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Fault detection in transmission networks of power systems

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ABSTRACT

An online fault detection scheme for a sample power system is introduced in this paper. The detection approach is based on the use of a variable structure system called "sliding mode observer", where information contained in the output measurements is utilized to detect the onset of faults in the transmission network of the sample power system in real time and online. The power system comprises a generating unit connected to an infinite bus through double line transmission network. The common case of a fault occurring on a transmission line is illustrated through simulation studies.

1. Introduction

Power systems are prone to frequent faults, which may occur in any of its components, such as generating units, transformers, transmission network and/or loads. It is well known that faults can cause significant disruption of supply, destabilise the entire system and may also cause injuries to personnel. Detection of faults is therefore of a paramount importance from economic and operational viewpoints. In addition faults should be detected as quickly as possible, in real time if possible, so that an appropriate remedial action can be promptly taken before major disruptions to the power supply can occur.

So far such faults are detected by fault locators, which form an integral part of "protection systems". However, the accuracy of fault locators is known to be below desirable levels. It is also known that fault locators may not able to detect faults in real time. In this paper we introduce a software based scheme where faults in the transmission network are able to be detected in real time, using commonly available measurements of speed, load angle, terminal voltage, power, etc. Only symmetrical faults are considered here, as asymmetrical faults require dynamical incorporation of symmetrical components into the overall dynamical systems, which is beyond the scope of this paper. However research in this direction by the authors is ongoing and new results will soon be submitted for possible publication.

The novelty of the proposed scheme is two folds; development of a fault dependent model for a sample power system and design of a real time fault detectors, referred to in the control literature as "fault detection filter". The result of this study are among a very few *model based* results that have been reported in the open literature (see for example [1,2]) and may therefore offer tangible benefits to the protection industry if incorporated in the design of fault locators. It can be noted that this paper does not deal with "protection systems" per say but with how to locate faults in real time using control and estimation theory. Protection systems experts are therefore invited to make use of this approach.

Other reported contributions are reported in [16–18]. In [16], pre-fault and during fault phasor currents and voltages are measured and used in a two-bus Thevenin equivalent network model of the transmission system to locate a fault after its occurrence. In this method the dynamics of the system are ignored and each generator is represented by a voltage behind transient reactance. In [17], adaptive extended Kalman filter and probabilistic neural networks are combined to estimate different harmonic components in fault current signals. The harmonic components are then fed into a forward neural network for training and identification of high impedance faults in power distribution feeders off line. In [18], discrete wavelet transform and neural networks are used to parameterise and characterise fault signals.

Unlike the approach presented in this paper, the above approaches are not suitable for real time fault detection as they are based on acquiring fault date, which can then be used in knowledge based techniques for analysis and characterisation.

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Nomenclature

ψ	flux linkage	f	fault parameters
$\cdot^0$	superscript refers to nominal value	A, B, C, D, E, G, W	constant parameter matrices
$\cdot_q$	subscript refers to the quadrature axis	δ	rotor shaft angle
$\cdot_{G,Q}$	subscript refers to damper windings on the quadrature axis	ω	rotor shaft speed
$\cdot_d$	subscript refers to the direct axis	ω_b	speed base quantity
$\cdot_D$	subscript refers to damper winding on the direct axis	v, V	machine and network voltage
$\cdot_F$	subscript refers to field winding	i, I	machine and network current
$\cdot_{ex}$	subscript refers to exciter	$\lvert\cdot\rvert$	magnitude of a vector
$\cdot_N$	subscript refers to network	E_{FD}	field winding excitation voltage
$\cdot_G$	subscript refers to governor	H	synchronous machine inertia constant
x	state vector	k_d	rotor damping coefficient
y	output vector	T_m, P_m	mechanical torque and power

This paper is structured as follows: We start with the development of a comprehensive model of a power system suitable for fault studies and test its validity through simulation studies. Then we introduce a software based fault detection algorithm (filter) capable of detecting faults online and real time. The fault filter is then applied to the sample power system to detect faults in the transmission network. We finally present comprehensive simulation studies carried out on the power system under various scenarios and discuss the results in full.

2. Generating unit model

In the following we provide a detailed linearised model of a generating unit comprising an 8th order synchronous generator, a 3rd order model of an IEEE Type 1S exciter [3], and a 3rd order model of an IEEE steam-turbine speed governor [4]. These models are based on those presented in with some changes.

2.1. Synchronous generator

Detailed models of a synchronous generator should include electrical (flux-voltage equations) and mechanical (rotor shaft motion) parts [5–7]. We start with modelling the flux-voltage dynamical relationships along the d-axis. These relationships may be modelled by the set of linear equations listed below.

$$\dot{\psi}_d = \omega_b\psi_q(1+\dot{\delta}^\circ) + \omega_b\psi_q^\circ\dot{\delta} + \omega_b v_d + \omega_b r i_d \tag{1}$$

$$\dot{\psi}_F = \omega_b v_F - r_F i_F \omega_b \tag{2}$$

$$\dot{\psi}_D = \omega_b v_D - \omega_b r_D i_D \tag{3}$$

In the q-axis the voltage-flux dynamics are described by the following linear equations:

$$\dot{\psi}_q = -\omega_b\psi_d(1+\dot{\delta}^\circ) - \omega_b\psi_d^\circ\dot{\delta} + \omega_b v_q + \omega_b r i_q \tag{4}$$

$$\dot{\psi}_G = \omega_b v_G - \omega_b r_G i_G \tag{5}$$

$$\dot{\psi}_Q = \omega_b v_Q - \omega_b r_Q i_Q \tag{6}$$

The mechanical part of the machine is due to the motion of the rotor shaft and is expressed as follows:

$$\ddot{\delta} = -\frac{\omega_b}{2H}k_d\dot{\delta} + (T_m - T_e)\frac{\omega_b}{2H} \tag{7}$$

$$T_e = \psi_d i_q^\circ + \psi_d^\circ i_q - \psi_q i_d^\circ - \psi_q^\circ i_d \tag{8}$$

2.2. Excitation system

The synchronous machine is equipped with the following IEEE excitation system.

The state equations for the excitation system shown in Fig. 1 are derived as follows:

$$\dot{V}_R = -\frac{1}{\tau_R}V_R + \frac{K_R}{\tau_R}|V_N| \tag{9}$$

$$\dot{V}_F = -\frac{1}{\tau_F}V_F + \frac{K_F}{\tau_F}\dot{V}_A \tag{10}$$

$$\dot{V}_A = -\frac{1}{\tau_A}V_A + \frac{K_A}{\tau_A}(V_{REF} - V_R - V_F) \tag{11}$$

2.3. IEEE governor model

A model of a steam turbine speed governing system used in this study is shown in Fig. 2 and its model is derived below:

$$\dot{P}_{ST} = -\frac{1}{T_{ST}}P_{ST} + \frac{1}{T_{ST}}P_{GV} \tag{12}$$

$$\dot{P}_{GV} = -\frac{1}{T_{SM}}P_{GV} + \frac{1}{T_{SM}}P_{SR} \tag{13}$$

$$\dot{P}_{SR} = -\frac{1}{T_{SR}}P_{SR} + \frac{1}{T_{SR}}\left(P_r - \frac{\dot{\delta}}{R\omega_B}\right) \tag{14}$$

In order to interface the governor with the synchronous generator, the governor output, which is the mechanical power, P_m, needs to

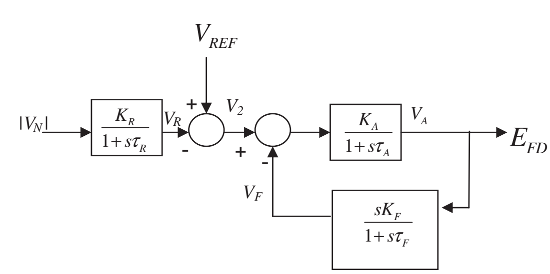

Fig. 1. IEEE type 1 excitation system.

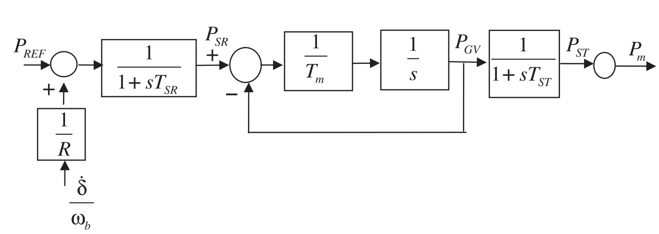

Fig. 2. IEEE steam turbine speed governing system.