Electric Power Systems Research 138 (2016) 195–201

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

A study of electromagnetic transient simulations using IEEJ's West-10 benchmark power system model

Taku Noda[a,*], Hiroshi Takizawa[b], Takayuki Nakajima[b]

[a] Electric Power Engineering Research Laboratory, CRIEPI (Central Research Institute of Electric Power Industry), 2-6-1 Nagasaka, Yokosuka, Kanagawa 240-0196, Japan
[b] DCC (Denryoku Computing Center), 2-11-1 Iwado-kita, Komae-shi, Tokyo 201-8511, Japan

ARTICLE INFO

Article history:
Received 30 October 2015
Received in revised form 6 March 2016
Accepted 14 March 2016
Available online 30 April 2016

Keywords:
EMT simulations
IEEJ's West-10 benchmark power system model
Relatively-large power systems
Stability-type simulations

ABSTRACT

Electromagnetic-transient (EMT) simulations of relatively-large power systems with generator mechanical dynamics have become quite common especially for studies of power systems including power-electronics converters. The Power and Energy Society of the Institute of Electrical Engineers of Japan (IEEJ) prepared benchmark power system models for transient stability (TS) simulations. Among those, the West-10 benchmark power system model approximately represents the long radial power system in the western part (60-Hz part) of Japan with ten generators. In this paper, the West-10 benchmark power system model is expanded and converted to an EMT model, and it is shown that the results obtained by the EMT model agree well with those obtained by the TS model in most cases. It is also found that when the dc components of fault currents are large the results obtained by those two simulation methods are different due to current zero missing of circuit breakers.

1. Introduction

Modern power systems utilize power-electronics converters for dc transmission, back-to-back system interconnection (frequency conversion between 50 and 60 Hz), system stabilization, and so on. Since waveform-level calculations are essential to take into account switchings in power-electronics converters, studies of power systems including power-electronics converters are now often carried out by electromagnetic transient (EMT) simulations. This trend gives further importance to EMT simulations in addition to studies of conventional phenomena such as overvoltages, inrush currents, and abnormal oscillations. Thanks to the research and development of simulation methods and also to the progress of simulation hardware (computers), EMT simulations of relatively-large power systems with generator mechanical dynamics have become quite common. The EMT simulations related to power electronics converters mentioned above and sub-synchronous resonance often involve relatively-large power systems. The Power and Energy Society of the Institute of Electrical Engineers of Japan (IEEJ) prepared benchmark power system models for transient stability (TS) simulations. Among those, the West-10 benchmark power system model approximately represents the long radial power system in the western part (60-Hz part) of Japan with ten generators. In this paper, the West-10 benchmark power system model is expanded and converted to an EMT model for the implementation in EMT simulation programs. The major differences between the EMT and the TS simulation are as follows. The EMT simulation calculates three-phase voltage and current waveforms, while the TS simulation calculates positive-sequence r.m.s. values. In addition, voltages and currents in the EMT simulation are in units of volts and amperes, while those in the TS simulation are based on the per-unit system. Therefore, all models have to be expanded and converted to three-phase waveform-based ones, and appropriate nominal voltages have to be given for all buses. Furthermore, an appropriate winding connection, such as star-delta, star–star-delta, and so on, has to be assumed for each transformer, and an appropriate grounding impedance has to be added to each neutral point.

Using the developed EMT model of the West-10 benchmark power system, simulations with various fault scenarios are carried out. It is shown in this paper that the results obtained by the EMT model agree well with those obtained by the original TS model in most cases. It is also found that when the dc components of fault currents are large, the results obtained by those two simulation methods are different due to current zero missing of circuit breakers. For the comparison with the TS results, π equivalents are used for the modeling of the transmission lines, and they are then replaced with constant-parameter line models for more practical simulation so as to discuss the impact of line modeling.

* Corresponding author. Tel.: +81 7055907052; fax: +81 468563540.
E-mail addresses: takunoda@criepi.denken.or.jp (T. Noda), taki@dcc.co.jp (H. Takizawa), nakaji@dcc.co.jp (T. Nakajima).

http://dx.doi.org/10.1016/j.epsr.2016.03.028
0378-7796/

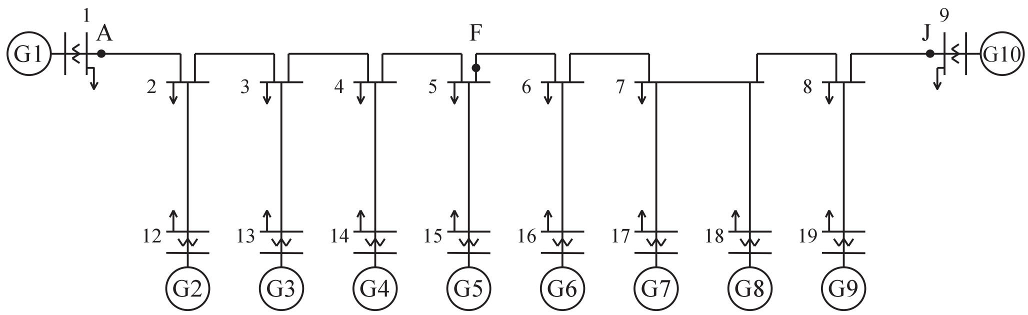

Fig. 1. One-line diagram of the West-10 Benchmark System (IEEJ's West-10 benchmark power system model).

Table 1
Generator model constants.

d-axis synchronous reactance x_d [p.u.]	1.70
q-axis synchronous reactance x_q [p.u.]	1.70
d-axis transient reactance x'_d [p.u.]	0.35
d-axis subtransient reactance x''_d [p.u.]	0.25
q-axis subtransient reactance x''_q [p.u.]	0.25
d-axis transient time constant T'_d [s]	1.00
d-axis subtransient time constant T''_d [s]	0.03
q-axis subtransient time constant T''_q [s]	0.03
armature time constant T_a [s]	0.40
armature leakage reactance x_l [p.u.]	0.225

2. IEEJ's West-10 benchmark power system model

The 60-Hz power system in Japan interconnects several electric power companies with 500-kV transmission lines and extends more than 1000 km in an east-west direction. The system can roughly be considered a radial system. IEEJ's West-10 benchmark power system model, called the "West-10 Benchmark System" hereafter, approximates hundreds of generator stations included in this radial system with ten generators. In this approximation, low-frequency swing modes of the actual system are captured as close as possible, and the total generation capacity and the total length of the transmission lines are set very close to the actual values. Since only the summary of the West-10 Benchmark System is given here, Ref. [1] should be consulted for details. Fig. 1 shows the one-line diagram of the West-10 Benchmark System. The system frequency is 60 Hz.

The IEEE 10-generator 39-bus system [2,3] is well-known and about the same system size as the West-10 Benchmark System. The IEEE 39-bus system includes loops and is a grid system, while the West-10 Benchmark System is a purely radial system. The exciter and turbine-governor models used in the West-10 Benchmark System closely reflect actual equipment used in Japan.

2.1. Generators

All of the ten generators are represented by a dq-frame-based synchronous generator model with one damper winding for each of the d and the q frame [4]. The constants of the generator models are set to the values shown in Table 1. These values are typical for large-scale thermal-plant generators, and the reactance values are based on their own ratings shown in Table 2 (see Section 2.4 for the peak-load and light-load conditions). The inertia constants of all generator models are set to 7 s. Each generator model has an exciter (AVR: automatic voltage regulator) model and a turbine-governor model. The exciter model represents a rotating exciter, and its control-block diagram is shown in Fig. 2(a). The turbine-governor model whose control-block diagram is shown in Fig. 2(b) represents a typical turbine governor used by thermal and nuclear power plants. Each generator station is equipped with a step-up transformer whose impedance is 0.14 p.u. based on its own rating, and its tap ratio is unity.

Table 2
Generator ratings.

Generator	Peak-load rating (MVA)	Light-load rating (MVA)
G1	15,000	9000
G2–G7, G9	10,000	6000
G8	5000	3000
G10	30,000	18,000

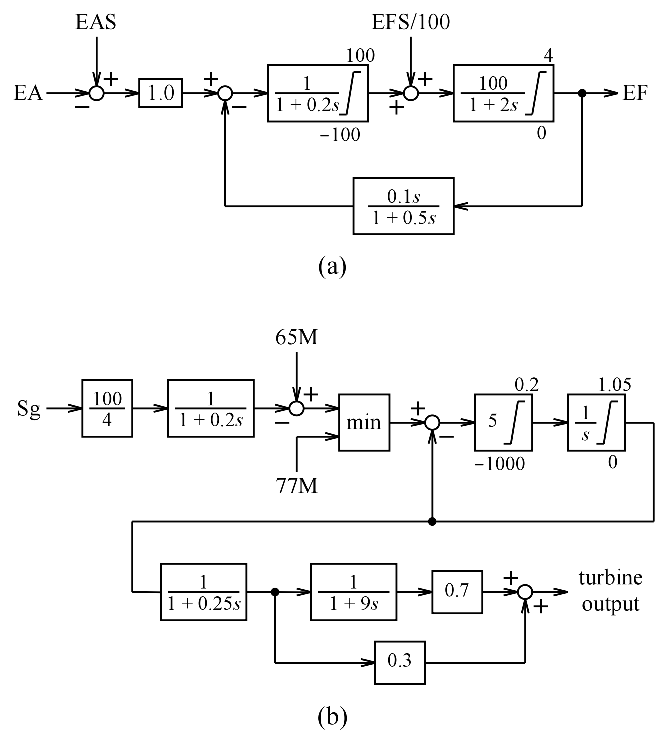

Fig. 2. Exciter and turbine-governor models. (a) Control-block diagram of the rotating exciter model, where EA and EAS are the generator terminal voltage and its initial value and EFS is the initial value of the field voltage. (b) Control-block diagram of the turbine-governor model, where Sg is the generator speed deviation. 65M and 77M are parameters related to governor-free operations and not used in the simulations in this paper.

2.2. Transmission lines

The nominal voltage of all transmission lines is 500 kV. Since G1 and G10 equivalently represent interconnected neighboring systems, they are considered as substations in the discussion below. The transmission lines connecting between substations are double-circuit and their length are 100 km. The impedance of these lines is $0.0021 + j0.063$ p.u. and a half of their admittance is $j0.122$ p.u. Those connecting generator stations to substations are also double-circuit. Except the one connecting Bus 18–Bus 7, their