ELSEVIER

Electric Power Systems Research 53 (2000) 217–222

ELECTRIC POWER SYSTEMS RESEARCH

www.elsevier.com/locate/epsr

A comprehensive EMF behind transient reactance (EBTR) model for power system stability study

S.M.L. Kabir [a], A.H. Chowdhury [a], M.A. Kashem [b,*], M.A. Choudhury [b]

[a] *Bangladesh University of Engineering and Technology, Dhaka, Bangladesh*

[b] *Faculty of Engineering, Multimedia University, Jalan Ayer Keroh Lama, Bukit Beruang, 75450 Melaka, Malaysia*

Received 10 June 1998; received in revised form 21 June 1999; accepted 22 June 1999

Abstract

EMF behind transient reactance (EBTR) model of a synchronous generator has widely been used in the studies of power system stability. The damping in the quadrature axis of a synchronous machine is normally represented by a single time constant equivalent circuit. However, the presence of field in addition to the damper circuit in the direct axis of the machine makes modelling difficult in the direct axis based on the emf behind transient reactance. As a result approximate representations are normally employed. The models based on appropriate representations do not produce accurate results. In this paper, an accurate comprehensive model for the direct axis is presented. The development emerges from the detailed representation of the machine with fluxes as the state variable. The emfs behind field and d-axis damper transient reactances are considered in the model. The validity of the model is tested by comparison with the responses obtained from a detailed model [1].

Keywords: EMF behind transient reactance (EBTR); Machine modeling; Power system stability

1. Introduction

Modeling a large power system is a complex task due to the difficulties in representing the non-linear phenomenon within different components of the system. In stability studies, the overall accuracy is primarily decided by how correctly the synchronous machines within the system are modelled. The behavior underlying the performance of a synchronous machine is represented by a set of non-linear differential equations. The detailed model includes at least seven nonlinear differential equations for each machine. In addition to these, other equations describing different constraints introduced by the loads and/or network, the excitation system, and mechanical control system etc., are included. Thus the complete mathematical description of a large power system becomes exceedingly difficult. The model describing the equations are arranged in state space form and solved numerically simulating a disturbance. In a large power system, usually the machines and components nearest to disturbance are modeled in detail, while others are described by simple models.

The simplest model is the 'constant emf behind the reactance model' [2]. The model provides only the idea of responses following a disturbance. It is, however, essential to consider the rate of change of emf behind transient reactance. In most of the cases transient variation of damping fluxes in both the axes are neglected for simplicity [3]. But these damping fluxes have a significant influence in the rotor movement, especially, during the initial moments following a disturbance. As a result, total omission of the effect of damping produce inaccurate prediction. In some models only the damping of quadrature axis is considered [4], whereas, attempts have been made to include the d-axis damper effects with over simplifications [5]. The simplified inclusion does not provide improvement in the prediction. Therefore, for large power system stability studies investigators accept the approximate results from the existing emf behind transient reactance models with a compromise between the accuracy and simplicity of the models.

* Corresponding author. Tel.: +60-6-2523014; fax: +60-6-2316552.

E-mail address: kashem@mmu.edu.my (M.A. Kashem)

0378-7796/00/$ - see front matter
PII: S0378-7796(99)00064-4

This paper describes a newly developed comprehensive emf behind transient reactance model which is derived from the detailed representation of a synchronous generator. Since the development is based on the same set of equations as used in the development of detailed state space model, the new model provides accurate results comparable to results obtained by detailed modelling. The model is represented by emfs behind fields, d-damper and q-damper transient reactances. The variation of field and d-damper emfs are found to be coupled with each other and the overall time constant for flux distribution is determined by field and damper time constants simultaneously.

2. Mathematical formulation

For an alternator, the field and d-axis damper flux linkages are expressed in terms of currents as,

$$\omega_o\psi_f = X_{md}i_d + X_{fd}i_f + X_{md}i_{kd} \tag{1}$$

$$\omega_o\psi_{kd} = X_{md}i_d + X_{md}i_f + X_{kdd}i_{kd} \tag{2}$$

From Eqs. (1) and (2), the expression for i_f and i_{kd} can be obtained as,

$$i_f = \frac{X_{kdd}}{X}\omega_o\psi_f - \frac{X_{md}}{X}\omega_o\psi_{kd} - \frac{X_{kd}X_{md}}{X}i_d \tag{3}$$

$$i_{kd} = \frac{X_{fd}}{X}\omega_o\psi_{kd} - \frac{X_{md}}{X}\omega_o\psi_f - \frac{X_fX_{md}}{X}i_d \tag{4}$$

where

$$X = X_{md}X_f + X_fX_{kd} + X_{kd}X_f$$

During a disturbance, the rate of change of field and d-axis damper flux linkages are given by

$$p\Psi_f = U_f - R_fi_f \tag{5}$$

$$p\psi_{kd} = -R_{kd}i_{kd} \tag{6}$$

Replacing the expression of i_f and i_{kd} from Eqs. (3) and (4) in Eqs. (5) and (6) respectively, the later set of equations after simplification becomes,

$$T'_{do_1}pE'_{q_1} = \frac{X'_f}{X_{fd}}E_{fd} - E'_{q_1} + \frac{X_{md}}{X_{fd}}E'_{q_2} + \frac{X_{kd}}{X_{kdd}}(X_d - X'_{d_1})i_d \tag{7}$$

where,

$$T'_{do_2}pE'_{q_2} = -E'_{q_2} + \frac{X_{md}}{X_{kdd}}E'_{q_1} + \frac{X_f}{X_{fd}}(X_d - X'_{d_2})i_d \tag{8}$$

where,

$$E_{fd} = X_{md}\frac{U_f}{R_f},\quad E'_{q_1} = \frac{X_{md}}{X_{kdd}}\omega_0\varphi_f, E'_{q2} = \frac{X_{md}}{X_{kdd}}\omega_o\psi_{kd},\qquad X'_f = X_f + X_{kd}\|X_{md}$$

$$X'_{kd} = X_{kd} + X_f\|X_{md},\qquad X'_{d_1} = X_a + X_f\|X_{md},\qquad X'_{d_2} = X_a + X_{kd}\|X_{md}$$

$$T_{do_1} = \frac{X'_f}{\omega_oR_f},\qquad T_{do_2} = \frac{X'_{kd}}{\omega_oR_{kd}}$$

The term E'_{q_1} may be termed as emf behind field transient reactance, E'_{d_1}, and E'_{q_1} as emf behind d-damper transient reactance, X'_{d_2}.

Since only one rotor circuit is normally considered in the quadrature axis, the expression for emf behind q-axis transient reactance, X'_q can easily be obtained. The expression is,

$$T'_{q0}pE'_d = -E'_d + (X_q - X'_q)i_q \tag{9}$$

where,

$$X'_q = X_a + X_{mq}\|X_{kq},\qquad E'_d = \frac{X_{mq}}{X_{kqq}}\omega_o\psi_{kq},\qquad T'_{qo} = \frac{X_{kqq}}{\omega_oR_{kq}}$$

The Eqs. (7)–(9) relate the emf behind the reactances with the rotor quantities. In order to obtain the relationship for the stator quantities, the expression for d- and q-axis component of stator voltage are analyzed. The expressions are,

$$V_d = p\psi_d + \omega_o\psi_q + R_ai_d \tag{10}$$

$$V_q = p\psi_q - \omega_o\psi_d + R_ai_Q \tag{11}$$

In most of the power system stability studies, the $p\psi_d$ and $p\psi_q$ are normally omitted. These terms are responsible for the dc components of phase voltage and currents and alternating component of electrical torque. Of course, a compensation for the omission needs to be incorporated for accurate prediction of dynamic movement of rotor following a disturbance [6].

Eqs. (10) and (11) can be expressed in terms of currents by replacing i_f and i_{kd} of Eqs. (3) and (4) in Eqs. (10) and (11). After this replacement and simplification the equation becomes as follows,

$$V_d = X'_qi_q + E'_d + R_ai_d \tag{12}$$

$$V_q = -X''_di_d - \frac{(X''_d - X_a)}{X'_{d_1} - X_a}E'_{q_1} - \frac{(X''_d - X_a)}{X'_{d_2} - X_a}E'_{q_2} + R_ai_q \tag{13}$$

where, $X''_d = X_a + X_{md}\|X_f\|X_{kd}$.

The relationship between the terminal voltages and the component of infinite bus bar voltage are expressed as,

$$V_{bd} = V_d + Xi_q + Ri_d \tag{14}$$

$$V_{bq} = V_d - Xi_d + Ri_q \tag{15}$$

where, R and X are the line resistance and inductive reactance respectively.