Modelling and Simulation for a Multimachine Power System

D.V. BANDEKAS, N. VORDOS, J. FANTIDIS
Department of Electrical Engineering
Kavala Institute of Technology
St. Lucas, 65 404, Kavala
GREECE
dbandek@teikav.edu.gr

Abstract: This paper presents a new modelling and simulation method for the dynamic performance analysis of a multimachine power system under symmetrical and unsymmetrical fault conditions. This method is called dynamic voltage-current combination method and the transient analysis of the system is based on a-d-c phase coordinate system. Modeling and simulation technique using digital computer with the appropriate software has also been described.

Key-Words: Modelling, simulation, multimachine power system, fault conditions

1. Introduction
In recent years, there has been considerable interest in the dynamic performance analysis of a multimachine power system under fault conditions. There are four general fault conditions occurring in power systems. They are the single-phase-earthed fault, the phase-to-phase short circuit fault, the phase-to-phase earthed fault and the three-phase balanced fault.

The d-q-o reference frame models of synchronous and induction machines are not capable of simulating some conditions, such as unsymmetrical faults. For these reasons a more accurate solution to a wider range of problems is possible with a direct phase model (a-b-c coordinate model).

In the present paper a combination of nodal analysis and the current summation method is devised to simulate fault conditions in addition to normal operational conditions in the multimachine power system.

The method of analysis is based on the applications of Kirchhoff's current and voltage laws, and is called "dynamic voltage-current combination method" [1,2]. The only approach available to solve the above conditions is to model the multimachine power system as the combination of differential equations that are required.

With the advent of modern computers, numerical methods can be employed efficiently for solving nonlinear differential equations. In the case the differential equations have been solved using 4th-order Runge-Kutta method.

The linearized mathematical model of the multimachine power system contains detailed representation of the turbogenerators, transmission networks, power transformers, induction motors and static loads, in (a-b-c) phase coordinate representation.

In this work a large multimachine power system is described in which all the above four symmetrical and unsymmetrical fault conditions are applied in different nodes of the system.

2. Modeling of the multimachine power system under study.
The complete multimachine system under study is show in Fig.1. The complete data of the system are shown in Ref.[3]. The detailed models of various power system components have been described in [1-6].
It is sufficient for the voltage and the current equations to be represented in the following sections in matrix form.

2.1 Three-phase synchronous generator
The voltage equation for the synchronous generator can be expressed as:

\[ [V_{sg}] = [R_{sg}] [I_{sg}] + [L_{ssg}] \omega [I_{sg}] + [L_{srg}] \omega [I_{rg}] + \omega [G_{ssg}] [I_{sg}] + \omega [G_{srg}] [I_{rg}] \]  

\[ [V_{rg}] = [R_{rg}] [I_{rg}] + [L_{rsg}] \omega [I_{sg}] + [L_{rrg}] \omega [I_{rg}] + \omega [G_{rsg}] [I_{sg}] + \omega [G_{rrg}] [I_{rg}] \]  

The negative sign associated with stator current \( I_{sg} \) in the equations indicates that the current is flowing out of the machine, i.e. flowing into the generator bus.

2.2 Three-phase Induction Motor
The voltage equation for the induction motors can be expressed as:

\[ [V_{sm}] = [R_{sm}] [I_{sm}] + [L_{ssm}] \omega [I_{sm}] + [L_{srm}] \omega [I_{rm}] + \omega [G_{ssm}] [I_{sm}] + \omega [G_{srm}] [I_{rm}] \]  

\[ [V_{rm}] = [R_{rm}] [I_{rm}] + [L_{rsm}] \omega [I_{sm}] + [L_{rrm}] \omega [I_{rm}] + \omega [G_{rsm}] [I_{sm}] + \omega [G_{rrm}] [I_{rm}] \]  

The direction of the current flowing into the machine, i.e. flowing out of the connected bus, is defined as positive.

2.3 Three-phase Power Transformer
The power transformer is presented with six windings, three primary windings and three secondary windings. After referring the parameters of the secondary windings to the primary, the voltage equations can be expressed as:

\[ [V_1] = [R_1] [I_1] + [L_{11}] \omega [I_1] + [L_{12}] \omega [I_2] \]  

\[ [V_2] = [R_2] [I_2] + [L_{21}] \omega [I_1] + [L_{22}] \omega [I_2] \]  

where \( R_1 \) is the resistance of a primary windings and is identical for all three phases, \( R_2 \) is the resistance of the secondary windings. Subscripts 1 and 2 denote the primary and secondary quantities respectively.

The direction of the current flowing into the transformer, i.e. flowing out of the connected bus, is defined as positive.

2.4 Three-phase static load
The lumped static load can be modeled as a resistive load \( (R_L) \) and a reactive load \( (L_L) \). The voltage equation for the load can be expressed as:

\[ p_{L} = (1/L_L) \left( V_L - R_L I_L \right) \]  

where: \( [V_L] = [V_{La}, V_{Lb}, V_{Lc}]^T \)

2.5 Three-phase Transmission Lines
The transmission lines connecting the system nodes are analyzed in terms of the nominal sections shown in Fig. 1 and the equations of the typical \( \pi \)-section model shown in Fig. 2 are:

\[ pV_1 = (1/C_1) I_{c1} \]  

\[ pV_2 = (1/C_2) I_{c2} \]  

\[ p_{T} = (1/L_T) \left[ V_1 - V_2 - R_T I_T \right] \]  

where:
\([V_1] = [V_{a1}, V_{b1}, V_{c1}]^T,\)

\([V_2] = [V_{a2}, V_{b2}, V_{c2}]^T,\)

\([I_T] = [I_{Ta}, I_{Tb}, I_{Tc}]^T.\)

Each section gives rise to three states in each axis, comprising the two node voltages and the transmission current. The presence of shunt reactor compensation at a system node modifies eqns 8,9 and 10.

Fig. 2 Equivalent π-section of transmission line

### 2.6 Fault simulation

#### 2.6.1 Single-phase earthed fault

The single-phase earthed fault is modeled by the connection of resistance \(R_f\) and inductance \(L_f\) between the fault point and earth.

#### 2.6.2 Phase-to-phase short-circuit fault

The phase-to-phase short-circuit fault may be represented by a fault impedance \(R_f\) and \(L_f\) across say phase b and phase c as shown in Fig. 3.

Consequently, an additional differential equation is introduced to the system of equation

\[V_b - V_c = R_f I_f + L_f p I_f\] (11)

where \(V_b\) and \(V_c\) are the voltages of the phase b and phase c. \(I_f\) is the fault current between phase b and phase c.

The current relationship between the generator and load can be represented as

\[I_{as} = I_{ai}\]

\[I_{bs} = I_{bi} + I_f\] (12)

\[I_{cs} = I_{ci} - I_f\]

where \(I_{as}, I_{bs}, I_{cs}\) are the generator stator currents of each phase. \(I_a, I_b, I_c\) are the phase a, b, and c currents, respectively.

#### 2.6.3 Phase-to-phase earthed fault

The phase-to-phase earthed fault is modeled by the connection of two sets of equal resistance \(R_f\) and inductance \(L_f\) in phase b and phase c respectively between the fault point and earth.

#### 2.6.4 Three-phase balanced fault

The three-phase balanced fault is modeled by the connection of three sets of equal resistance \(R_f\) and inductance \(L_f\) between the three lines to represent the fault.

### 2.7 Simulation results

A special digital computer program is developed, based on the system configuration of Fig. 1 and the pertinent theory.

The transient performance of the overall multimachine power system, was obtained through the use of the above computer program applied to the power system of Fig. 1.

Various types of faults have been applied to the test system. The following responses are produced for a phase-to-phase short-circuit fault conditions, for synchronous generator (GEN 1), at node 2 of Fig. 1:

- Synchronous generator voltage, \((V_t)\)
- Synchronous generator load angle \((\delta)\)
- Synchronous generator current \((I)\)
- Synchronous generator excitation voltage \((V_f)\)

Figures 4-7, where:

1: IEEE Type-2 AVR model applied in GEN1
2: Adaptive excitation controller applied in GEN1...
3. Conclusions
The paper presents an appropriate modeling and simulation method applied in a multimachine power system, based on phase coordinates system.

The dynamic voltage - current combination method is presented based on Kirchhoff’s current and voltage laws.

In this paper an example of simulation responses of a synchronous generator (GEN1), in a multimachine power system environment are presented.

The results obtained were based on a detailed multimachine model in phase coordinates containing steam turbine synchronous generator units, excitation and turbine-governor systems, transmission networks, power transformers, induction motors and static loads. These results show that the proposed modelling and simulation method performs satisfactory in a multimachine power system environment.
References