theory and circuit theory.

Field theory gives the most accurate representation of power system model [2]. However mathematical formulation of electromagnetic field calculation problem produces a partial differential equation system that leads to computational difficulties. Therefore field theory can only be applied to specific tasks such as in-depth testing of protective relays.

Circuit theory is most widely used for power system modeling. In that case power system model is based on time domain representation. Because of relative mathematical simplicity circuit theory is applied to a wide range of practical tasks. The following description concerns the power system model based on circuit theory methods.

The power system model is represented by a set of nonlinear differential equations. A major problem with a time domain solution is the “stiffness” of the system. That is, the time constants associated with the system variables vary enormously. Some simplifications are usually applied to the

original system model. According to it power system models can be classified into the following groups:

- Steady-state models;
- Quasi-transient models;
- Transient models.

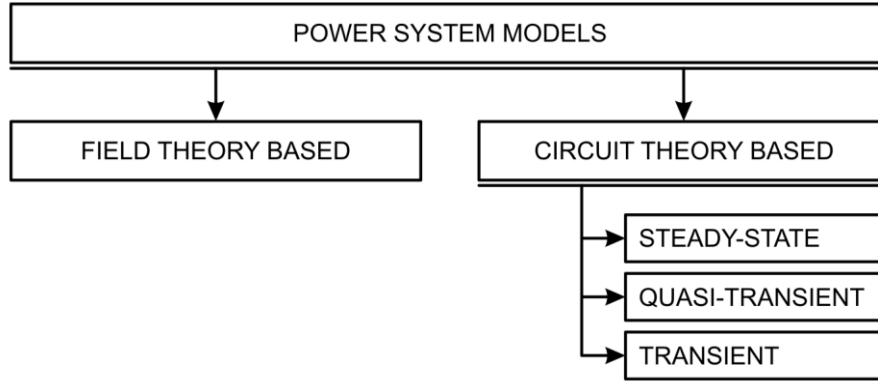


Fig. 1: Classification of power system models

Steady-state models

Steady-state model is based on the assumption that power systems operate in their steady-state modes only. The model is represented by a nonlinear algebraic equation system. Because of nonlinearity of the problem the numerical solution must be iterative. The Gauss-Seidel or the Newton-Raphson iteration schemes can be applied. On the assumption of power system network symmetry a single-phase representation is used. Unbalanced system condition is represented by symmetrical components transformation.

A diagram of the basic Newton-Raphson algorithm is given in Figure 3(a).

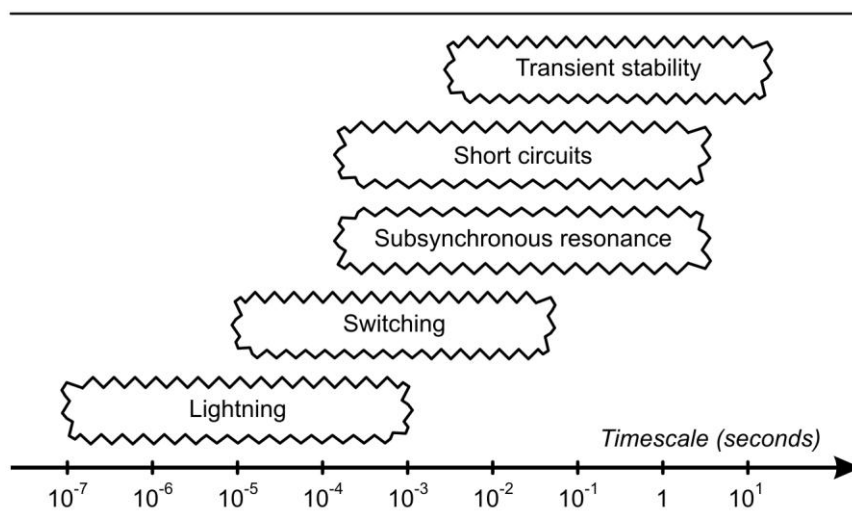


Fig. 2: Typical time frames for power system transients

Quasi-transient models

Quasi-transient model is appropriate for a certain type of transient characterized by a restricted time frame. For example, electromechanical transients investigation requires simulation for about several seconds. Electromagnetic transients associated with the disturbance are neglected. Mathematical formulation of the considered model leads to a set of algebraic differential equation. The network solution at each time step is of the form:

$$[I] = [Y] \cdot [V]$$

where $[I]$ is a vector of source current; $[Y]$ is a conductance matrix; $[V]$ is a vector of bus voltages.

In the case of pure impedance elements, including loads, the solution is straightforward algebraic operation without iterations. If loads characteristics are nonlinear, network solution involves iteration with nonlinear load effect. Numerical integration algorithms widely used to solve differential equation are Euler's Method, Trapezoidal Method, Runge-Kutta Method.

Typical integration time step is 10 milliseconds.

The principal steps of dynamic simulation as produced by quasi-transient model are shown in Figure 3(b).

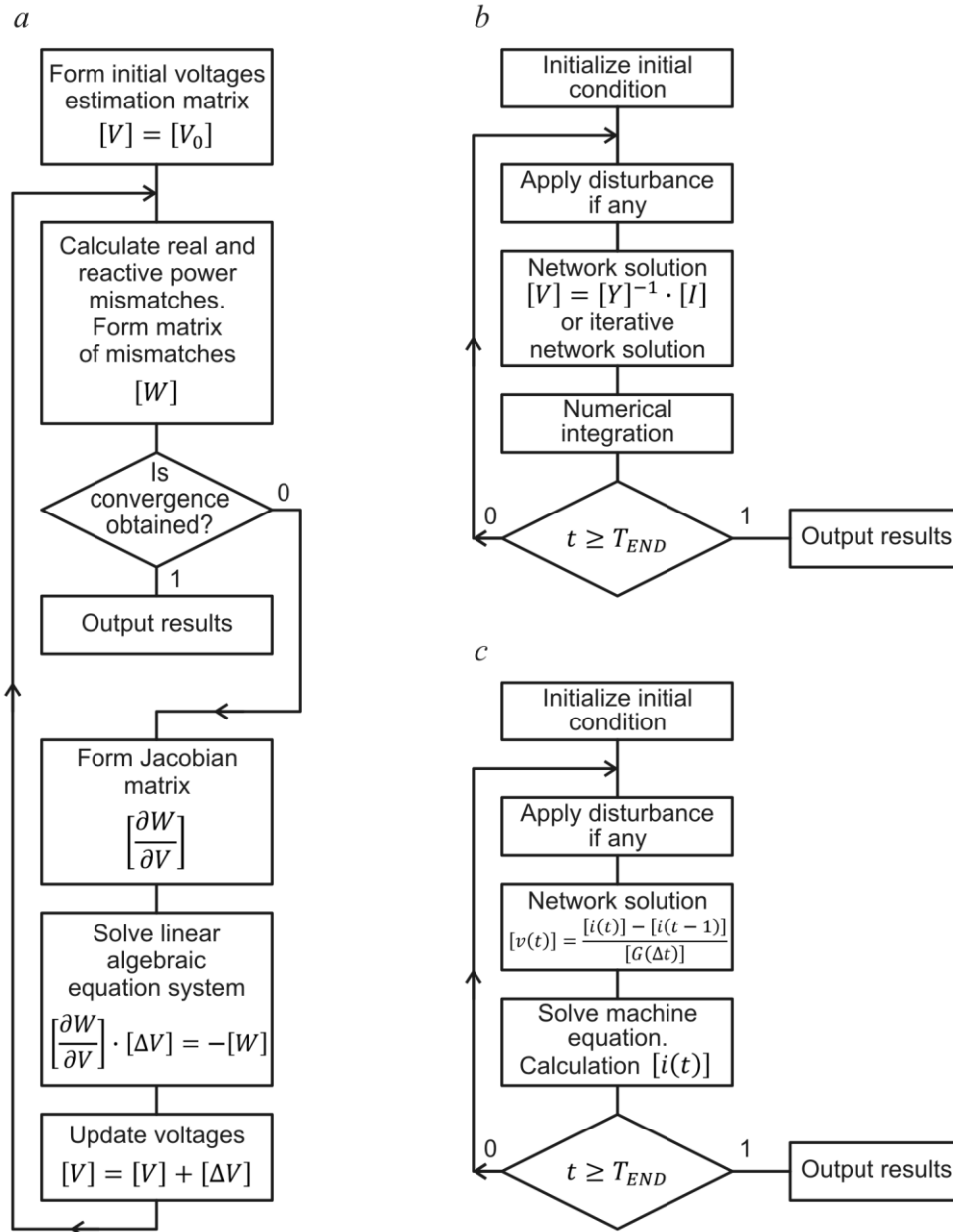


Fig. 3: Diagram of the basic algorithm: (a) Newton-Raphson solution; (b) quasi-transient simulation; (c) transient simulation.

Transient models

Transient model is appropriate for a wide range of power system transients. The model is based on original power system model representation. Other system models can be derived from the transient model.

The two broad classes of the method used to solve the differential equations representing transient model are state variable analysis and numerical integration substitution.

State variable analysis represents a power system by a set of first order differential equations, which are then solved by numerical integration. Numerical techniques used are variable step implicit integration algorithm (Euler Method, Runge-Kutta Method). The main limitation is the need to recognize dependability between system variables that makes state variable analysis unsuited for very large systems.

Numerical integration substitution method is implemented in the Electromagnetic Transient Program [3]. The trapezoidal integration is used to form the difference equations associated with the network. In that case the lumped components (inductance, capacitance) can be replaced at each time step by a current source in parallel with a resistance (Figure 4) and then combined in a solution for the nodal voltages.

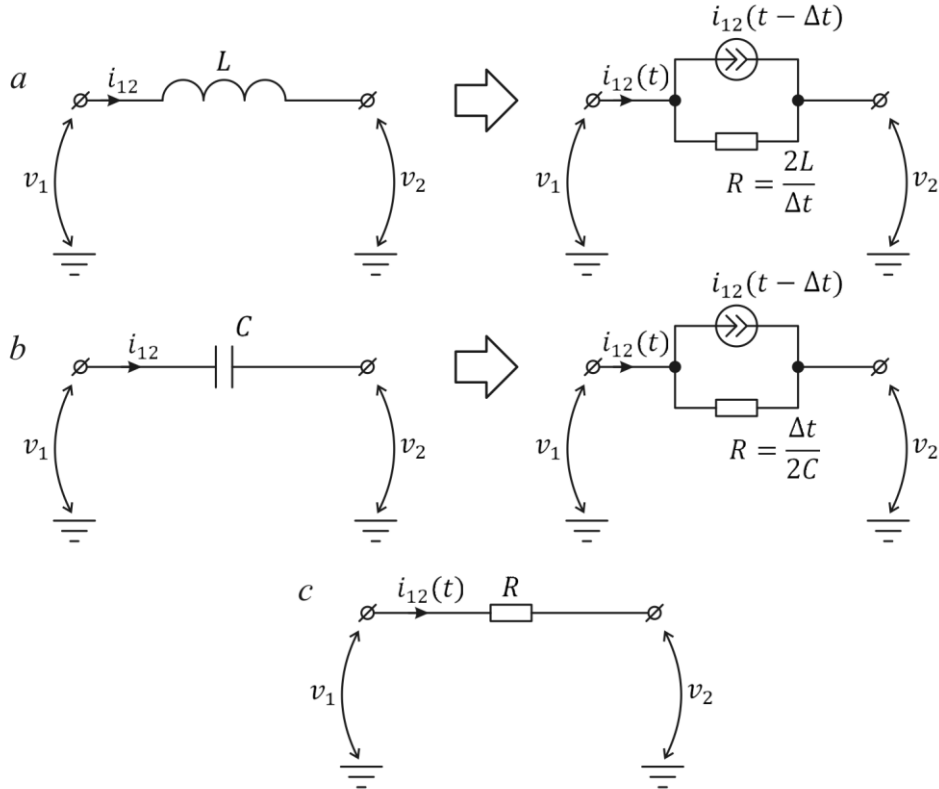


Fig. 4: Equivalent circuits: (a) inductance; (b) capacitance; (c) resistance.

Let us consider a simple network (Figure 5).

The branches currents are:

$$i_{12}(t) = \frac{v_1(t) - v_2(t)}{R};$$

$$i_{13}(t) = \frac{\Delta t}{2L}(v_1(t) - v_3(t)) + i_{13}(t - \Delta t);$$

$$i_{14}(t) = \frac{2C}{\Delta t}(v_1(t) - v_4(t)) + i_{14}(t - \Delta t).$$

Using first Kirhgoff's law in Figure 5 we can write

$$\left(\frac{1}{R} + \frac{\Delta t}{2L} + \frac{2C}{\Delta t} \right) v_1(t) - \frac{1}{R} v_2(t) - \frac{\Delta t}{2L} v_3(t) - \frac{2C}{\Delta t} v_4(t) = i_1(t) - i_{13}(t - \Delta t) + i_{13}(t - \Delta t).$$

The whole network can be represented by the following system of linear algebraic equations:

$$[G(\Delta t)] \cdot [v(t)] = [i(t) - i(t-1)]$$

where $[G(\Delta t)]$ is the nodal conductance matrix; $[v(t)]$ is the column vector of the node voltages; $i(t)$ is the column vector of current sources; $i(t-1)$ is the column vector of past history current sources.

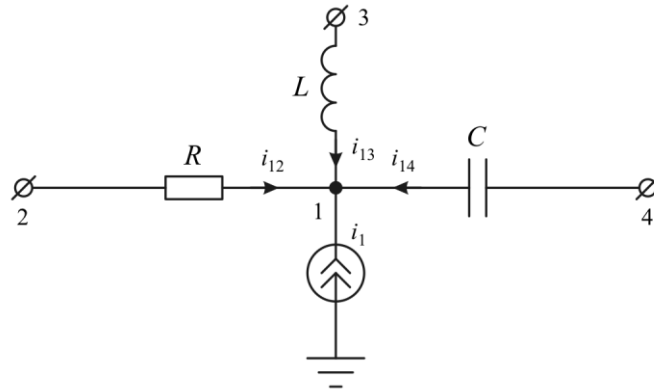


Fig. 5: Simple electrical network

Efficient solution is possible by the use of a constant integration step length Δt throughout the study which permits performing a single conductance matrix. Typical time step length is 10-60 microsecond.

The EMTP-type programs permit to simulate the network involving distributed parameters as well. A solution for distributed parameters transmission lines are based on Bergeron's Method [3]. According to it equivalent circuit of transmission line consists of two line terminals which don't have direct connection (Figure 6).

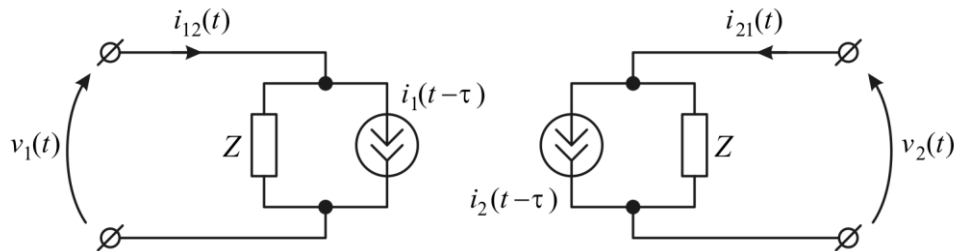


Fig. 6: Equivalent circuit of lossless transmission line

Simulation of electrical machines involves electromagnetic as well as electromechanical transients. In that case generator and turbine mechanical characteristics should be taken into account. Figure 7 shows a diagram of the network including a.c. machine model with the electromagnetic and electromechanical components.

A diagram of transient simulation is given in Figure 3(c).

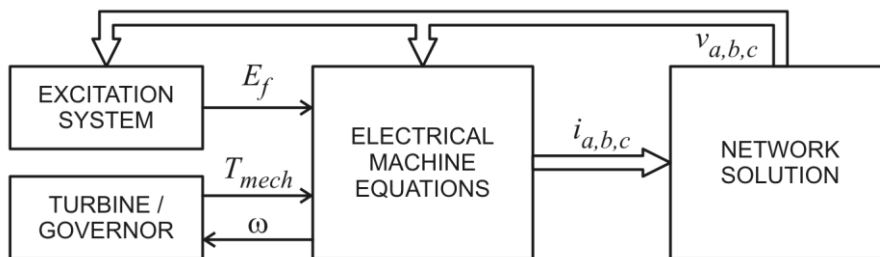


Fig. 7: Network diagram including a. c. machine model

Recent developments have made it possible to run the transient model in real time. The Real Time Digital Simulator developed by RTDS Technologies Incorporation performs simulation of all

possible faults and operating conditions in real time [4]. Since the simulation runs in real time protective relays can be closed-loop tested with power system model.

Application of described above power system models for relay protection and automation tasks is shown in Table 1.

Relay protection and automation tasks	Power system models	Transients
Selecting relay protection functions and protection equipments	steady-state; quasi-transient	Power-flow
Relay configuring and setting		Faults analysis
Estimating efficiency of relay protection and automation function		Electromechanical transients analysis
Development of new relay protection and automation algorithms Development of new method for relay protection and automation settings calculation	quasi-transient ; transient	Faults analysis Electromechanical transients analysis Electromechanical and electromagnetic transients analysis

Table 1: Application of power system models for relay protection and automation tasks

Due to the latest developments in simulation technologies the transient power system model is becoming more widely used. It can be applied for estimation of relay protection and automation system behavior under transient conditions. The real time transient model can be effectively used in specified stages of relay protection and automation equipments certification.

3 CONCLUSION

Simulation technologies play an important role in solving relay protection and automation tasks. Depending on the simulation technique applied power system models can be classified into three groups: steady-state; quasi-transient, transient. Each of the models is appropriate for certain power system conditions studies that define its application for relay protection and automation tasks.

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