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LOCAL CONTROL OF TRANSIENT STABILITY BY OPTIMAL AIM STRATEGY

Abdul Malek Miah

College of Science, Mathematics & Engineering Technology; South Carolina State University
300 College Street NE, Orangeburg, South Carolina 29117, U.S.A.
E-mail: miah@scsu.edu

ABSTRACT

Transient stability assessment and control are crucial in the secured operation of electric power systems. All the transient stability methods proposed in the literature require some expensive system-wide transfer of measurement data to the system control center for their use in real-time control. To avoid this transfer of measurement data, local equilibrium frame (LEF) has been suggested for local control of transient stability. But the equilibrium condition of a power system in the LEF is considered to be a condition at which all the generators run at synchronous speed. This equilibrium condition is too restrictive. Further, no dynamic equation is available in the LEF. To overcome the drawbacks of the LEF, a new method of transient stability coupled with local control by optimal aim strategy (OAS) is currently under investigation. In this new method, system equilibrium state refers to a state at which all the generators run at the same speed that is not necessarily the synchronous speed. In this paper, local control by OAS is presented with respect to a two-generator system. But the system equilibrium state considered here is a state at which all the generators run at the same speed that is not necessarily the synchronous speed. Sample preliminary results on the local control of a general multi-machine power system that is under investigation are also presented to demonstrate the high potential of OAS.

1. INTRODUCTION

Transient stability assessment is very important in power system planning and operation. It is well known that the standard time-domain simulation or step-by-step (SBS) numerical integration method is the most reliable and accurate method to assess transient stability. But due to its heavy computational burden, the method is unsuitable for on-line applications even with classical representation of power systems. Direct methods such as the transient energy function method [1] and extended equal area criterion [2-3] have been proposed for on-line applications. To reduce the computational burden of standard SBS method, large step-size integration has been suggested in [4] and the use of truncated Taylor's series expansion has been suggested in [5]. All these methods use classical representation of power systems and hence assess first swing stability. These methods are faster than the standard SBS method. They can be made even faster by coupling with them reduction techniques using simple dynamic equivalents [6-7]. To speed up the computation of SBS method, a dynamic equivalent power system (DEPS) model for the post-fault system has been suggested in [8]. This method also uses classical representation of power systems. Recently, parallel processing [9] has been suggested to speed-up the time-domain simulations.

However, all the transient stability methods require some expensive system-wide or global transfer of measurement data to the system control center for their use in real-time transient stability control. To avoid this, a new frame of reference called the local equilibrium frame (LEF), has been suggested in [10] for the purpose of local control of transient stability. In LEF, control is completely in local form. A local control strategy in this frame of reference attempts to move a generator towards its respective local equilibrium. When each of the generators is driven to its respective local equilibrium, the power system is in equilibrium in the sense that all the generators are running at synchronous speed. This equilibrium condition is sufficient, but not necessary, as it is too restrictive. It is well known that the satisfactory operation of a power system can occur when all the generators run at the same speed which may be slightly different from the synchronous speed. The LEF thus suffers from a serious drawback. Machine and COA frames do not suffer from such drawback.

The equilibrium state in these reference frames refers to a state at which all the generators run at the same speed that is not necessarily the synchronous speed. Further, the LEF cannot provide any dynamic equation. This is another drawback of the LEF. To overcome the drawbacks of the LEF, a new method of transient stability coupled with local control using optimal aim strategy [11-13] is currently under investigation at South Carolina State University. This new method includes the primary benefit of the LEF in terms of local control of transient stability. But unlike the LEF, system equilibrium state in this method refers to a state at which all the generators run at the same speed that is not necessarily the synchronous speed.

Optimal aim strategy (OAS) [11-13] is very suitable in driving a two-state system towards its equilibrium. For a two-state system, OAS can provide an explicit solution of the control function required to move the current state towards the equilibrium state. This strategy is a feedback control strategy that requires only a crude system model. With reference to the local control of transient stability of power systems, this control strategy referred to as a Localized Aiming Strategy (LAS), has been described in detail in [13]. In LAS, each individual generator is driven to its stable equilibrium point by using local control means available at the generator. But the stable equilibrium that has been considered in LAS is the equilibrium at which all the generators run at synchronous speed. In the work presented here, optimal-aim strategy (OAS) is used to drive the power system to its stable equilibrium point in the sense that all the generators are operating at the same speed that is not necessarily the synchronous speed. In this presentation, it is assumed that the local control means are available at the generators.

2. LOCAL CONTROL BY OAS

To describe the local control by optimal aim strategy (OAS), we consider a two-generator system with classical representation. Such a system can be reduced to a one-machine infinite-bus (OMIB) system by mathematical manipulation of the dynamic equations of the two generators. So, the OMIB-system corresponding to an individual generator, say generator 1, can be represented by

$$\dot{\delta} = \omega \qquad (1a)$$

$$M\dot{\omega} = P_m - [P_c + P_{\max}\sin(\delta - \gamma)] \qquad (1b)$$

where

$$\delta = \delta_1 - \delta_2 \qquad (1c)$$

$$M = \frac{M_1 M_2}{M_1 + M_2} \qquad (1d)$$

$$P_m = \frac{M_1 P_{m1} - M_2 P_{m2}}{M_1 + M_2} \qquad (1e)$$

$$P_c = \frac{M_2 E_1^2 G_{1,1} - M_1 E_2^2 G_{2,2}}{M_1 + M_2} \qquad (1f)$$

$$P_{\max} = \frac{E_1 E_2}{M_n + M_R}\sqrt{[(M_1 + M_2)^2 B_{1,2}^2 + (M_1 - M_2)^2 G_{1,2}^2]} \qquad (1g)$$

$$\gamma = \tan^{-1}[\frac{(M_1 - M_2)G_{1,2}}{(M_1 + M_2)G_{1,2}}] \qquad (1h)$$

In the above equations, (M_1, M_2) are the inertia constants of the individual generators, (P_{m1}, P_{m2}) are the input mechanical powers, and (δ_1, δ_2) are the rotor angles. ($G_{1,1} + j\,B_{1,1}$), ($G_{2,2} + j\,B_{2,2}$), ($G_{1,2} + j\,B_{1,2}$), and ($G_{2,1} + j\,B_{2,1}$) are elements of the admittance matrix reduced to the internal buses of the two generators. δ and ω are respectively the angular deviation and speed deviation of generator 1 with respect to generator 2.

The stable equilibrium point of equation (1) can be defined as $(\delta_s, 0)$ with the stable equilibrium angle δ_s given by

$$\delta_s = \sin^{-1}[\frac{P_m - P_c}{P_{\max}}] + \gamma.$$

The state variables of the OMIB system can now be defined in a more convenient form as

$$\theta = \delta - \delta_s \quad \omega = \dot{\theta} = \dot{\delta}.$$

With the passive network model, fault information, and inertia constants of the generators known, and the real-time measurement data taken solely at the site of generator 1, all the parameter of equation (1) and the state variables θ and ω can be determined. So, the OMIB system described by equation (1) is referred to as the localized one-machine infinite-bus (LOMIB) representation of the power system as viewed at the local generator 1. Further, the two-dimensional state-space of this LOMIB system with the stable equilibrium point at its origin is referred to as the local state-space. The LOMIB system corresponding to generator 2 can be obtained in a similar way.

For the purpose of local control of a LOMIB system, say the LOMIB system corresponding to local generator 1, the dynamic equation (1) can now be written in the following local state-space form

$$\omega = \dot{\theta}, \quad \dot{\omega} = (P_m - P_e)/M\,;$$

where

$$P_e = [P_c + P_{\max}\sin(\theta + \delta_s - \gamma)].$$

To control a LOMIB system by OAS using the control means available at its respective local generator, the control dependent dynamic equation of the LOMIB system is written as

$$\omega = \dot{\theta} \quad (2a), \quad \dot{\omega} = (P_m - P_e + U(t))/M \quad (2b).$$

Here, *U(t)* represents an additive power control in the LOMIB system subject to some limits given by

$$U_{\min}(x(t)) \le U(t) \le U_{\max}(x(t) \qquad (2c)$$

where $x(t) = (\theta(t), \omega(t))$ is the current state. The limits on *U(t)* are due to the practical limitation of control function *u(t)* available at the local generator. The control dependent dynamic equation of a local generator, say generator 1, is given by

$$\dot{\delta}_1 = \omega_1 \quad (3a), \quad M_1 \dot{\omega}_1 = P_{m1} - P_{e1} + u_1(t) \quad (3b).$$

Here, P_{e1} is the electrical power output of generator 1. Further, $u_1(t)$ represents the additive power control at the local generator having the practical limits given by

$$u_{\min,1} \le u_1(t) \le u_{\max,1} \qquad (3c)$$

The relationship between *U* and u_1 is given by

$$U = \frac{u_1 M_2}{(M_1 + M_2)} \qquad (4)$$

Using equations (3c) and (4), the admissible values of *U(t)* can be obtained. Using these values of *U(t)* in equation (2b), the values of available accelerations from $\dot{\omega}_{\min}(t)$ to $\dot{\omega}_{\max}(t)$ can be computed. Now, an optimal value of $\dot{\omega}(t)$ denoted as $\dot{\omega}^*(t)$ is selected from among the available acceleration values so that the angle between the direction of the resulting system movement given by the vector $\dot{x} = (\dot{\theta}, \dot{\omega})$ and the direction of reference vector drawn from the current state to the equilibrium state (origin) is minimum. This is illustrated in Fig. 1. Further details on two-state system are available in [13].

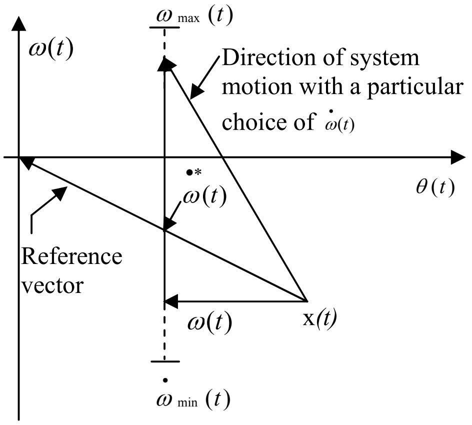

Fig. 1 Local control of a LOMIB system by OAS

In the local control of the two-generator system described here, OAS is applied to each of the LOMIB systems in time-steps to drive the current state of a LOMIB system towards its respective stable equilibrium. The optimal additive power control *U(t)* required in a LOMIB system is obtained first using the minimum angle criteria. Then, the corresponding additive power control *u(t)* required at the respective local generator is found and applied. When each of the LOMIB systems is driven to its respective stable equilibrium, the power system is in equilibrium in the sense that all the generators are running at the same speed that is not necessarily the synchronous speed.

3. TEST RESULTS

Due to space limitation, only sample results demonstrating the local control of transient stability by OAS in the post-fault configuration are presented here. In each of these cases, control was applied to each generator locally to drive the power system to an equilibrium state in the sense that all the generators run at the same speed that is not necessarily the synchronous speed. All the angular trajectories reported here are in COA reference frame.

A two-generator, 5-bus system was chosen arbitrarily. Sample results are shown in Fig. 2 and Fig. 3. In these figures, broken lines indicate the un-

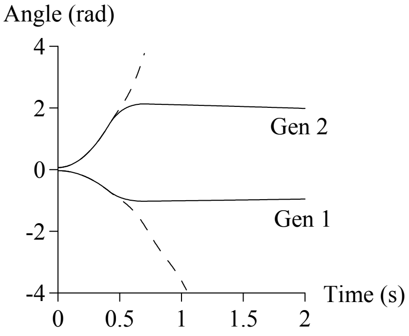

Fig. 2 Trajectories in Fault case I

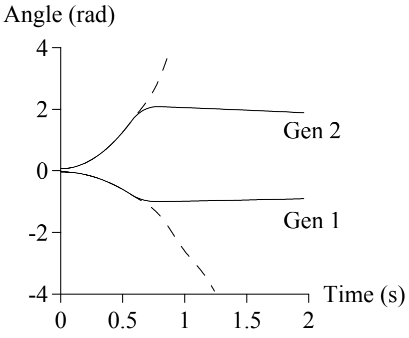

Fig. 3 Trajectories in Fault case II

controlled trajectories and the solid lines indicate the controlled trajectories. Fault case I corresponds to a 3-phase short-circuit fault at a bus that is cleared by removing a line at 0.41 s, while Fault case II corresponds to a 3-phase short-circuit fault at another bus that is cleared by removing a different line at 0.57 s. The critical clearing times for these two cases are respectively 0.34-0.35 s and 0.49-0.50 s.

Local control of general multi-machine systems by a new transient stability method coupled with OAS is under investigation. Sample preliminary results on the local control of New England 10-generator, 39-bus system [14] by the new method are shown in Fig. 4 and Fig. 5. Only the controlled trajectories are shown here. Fault case III corresponds to a 3-phase short-circuit fault at bus 22 that is cleared by removing line 22-21 at 0.27 s, while Fault case IV corresponds to a 3-phase short-circuit fault at bus 2 that is cleared by removing line 2-3 at 0.3 s. The critical clearing times for these two cases are respectively 0.17-0.18 s and 0.25-0.26 s.

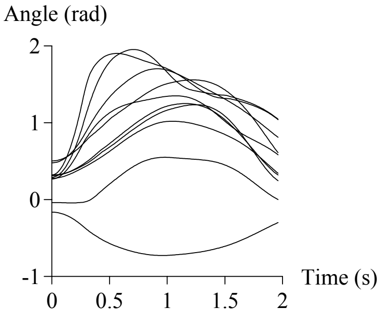

Fig. 4 Trajectories in Fault case III

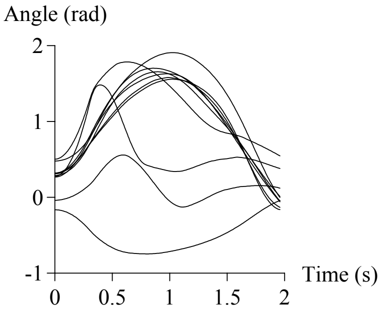

Fig. 5 Trajectories in Fault case IV

4. CONCLUSION

Local control of transient stability by optimal aim strategy (OAS) is presented with respect to a two-generator system. But the system equilibrium state considered here is a state at which all the generators run at the same speed that is not necessarily the synchronous speed. Sample preliminary results on the local control of a general multi-machine system that is under investigation are also presented. The results presented here clearly indicate the high potential of optimal aim strategy (OAS) in the local control of power system transient stability.

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