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Design of Simulation for Transient Stability Analysis in Smart Grid by Using Critical Clearing Time Index

Hartono and Ming-Tse Kuo

Abstract**—The computationally efficient of processing real-time is utilized to determine whether an evolving event will ultimately stable or unstable. Therefore, a real-time simulation for multi-machines power system has been used to demonstrate a large interconnected power system which requires a lot of computational time in real time scenarios. In order to analyze multi machines power systems, a model of real-time transient stability's method is employed to understand computation time required through the simulation proposed in this study. In fact, the transient stability provides quick responses into the behavior of the generators under a three-phase fault. The proposed optimal power flow on transient stability model was tested and analyzed using an illustrative the IEEE Western System Coordinating Council (WSCC) 3-machines 9-bus test system. The result indicates an optimal power flow model includes discrete time equations describing the time evolution of all machines in the system.**

Index Terms**—Transient stability, critical clearing time, damping.**

I. INTRODUCTION

Transient stability is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance, such as a fault on transmission facilities, sudden loss of generation, or loss of a large load. The system response to such disturbances involves large excursions of generator rotor angles, power flows, bus voltages, and other system variables. It is important that, while steady-state stability is a function only of operating conditions, transient stability is a function of both the operating conditions and the disturbance's [1].

Transient stability assessment (TSA) performed as a part of analysis of the secure operation mode involves the evaluation of the ability of a power system to remain stable under a set of severe contingencies. It is used to assess the stability contingencies and well applied to critical clearing time calculation [2].

This complicates the analysis of transient stability considerably. Repeated analysis is required for different disturbances are the short circuits of different types. Out of these, normally the three-phase short circuit at the generator bus is the most severe type, as it causes maximum acceleration of the connected machine [3].

Dynamic power flow transients in the transmission network following a fault are in the order of a hundred milliseconds to several seconds. A short circuit fault in a transmission line will cause a sudden cut in electrical power output at each generation unit, resulting in an oscillation among internal generator angles. If the oscillation exceeds the critical angle difference, the generator step out will take place in a couple of second [4].

II. ENGINEERING MODEL DESIGN

A. Model Mathematic

A complete model for transient stability of a multi-machine power system was developed using simulink. A Simulink model is very user friendly. Typically, for a transient stability study the model facilitates fast and precise solution of nonlinear differential equations in the swing equation.

Simulink is an interactive environment for modeling, analyzing and simulating a wide variety of dynamic systems. It provides a graphical user interface for constructing block diagram models using 'drag and drop' operations. It is particularly useful for studying the effects of non-linearity on the behavior of the system and as such, is also an ideal research tool [11]. Through the use of scopes and plots the package has exhibited quite interesting capabilities: it has allowed clear observation as to how the system stability and the severity and mode of unstable.

The typical parameter values are given in reference [1]. These values can be either defined in m-file program or can be directly supplied to the simulink models.

The system is modeled by the network-reduction model with generators without damping and generator having the uniform with damping $d_0 = 0.1661$.

Review the model for transient stability analysis. Consider a power system consists of n generators. The loads have been modeled as constant impedances. Then the dynamics of the $k-th$ generator can be written with the usual notation as follow [2]:

$$\delta_k = \omega_0 \omega_k \qquad k = 1,\ldots,n \tag{1}$$
$$2H_k \omega_k = P_{mk} - P_{ek} - D_k \omega_k$$

where $\omega_0 = 2\Pi f_B$, δ_k and ω_k are the rotor angle and speed of machine k, D_k and H_k are the damping ratio and inertia constant of machine k, P_{mk} and P_{ek} are the mechanical power and the electrical power at machine k;

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$$P_{ek} = \{E_k^2 G_{kk} + E_k(\sum_{j\neq k}^{n} E_j(G_{kj}\cos\phi_{kj} + B_{kj}\sin\delta_j))\}$$

where $\delta_{kj} = \delta_k - \delta j$, E_k is the constant voltage behind direct axis transient reactance of machine k , $Y = (G_{ij} + jB_{ij})_{nxn}$ is the reduced admittance matrix [2]. Using the n machines as referenced, in equation (1) can be transformed as follows:

$$\delta_k = \omega_0\omega_{kn} \qquad k = 1,...,n-1 \qquad (2)$$

$$2H_k\omega_k = P_{mk} - P_{ek} - D_i\omega_k \qquad k = 1,...,n$$

$$d_0 = D_k/(2H_k)$$

The power into the network at node i, which is the electrical power output of machine i, is given by [13]

$$P_{ei} = E_i^2 G_{ii} + \sum_{\substack{j=1 \\ j\neq 1}}^{n} E_i E_j Y_{ij}\cos(\phi_{ij} - \delta_i + \delta_j).....i = 1,2,...n \qquad (3)$$

The equations of motion are then given by

$$\frac{2H_i}{\omega_R}\frac{d\omega_i}{dt} + D_i\omega_j = P_{mi} - [E_i^2 G_{ii} + \sum_{\substack{j=1 \\ j\neq i}}^{n} E_i E_j Y_{ij}\cos(\phi_{ij} - \delta_i + \delta_j)] \qquad (4)$$

$$\frac{d\delta_i}{dt} = \omega_i - \omega_R ...i = 1,...n$$

It should be noted that prior to the disturbance $(t = 0)$ $P_{mi0} = P_{ei0}$;

Thereby:

$$P_{mi0} = E_i^2 G_{ii0} + \sum_{\substack{j=1 \\ j\neq i}}^{n} E_i E_j Y_{ij0}\cos(\phi_{ij0} - \delta_{i0} + \delta_{j0}) \qquad (5)$$

The subscript 0 indicates the pre-transient conditions.

B. Design of Simulink

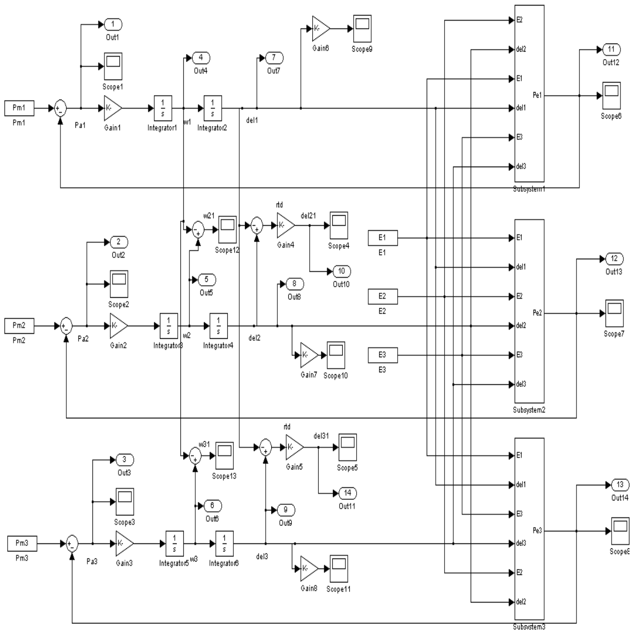


Fig. 2. Model design of simulink for transient stability.

III. ALGORITHM

We can have the general algorithm for the objective of this paper is that the resulted power flow will be trained on transient stability model on-line application in below.

Converting the whole time-domain simulation of the system transient by Simulink model may require prohibitive computing time and prohibitive memory size, and may lead to convergence issues [15].

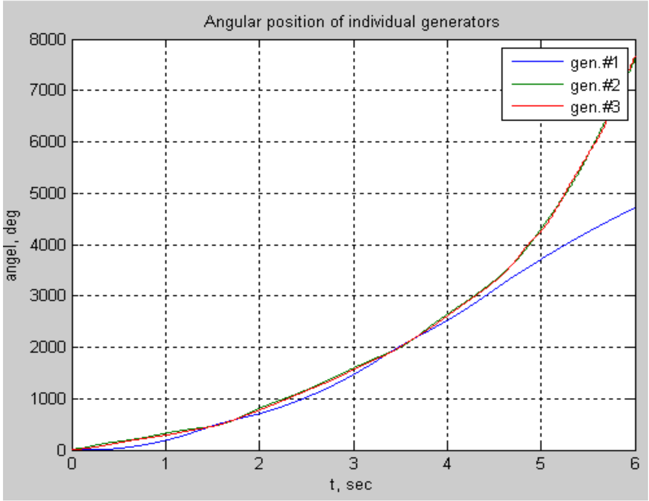
The proposed procedure is as follows:

1) Input data consist of data: bus, line, and generator.
2) Admittance matrix: before, during and after faults
3) Power flow solution by Newton-Raphson method.
4) Select every scenario: location scenario-1 until scenario-6, enter critical clearing time.
5) Open Simulink transient stability model.
6) Select duration simulation stop time.
7) Running Simulink transient model.
8) Output results are data and information on items such as
9) The relative generator rotor angle and speeds of
10) Generator for the time domain simulation.

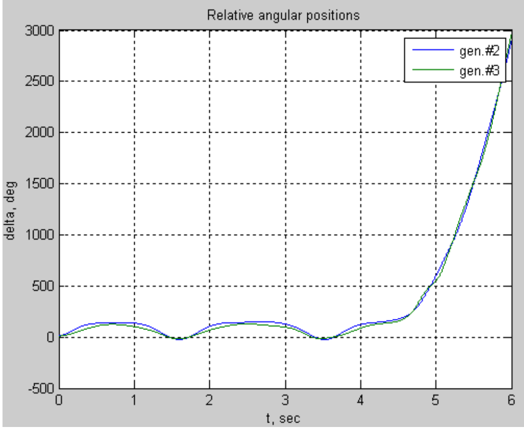
IV. RESULTS

The system responses are given for different values of critical clearing time (CCT). Fig. 3(A) and (B) show the individual generator angles and difference angles (with generator 1 as reference) for the system with CCT = 0.1606 s, whereas Fig. 3(C) and (D) show the rotor angular speed deviations and accelerating powers for the same case. In this case, the result shows that the power system is stable. We can see in the complete model in Fig. 2 that output ports 7, 8 and 9 give the individual generator angles of the respective machine. Ports 10 and 11 (or alternatively scopes 4 and 5) give the relative angular positions of generator 2 and 3 respectively, with generator 1 as reference. Similarly, port 4, 5 and 6 give the angular velocities of the machine, whereas scopes 1-3 (or the corresponding ports) display the accelerating powers. At this point the system is critical stable.

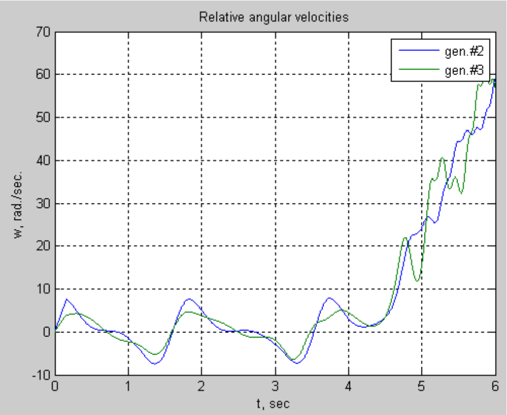
Fig. 4(A), (B), (C) and (D) show the system responses for a CCT unstable value. At this point the system unstable for CCT = 0.1607 s. [11]



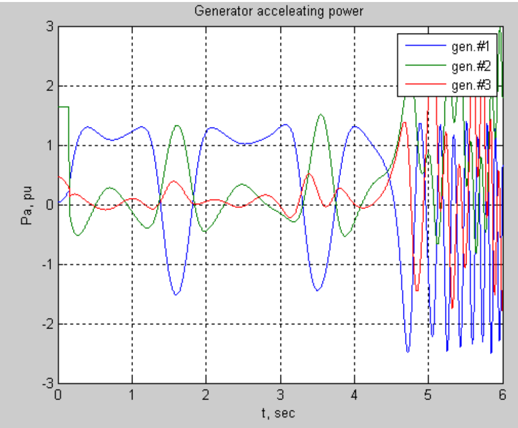
(A). Angular position of individual generators.



(B). Relative angular δ21 and δ31.



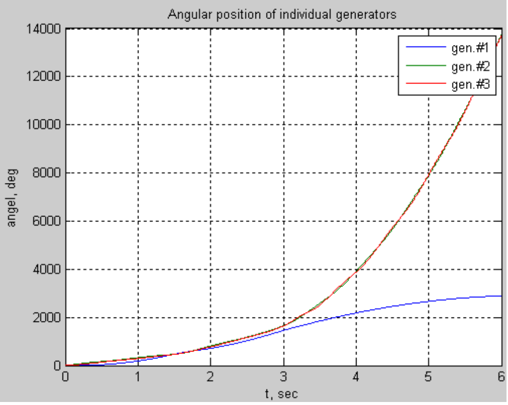
(C). Relative angular velocities.



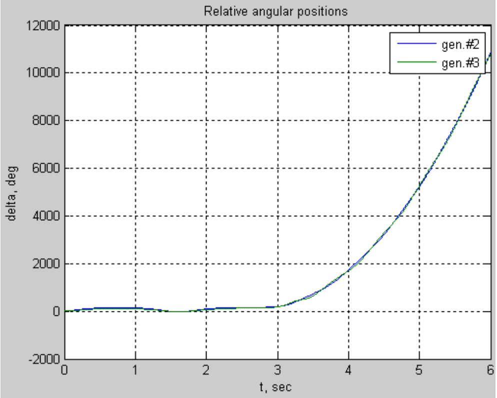
(D). Generator accelerating powers.

Fig. 3. System responses scenario-1 without damping for CCT = 0.1606.

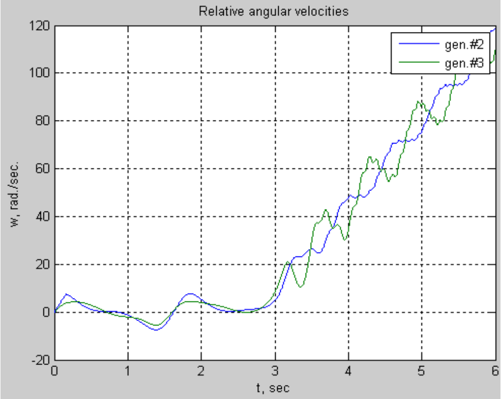
Without damping for CCT = 0.1606.



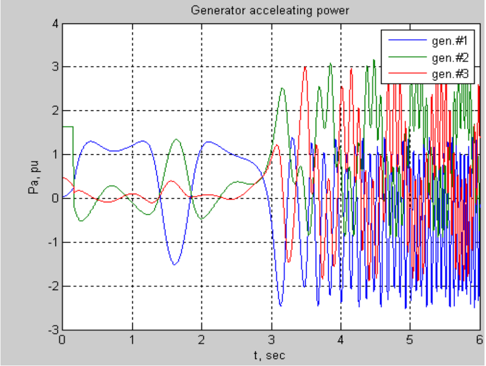
(A). Angular position of individual generators.



(B). Relative angular δ21 and δ31.



(C). Relative angular velocities.



(D). Generator accelerating powers

Fig. 4. System responses scenario-1 without damping for CCT = 0.1607.

It is clear from Fig. 4. That the most severe situation in terms of minimum critical clearing time CCT as obtained by the System responses without damping at the point the system after 3 second will be unstable.

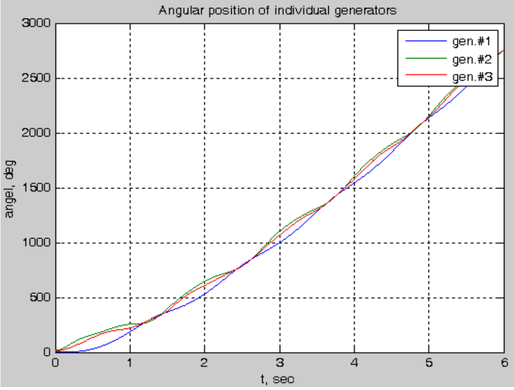
Fig. 5. Shows that during the critical clearing time, the system is still in stable condition for 3 seconds.

In Fig. 5. (A), values of angles are plotted. It is clear that all angles of the generators increase and they swing almost together.

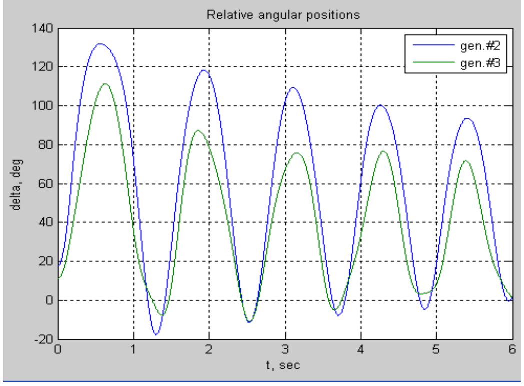
In Fig. 5. (B), the angles of generator 2 and 3 are plotted with reference to the angle of generator 1, where the relative angle displacement with respect to generator 1 is shown. However, plotting angle displacement relative to a generator and observing it from the relative angles in synchronism is not a confirmed test of stability. This is because it may happen that generator 1 is not in synchronism with respect to generator 2 and 3. However since generators 2 and 3 are almost in synchronism with respect to each other, a plot of their relative angles with respect to generator 1 will also show synchronism.

The plot for speed of the machine is shown in Fig. 5. (C). It can be seen that the speed become weakened after crossing the zero axis

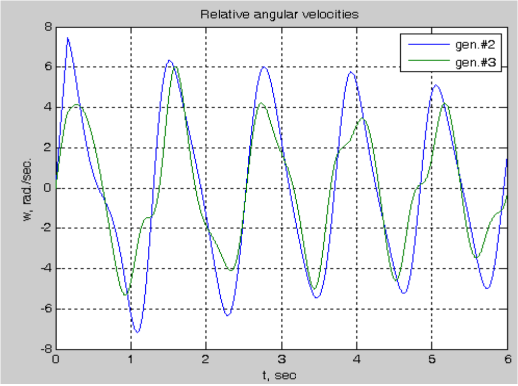
The accelerating power (P_a) is shown in Fig. 5. (D).



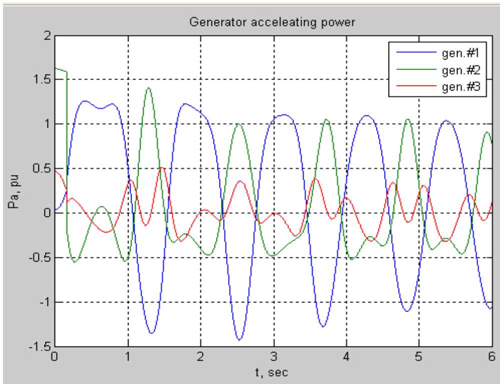
(A). Angular position of individual generators.



(B). Relative angular δ_{21} and δ_{31}.



(C). Relative angular velocities.



(D). Generator accelerating powers.

Fig. 5. System responses scenario-1 with damping = 0.1661 for CCT = 0.1607.

The time domain simulation method was also run providing a reference for assessment of the test results. In the same manner, using critical clearing time (CCT) we can obtain the severity order scenario 2,3,4,5, and 6 for each of the faults as follows in Table I.

TABLE I: CRITICAL CLEARING TIMES FOR THE FAULTS AT DIFFERENT LOCATION WITHOUT AND WITH DAMPING [11]

Scenario	Without damping		With damping		δ_{21} and δ_{31} unstable
	Stable	Unstable	Stable	Unstable	
1	0.1606s	0.1607s	0.1607s	0.1674s	G2, G3
2	0.1820s	0.1821s	0.1821s	0.1862s	G2
3	0.2341s	0.2342s	0.2342s	0.2415s	G3
4	0.2139s	0.2140s	0.2140s	0.2196s	G2, G3
5	0.3072s	0.3073s	0.3073s	0.319 s	G2, G3
6	0.3092s	0.3093s	0.3093s	0.3157s	G2, G3

Table I. Display the CCTs of different faults location in each scenario without and with damping. From Table I. It can be seen that, the most vulnerable are the contingency scenario-1 while the safest is scenario-6.

V. CONCLUSION

This paper presents parameters modeling for transient stability improvement of a multi-machine power system.

The performance of the faults at different location with damping is tested over a 3-machins 9-bus power system, for the most severe situation in terms of critical clearing time.

The main contribution of this paper is to develop transient model on-line application on affective method for transient stability assessment.

Furthermore the proposed transient stability analysis can rank the severity of different contingencies.

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