Transient Stability Analysis of Multi Machine System for Different Contingent Cases

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Abstract— Now a day's power system operate closer and closer to their limits. So it makes instability in the system more probable. Due to some uncertain conditions synchronism of machines connected in system might be loss and it leads to the transient instability. Therefore Preventive control or remedial actions for transient stability enhancement should be taken if dangerous instability is detected. Assessment of transient stability of the system with considering the contingencies has to be done. Transient stability of the unhealthy system is assessed using direct approach from rotor angle of synchronous machine. For assessment the value of relative rotor angles in pre-fault, in-fault & post-fault condition has been derived. For this test two different systems (6 bus system & IEEE 39 New England system) are considered. For 6 bus system CCT (critical clearing time) analyzed for single contingency. For 39 bus system multi contingency considered.

Key words: MATLAB, Matpower, CCT

I. Introduction

Transient stability is major problem for power system operation. To maintain reliability in power system operation the system has to be stable in normal as well as in disturbed condition.

Transient stability is defined as the ability of a synchronous power system to return to stable condition and maintain its synchronism following a relatively large disturbance arising from very general situations like switching 'on' and 'off' of circuit elements, or clearing of faults.[1]

Normally, there are two different types of power system instability occurs in the system. Rotor angle instability and voltage instability. With stability study we evaluate the impact of small and large disturbances on the behavior of synchronous machines of the power system. And they are of two types – transient stability and steady state stability. The transient stability studies gives the information about the synchronous machines that whether synchronism is maintained or not after the machine has been subjected to a large disturbance. These disturbance may be a sudden application of large load, a loss of generation, a loss of large load, or a fault (short circuit) on the system. In most disturbances, oscillations are of such magnitude that linearization of system parameters is not permissible and nonlinear equations must be solved to determine the stability of the system. On the other hand, the steady-state stability is concerned with the system subjected to small disturbances wherein the stability analysis could be done using the linearized version of nonlinear equations. In this experiment we are concerned with the transient stability of power systems.

Power system stability problem was recognized during 1920s (Steinmetz in 1920 Evans and Bergvall, in 1924 & Wilkins in 1926). The complexity of the system in during 1930 stability problems increased and systems could not be treated as two machine systems [2]. During 1950s improved analog computer came in to the market. With the use of analog computers simulations of multi machines as well as dynamics of synchronous machine could become possible. After 1950s, the digital computers emerged to study the stability problems associated with large interconnected systems. In the 1960s, most of the power systems in the U.S. and Canada were part of one of two large interconnected systems, because of interconnection of two systems stability problem increased due to complexity of network. The Northeast Blackout happened on November 9, 1965 in US.

Here, we are focusing on transient instability for rotor angle instability. Rotor angle was used to indicate whether the system is transiently stable or not. [3]. Thomas, R.J. [3] derived new methodology in 2000 which eliminates the repeated simulation method to determine a transiently secure operating point. Dynamic system equations are converted in to numerical algebraic equations.

Some control system related and AI (artificial intelligence) techniques[4-5] based assessment methods found in literature. Natarajan Narasimhamurthi had taken instability index with potential energy as given bellow [6]

$$h = \sum_i (P_g^i - P_d^i)\,\theta^i + \frac{1}{2}\sum_i \sum_j F_{ij}(\cos\delta_{ij} - 1)$$

Here, F_{ij} is line capacity connected between i and j

θ^i is phase angle at ith bus

δ_{ij} is angle difference between i and j

$P_g{}^i$ is real power generation at ith bus

P_d^i is real power demand at ith bus

In [7] The Single Machine Equivalent (SIME) method is used to represent the multi-machines system's dynamics by a corresponding One Machine Infinite Bus (OMIB) equivalent; such that by controlling the equivalent system transient stability, The stability of the original multi-machine system is increased. To control the transient stability of the equivalent system. With equal area criterion they have defined the stability limits of OMIB. M. A. Pai[8] introduced TEF (transient energy function) for transient stability limits assessment. In this technique Lyapunov theorem was used to find transient energy function (TEF). Use of TEF method becomes increasingly complex while considering detailed dynamic models or dealing with differential-algebraic equation (DAE) models of power systems.

In this paper direct approach is used to identify most critical machine and least critical machine in multi machine system. For that rotor angle of all machine connected in system has been derived from simulation. And relative margin between them decide the stability margin for the particular system. Due to complexity of network It might be possible of failure of two transmission network simultaneously. So for IEEE 39 bus system multi contingency considered. For assessment CCT (critical clearing time) also discussed for 6 bus system.

II. METHODOLOGY

To plot rotor angles of the synchronous machines steps given in bellow flow chart has to be follow.

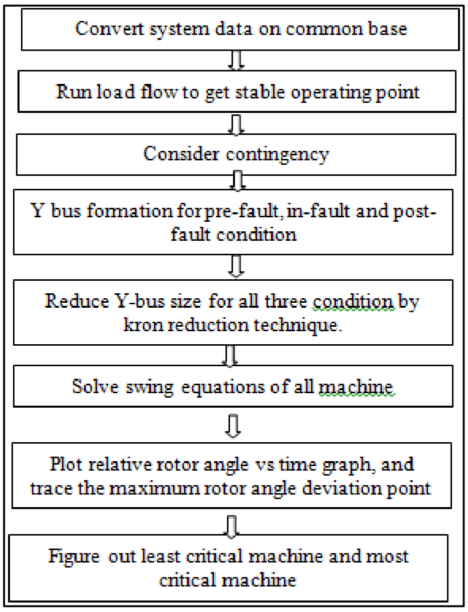

Fig. 1: Flowchart

III. MATHEMATICAL MODEL

Here all synchronous machines consider in classical model. System data is converted to common base, so all values must be in p.u. system

A. Load Flow[9]

For the formulation of the real and reactive power entering a bus, we need to define the following quantities. Let the voltage at the i^{th} bus be denoted by

$$V_i = |V_i|\angle\delta_i = |V_i|(\cos\delta_i + j\sin\delta_i) \text{-----------}(1)$$

Also let us define the self-admittance at bus-*i* as

$$Y_{ii} = |Y_{ii}|\angle\theta_{ii} = |Y_{ii}|(\cos\theta_{ii} + j\sin\theta_{ii}) = G_{ii} + jB_{ii}$$

Similarly the mutual admittance between the buses *i* and *j* can be written as

$$Y_{ij} = |Y_{ij}|\angle\theta_{ij} = |Y_{ij}|(\cos\theta_{ij} + j\sin\theta_{ij}) = G_{ij} + jB_{ij}$$

If the power system contains a total number of *n* buses. The current injected at bus-*i* is given as

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{in}V_n$$

$$= \sum_{k=1}^{n} Y_{ik}V_k$$

We shall assume the current entering a bus to be positive and that leaving the bus to be negative. As a consequence the power and reactive power entering a bus will also be assumed to be positive. The complex power at bus-*i* is then given by

$$P_i - jQ_i = V_i^* I_i = V_i^* \sum_{k=1}^{n} Y_{ik}V_k \qquad (2)$$

$$= |V_i|(\cos\delta_i - j\sin\delta_i)\sum_{k=1}^{n}|Y_{ik}V_k|(\cos\theta_{ik} + j\sin\theta_{ik})(\cos\delta_k + j\sin\delta_k)$$

$$= \sum_{k=1}^{n}|Y_{ik}V_iV_k|(\cos\delta_i - j\sin\delta_i)(\cos\theta_{ik} + j\sin\theta_{ik})(\cos\delta_k + j\sin\delta_k)$$

Here for further simplification

$$(\cos\delta_i - j\sin\delta_i)(\cos\theta_{ik} + j\sin\theta_{ik})(\cos\delta_k + j\sin\delta_k)$$

$$= (\cos\delta_i - j\sin\delta_i)[\cos(\theta_{ik} + \delta_k) + j\sin(\theta_{ik} + \delta_k)]$$

$$= \cos(\theta_{ik} + \delta_k - \delta_i) + j\sin(\theta_{ik} + \delta_k - \delta_i)$$

Substituting in (2) we get the real and reactive power as

$$P_i = \sum_{k=1}^{n}|Y_{ik}V_iV_k|\cos(\theta_{ik} + \delta_k - \delta_i)$$

$$Q_i = -\sum_{k=1}^{n}|Y_{ik}V_iV_k|\sin(\theta_{ik} + \delta_k - \delta_i)$$

Thus we get initial scheduling of generation from above equations.

B. Y-BUS Formation

Kron reduction technique is used [10]

All generator are considered as voltage source behind transient reactance as shown in figure.

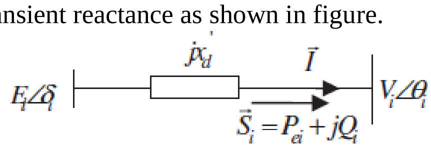

Fig. 2: Y-BUS Formation

With below equation generator internal voltage calculated

$$S = P_G + jQ_G = VI^*$$

So current injected at generator bus is given by I_i

$$I_i = S^*/V$$

And

$$E\angle\delta = V + jX_d'I_i$$

Here $E\angle\delta$ will become internal voltage of generator.

Now, load has to be transformed in equivalent admittance

So,

$$P_D + jQ_D = V_L I_L^* = S$$

$$I_L^* = \frac{V_L^*}{Z^*}$$

$$(P_D + jQ_D) = V_L\left(\frac{V_L^*}{Z^*}\right) = S$$

$$Y_L = \frac{S^*}{V_L^2}$$

With above result Y bus matrix for each case has been calculated.

The Ybus matrix for each situation has been reduced by eliminating all nodes except for the generator nodes

$$[I]=[Ybus][V]$$

Y bus is divided such that,

$$\begin{bmatrix} I_A \\ I_X \end{bmatrix} = \begin{bmatrix} M & L \\ L' & K \end{bmatrix}\begin{bmatrix} V_A \\ V_X \end{bmatrix}$$

Here I_A=injected current(Generator bus)

I_X=zero current injection

So Ybus divided in 4 parts as shown in equation

Now

$$I_X = L'V_A + KV_X = 0\text{------}(3)$$

$$I_A = MV_A + LV_X\text{----------}(4)$$

From equation (12) we obtain the value of V_X as,

$$V_X = -K^{-1}L'V_A$$

Now by putting value of V_X in eq.(4) we get,

$$I_A = MV_A - LK^{-1}L'V_A = (M - LK^{-1}L')V_A$$

$$I_A = [\text{Y\_red}]V_A$$

$$\text{Y\_red} = M - LK^{-1}L'$$

So this Y_red is reuired Ybus.

C. Swing Equation

Swing equation of synchronous machine can be define as,

$$\frac{H_i}{\pi f_0}\frac{d^2\delta}{dt^2} = P_{mi} - \sum_{j=1}^{m} E_i E_j Y_{ij}\cos(\theta_{ij} - \delta_i + \delta_j)$$

Here, H_i is moment of inertia of the machine

IV. CASE STUDY

With the use of above mathematical equations MATLAB code is developed and MATPOWER 5.1 is used. For test case two systems taken.

1) 3 machine 6-bus system[10]
2) 10 machine IEEE 39 bus system[11]

In 6 bus system 3 phase short circuit fault at line no. 5-6 given, near 6 number bus fault cleared in 0.4 sec and 0.5.

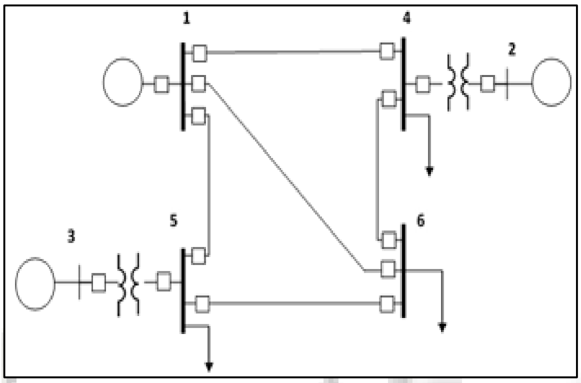

Fig. 3: 6 bus system 3 phase short circuit

Relative rotor angle vs time graph is shown in figure 3 for 0.4 fault clearing time

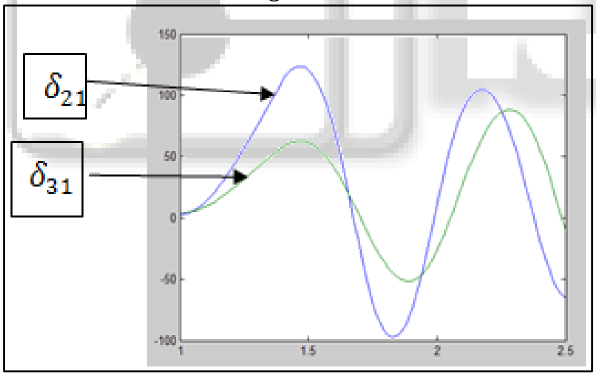

Fig. 4: Graph

Here, $\delta_{21} = \delta_2 - \delta_1$ $\delta_{31} = \delta_3 - \delta_1$

Relative rotor angle vs time graph is shown in figure 4 for 0.5 fault clearing time

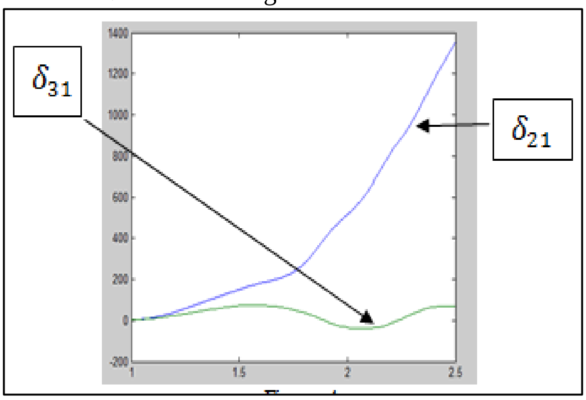

Fig. 5: Graph

From figure 4 & 5 we conclude that critical clearing time is lies between 0.4 & 0.5 sec. in general meaning if the relative rotor angle is more than 180 degree it will be treated as unstable condition.

Figure 6 shows IEEE 39 bus 10 machine new England system. System data is given in [11] on 100MVA base. Here three different cases were taken for analysis

A. Contingency 1:

A three phase fault occurred at the end of line 26–27 near bus 26. The fault was cleared by tripping the line at bus 26 & 27 after 110 ms.

B. Contingency 2:

A three phase fault occurred at the end of line 16–17 near bus 16. The fault was cleared by tripping the line at bus 16 & 17 after 80 ms.

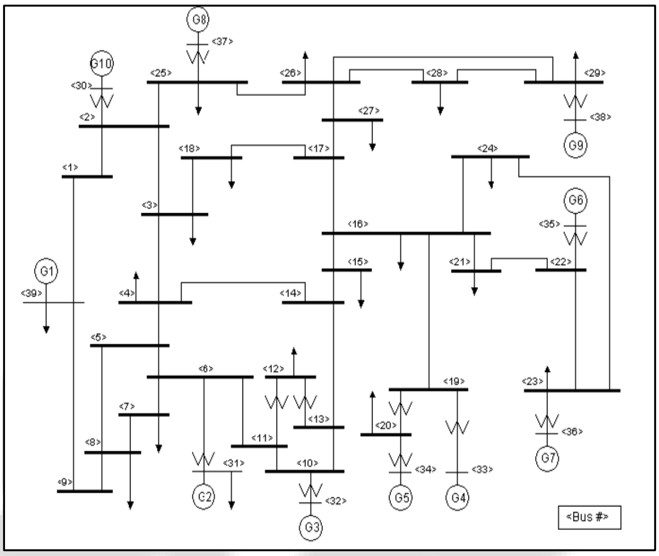

Fig. 6: IEEE 39 bus 10 machine new England system

Three different cases have taken to find rotor angle under COI reference frame.

- Case 1: considering transient stability constraints subjected to contingency 1.
- Case 2: considering transient stability constraints subjected to contingency 2.
- Case 3: considering transient stability constraints subjected to contingency 1 and 2.

1) Case 1: figure 7 shows the rotor angle in degree vs time under COI reference frame

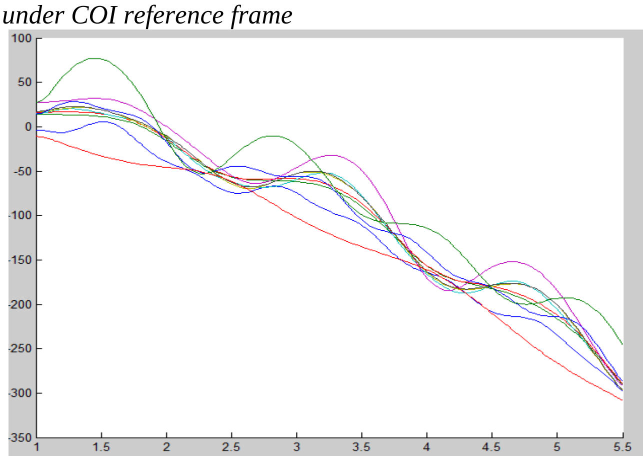

Fig. 7: Case 1

2) Case 2: figure 8 shows the rotor angle in degree vs time under COI reference frame

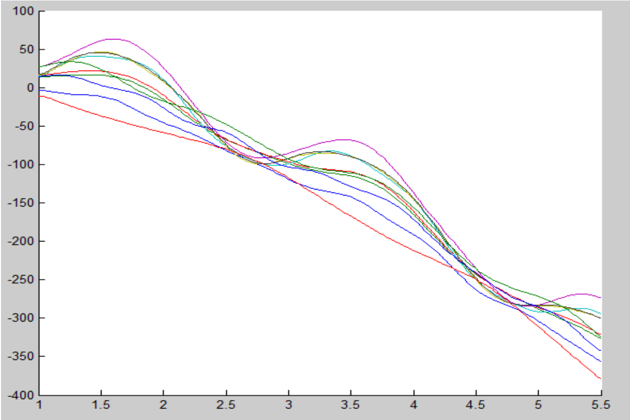

Fig. 8: Case 2

3) Case 3: figure 9 shows the rotor angle in degree vs time under COI reference frame

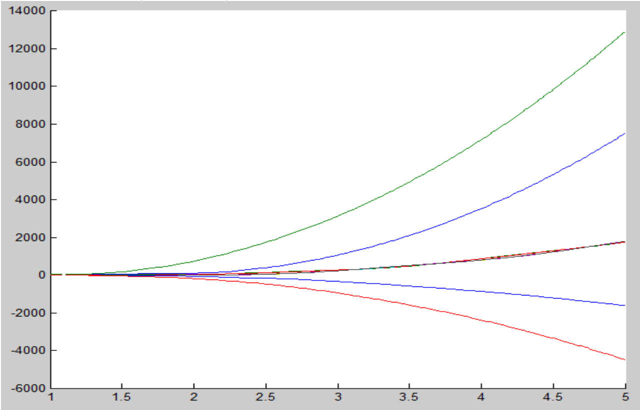

Fig. 9: Case 3

Here, in case 1 & 2 the system could be settle down to unstable equilibrium point. But for case 3 it is very savvier condition.

V. Conclusion

In power system controlling of transient stability is challenging thing because from above result we can see that synchronism between machines connected in the system will no longer possible after large disturbance. And if fault clearing time is less than CCT then system could be settle down to unstable equilibrium point (UEP). We can bring the system from UEP to stable equilibrium point by dynamic security dispatch. And if fault clearing time is greater than CCT then system transiently unstable condition.

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